

# Java™

An Introduction to Problem Solving & Programming

**EIGHTH EDITION** 

Walter Savitch



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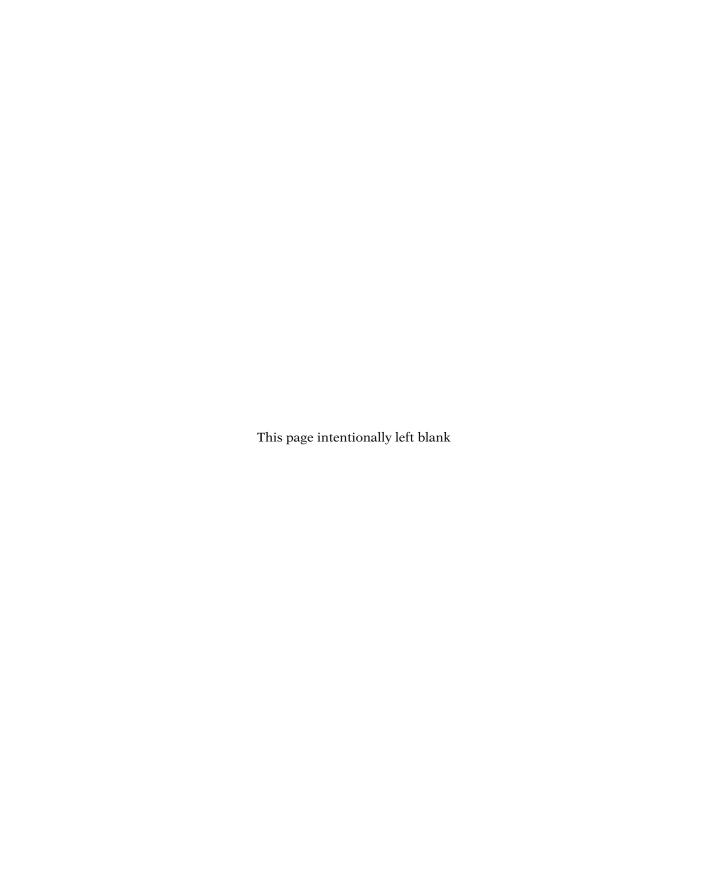
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# An Introduction to **Problem Solving & Programming**

**Eighth edition** 

**Global edition** 





Eighth edition Global edition

# An Introduction to Problem Solving & Programming

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# Preface for Instructors

Welcome to the eighth edition of *Java: An Introduction to Problem Solving & Programming.* This book is designed for a first course in programming and computer science. It covers programming techniques, as well as the basics of the Java programming language. It is suitable for courses as short as one quarter or as long as a full academic year. No previous programming experience is required, nor is any mathematics, other than a little high school algebra. The book can also be used for a course designed to teach Java to students who have already had another programming course, in which case the first few chapters can be assigned as outside reading.

# **Changes in This Edition**

The following list highlights how this eighth edition differs from the seventh edition:

- Correction of errors and edits for readability.
- The material on Java applets has been removed from the printed text but is available as an online chapter.
- With the exception of JOptionPane the graphics supplements have changed from Swing to JavaFX. The Swing chapters are available online. The JavaFX material introduces drawing, layout, event handling, and common UI controls.
- Examples of event-driven programming with the event handler in a separate class, the main application class, an anonymous inner class, and using lambda functions.
- Introduction to the Timeline and Scene Builder.
- Five new VideoNotes for a total of seventy seven VideoNotes. These VideoNotes walk students through the process of both problem solving and coding to help reinforce key programming concepts. An icon appears in the margin of the book when a VideoNote is available regarding the topic covered in the text.
- Ten new/revised Programming Projects.

### Latest Java Coverage

All of the code in this book has been tested using Oracle's Java SE Development Kit (JDK), version 8. Any imported classes are standard and in the Java Class Library that is part of Java. No additional classes or specialized libraries are needed.

# **Flexibility**

If you are an instructor, this book adapts to the way you teach, rather than making you adapt to the book. It does not tightly prescribe the sequence in which your course must cover topics. You can easily change the order in which you teach many chapters and sections. The particulars involved in rearranging material are explained in the dependency chart that follows this preface and in more detail in the "Prerequisites" section at the start of each chapter.

# **Early Graphics**

Graphics supplement sections in each of the chapters. This gives you the option of covering graphics and GUI programming from the start of your course. The graphics supplement sections emphasize GUIs built using JavaFX. Any time after Chapter 8, you can move on to the supplemental chapters on GUI programming using Swing (Chapters 13 through 15), which are now on the Web. Alternatively, you can continue through Chapter 10 with a mix of graphics and more traditional programming. Instructors who prefer to postpone the coverage of graphics can postpone or skip the graphics supplement sections.

# Coverage of Problem-Solving and Programming Techniques

This book is designed to teach students basic problem-solving and programming techniques and is not simply a book about Java syntax. It contains numerous case studies, programming examples, and programming tips. In addition, many sections explain important problem-solving and programming techniques, such as loop design techniques, debugging techniques, style techniques, abstract data types, and basic object-oriented programming techniques, including UML, event-driven programming, and generic programming using type parameters.

# **Early Introduction to Classes**

Any course that really teaches Java must teach classes early, since everything in Java involves classes. A Java program is a class. The data type for strings of characters is a class. Even the behavior of the equals operator (==) depends on whether it is comparing objects from classes or simpler data items. Classes cannot be avoided, except by means of absurdly long and complicated "magic

formulas." This book introduces classes fairly early. Some exposure to using classes is given in Chapters 1 and 2. Chapter 5 covers how to define classes. All of the basic information about classes, including inheritance, is presented by the end of Chapter 8 (even if you omit Chapter 7). However, some topics regarding classes, including inheritance, can be postponed until later in the course.

Although this book introduces classes early, it does not neglect traditional programming techniques, such as top-down design and loop design techniques. These older topics may no longer be glamorous, but they are information that all beginning students need.

## **Generic Programming**

Students are introduced to type parameters when they cover lists in Chapter 12. The class ArrayList is presented as an example of how to use a class that has a type parameter. Students are then shown how to define their own classes that include a type parameter.

# Language Details and Sample Code

This book teaches programming technique, rather than simply the Java language. However, neither students nor instructors would be satisfied with an introductory programming course that did not also teach the programming language. Until you calm students' fears about language details, it is often impossible to focus their attention on bigger issues. For this reason, the book gives complete explanations of Java language features and lots of sample code. Programs are presented in their entirety, along with sample input and output. In many cases, in addition to the complete examples in the text, extra complete examples are available over the Internet.

# **Self-Test Questions**

Self-test questions are spread throughout each chapter. These questions have a wide range of difficulty levels. Some require only a one-word answer, whereas others require the reader to write an entire, nontrivial program. Complete answers for all the self-test questions, including those requiring full programs, are given at the end of each chapter.

# **Exercises and Programming Projects**

Completely new exercises appear at the end of each chapter. Since only you, and not your students, will have access to their answers, these exercises are suitable for homework. Some could be expanded into programming projects. However, each chapter also contains other programming projects, several of which are new to this edition.

## **Support Material**

The following support materials are available on the Internet at www .pearsonglobaleditions.com/Savitch:

### For instructors only:

- Solutions to most exercises and programming projects
- PowerPoint slides

Instructors should click on the registration link and follow instructions to receive a password. If you encounter any problems, please contact your local Pearson Sales Representative.

### For students:

- Source code for programs in the book and for extra examples
- VideoNotes: video solutions to programming examples and exercises.

Visit www.pearsonglobaleditions.com/Savitch to access the student resources.

# Online Practice and Assessment with Pearson MyLab Programming

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MyLab Programming is offered to users of this book in partnership with Turing's Craft, the makers of the CodeLab interactive programming exercise system. For a full demonstration, to see feedback from instructors and students, or to get started using MyLab Programming in your course, visit www. myprogramminglab.com.

### **VideoNotes**

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videoNotes a

VideoNote

VideoNotes are designed for teaching students key programming concepts and techniques. These short step-by-step videos demonstrate how to solve problems from design through coding. VideoNotes allow for self-placed instruction with easy navigation including the ability to select, play, rewind, fast-forward, and stop within each VideoNote exercise.

Margin icons in your textbook let you know when a VideoNote video is available for a particular concept or homework problem.

# **Contact Us**

Your comments, suggestions, questions, and corrections are always welcome. Please e-mail them to savitch.programming.java@gmail.com.

# Preface for Students

This book is designed to teach you the Java programming language and, even more importantly, to teach you basic programming techniques. It requires no previous programming experience and no mathematics other than some simple high school algebra. However, to get the full benefit of the book, you should have Java available on your computer, so that you can practice with the examples and techniques given. The latest version of Java is preferable.

# If You Have Programmed Before

You need no previous programming experience to use this book. It was designed for beginners. If you happen to have had experience with some other programming language, do not assume that Java is the same as the programming language(s) you are accustomed to using. All languages are different, and the differences, even if small, are large enough to give you problems. Browse the first four chapters, reading at least the Recap portions. By the time you reach Chapter 5, it would be best to read the entire chapter.

If you have programmed before in either C or C++, the transition to Java can be both comfortable and troublesome. At first glance, Java may seem almost the same as C or C++. However, Java is very different from these languages, and you need to be aware of the differences. Appendix 6 compares Java and C++ to help you see what the differences are.

# Obtaining a Copy of Java

Appendix 1 provides links to sites for downloading Java compilers and programming environments. For beginners, we recommend Oracle's Java JDK for your Java compiler and related software and TextPad or DrJava as a simple editor environment for writing Java code. When downloading the Java JDK, be sure to obtain the latest version available.

# **Support Materials for Students**

- Source code for programs in the book and for extra examples
- Student lab manual
- VideoNotes: video solutions to programming examples and exercises.

Visit www.pearsonglobaleditions.com/Savitch to access the student resources.

# **Learning Aids**

Each chapter contains several features to help you learn the material:

- The opening overview includes a brief table of contents, chapter objectives and prerequisites, and a paragraph or two about what you will study.
- Recaps concisely summarize major aspects of Java syntax and other important concepts.
- FAQs, or "frequently asked questions," answer questions that other students have asked.
- Remembers highlight important ideas you should keep in mind.
- Programming Tips suggest ways to improve your programming skills.
- Gotchas identify potential mistakes you could make—and should avoid while programming.
- Asides provide short commentaries on relevant issues.
- Self-Test Questions test your knowledge throughout, with answers given at the end of each chapter. One of the best ways to practice what you are learning is to do the self-test questions *before* you look at the answers.
- A summary of important concepts appears at the end of each chapter.

# Online Practice with Pearson MyLab Programming

A self-study and practice tool, a MyLab Programming course consists of hundreds of small practice problems organized around the structure of this textbook. The system automatically detects errors in the logic and syntax of your code submissions and offers targeted hints that enable you to figure out what went wrong—and why. Visit www.myprogramminglab.com for more information.

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### This Text Is Also a Reference Book

In addition to using this book as a textbook, you can and should use it as a reference. When you need to check a point that you have forgotten or that you hear mentioned by somebody but have not yet learned yourself, just look in the index. Many index entries give a page number for a "recap." Turn to that page. It will contain a short, highlighted entry giving all the essential points on



that topic. You can do this to check details of the Java language as well as details on programming techniques.

Recap sections in every chapter give you a quick summary of the main points in that chapter. Also, a summary of important concepts appears at the end of each chapter. You can use these features to review the chapter or to check details of the Java language.

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Pearson MyLab<sup>®</sup> Programming breaks down programming concepts into short, understandable sequences of exercises. Within each sequence the level and sophistication of the exercises increase gradually but steadily.

# 

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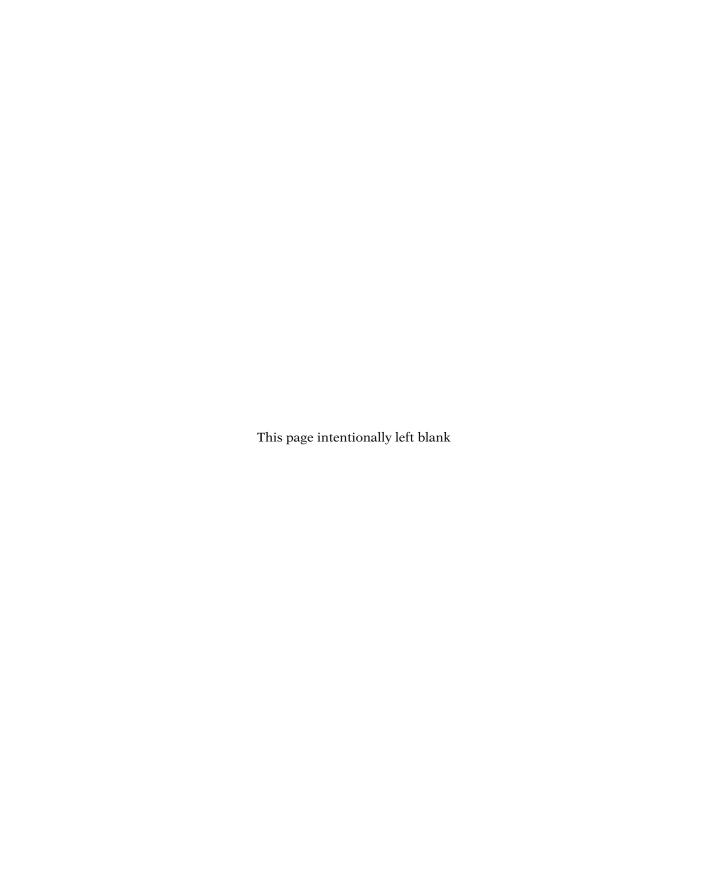
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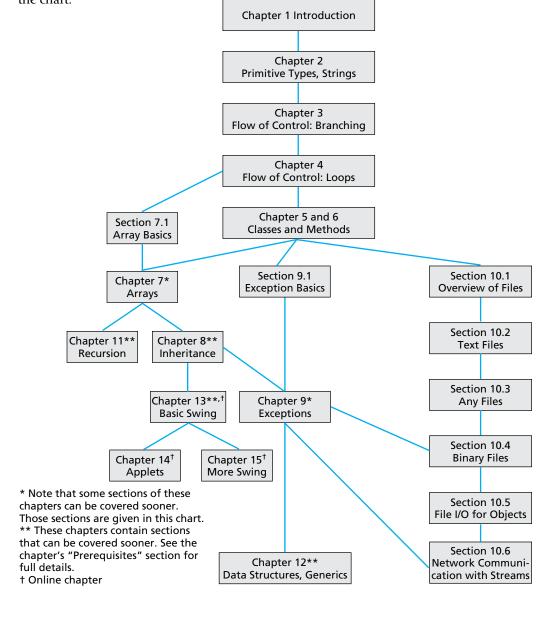
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# Dependency Chart

This chart shows the prerequisites for the chapters in the book. If there is a line between two boxes, the material in the higher box should be covered before the material in the lower box. Minor variations to this chart are discussed in the "Prerequisites" section at the start of each chapter. These variations usually provide more, rather than less, flexibility than what is shown on the chart.



# Features of This Text

### **Recaps**

Summarize Java syntax and other important concepts.

### Remembers

Highlight important ideas that students should keep in mind.

#### **RECAP Bytes and Memory Locations**

A computer's main memory is divided into numbered units called bytes. The number of a byte is called its address. Each byte can hold eight

binary digits, or bits, each data that is too large to fi adjacent bytes. These adja memory location whose a bytes.

#### **REMEMBER** Syntactic Variables

When you see something in this book like Type, Variable\_1, or Variable\_2 used to describe Java syntax, these words do not literally appear in your Java code. They are syntactic variables, which are a kind of blank that you fill in with something from the category that they describe. For example, Type can be replaced by int, double, char, or any other type name. Variable\_1 and Variable\_2 can each be replaced by any variable name.

## **Programming Tips**

Give students helpful advice about programming in Java.

### **■ PROGRAMMING TIP** Initialize Variables

A variable that has been declared, but that has not yet been given a value by an assignment statement (or in some other way), is said to be uninitialized. If the variable is a variable of a class type, it literally has no value. If the variable has a primitive type, it likely has some default value. However, your program will be clearer if you explicitly give the variable a value, even if you are simply reassigning the default value. (The exact details on default values have been known to change and should not be counted on.)

One easy way to ensure that you do not have an uninitialized variable is to initialize it within the declaration. Simply combine the declaration and an assignment statement, as in the following examples:

```
int count = 0;
double taxRate = 0.075;
char grade = 'A';
int balance = 1000, newBalance;
```

Note that you can initialize some variables and not initialize others in a declaration

Sometimes the compiler may complain that you have failed to initialize a variable. In most cases, that will indeed be true. Occasionally, though, the compiler is mistaken in giving this advice. However, the compiler will not compile your program until you convince it that the variable in question is initialized. To make the compiler happy, initialize the variable when you declare it, even if the variable will be given another value before it is used for anything. In such cases, you cannot argue with the compiler.

### **Gotchas**

Identify potential mistakes in programming that students might make and should avoid.

### **FAQs**

Provide students answers to frequently asked questions within the context of the chapter.

### **GOTCHA** Hidden Errors

Just because your program compiles and runs without any errors and even produces reasonable-looking output does not mean that your program is correct. You should always run your program with some test data that gives predictable output. To do this, choose some data for which you can compute the correct results, either by using pencil and paper, by looking up the answer, or by some other means. Even this testing does not guarantee that your program is correct, but the more testing you do, the more confidence you can have in your program.

### FAQ1 Why just 0s and 1s?

Computers use 0s and 1s because it is easy to make an electrical device that has only two stable states. However, when you are programming, you normally need not be concerned about the encoding of data as 0s and 1s. You can program as if the computer directly stored numbers, letters, or strings of characters in memory.

There is nothing special about calling the states zero and one. We could just as well use any two names, such as A and B or true and false. The important thing is that the underlying physical device has two stable states, such as on and off or high voltage and low voltage. Calling these two states zero and one is simply a convention, but it's one that is almost universally followed.

### Listings

Show students complete programs with sample output.

### LISTING 1.2 Drawing a Happy Face import javafx.application.Application; import iavafx.scene.canvas.Canvas: import javafx.scene.Scene; import javafx.scene.Group; import javafx.stage.Stage; import javafx.scene.canvas.GraphicsContext; import javafx.scene.shape.ArcType; public class HappyFace extends Application public static void main(String[] args) launch(args): @Override public void start(Stage primaryStage) throws Exception Group root = new Group(); Scene scene = new Scene(root): Canvas canvas = new Canvas (400, 300); GraphicsContext gc = canvas.getGraphicsContext2D(); gc.stroke0val(100, 50, 200, 200); gc.fillOval(155, 100, 10, 20); gc.fillOval(230, 100, 10, 20); gc.strokeArc(150, 160, 100, 50, 180, 180, ArcType.OPEN); root.getChildren().add(canvas); primaryStage.setTitle("HappyFace in JavaFX"); primaryStage.setScene(scene); primaryStage.show();

### Case Studies

Take students from problem statement to algorithm development to Java code.

### **CASE STUDY** Unit Testing

So far we've tested our programs by running them, typing in some input, and visually checking the results to see if the output is what we expected. This is fine for small programs but is generally insufficient for large programs. In a large program there are usually so many combinations of interacting inputs that it would take too much time to manually verify the correct result for all inputs. Additionally, it is possible that code changes result in unintended side effects. For example, a fix for one error might introduce a different error. One way to attack this problem is to write unit tests. Unit testing is a methodology in which the programmer tests the correctness of individual units of code. A unit is often a method but it could be a class or other group of code.

The collection of unit tests becomes the **test suite**. Each test is generally automated so that human input is not required. Automation is important because it is desirable to have tests that run often and quickly. This makes it possible to run the tests repeatedly, perhaps once a day or every time code is changed, to make sure that everything is still working. The process of running tests repeatedly is called **regression testing**.

Let's start with a simple test case for the Species class in Listing 5.19. Our first test might be to verify that the name, initial population, and growth rate is correctly set in the setSpecies method. We can accomplish this by creating

### **VideoNotes**

Step-by-step video solutions to programming examples and homework exercises.



### **Programming Examples**

Provide more examples of Java programs that solve specific problems.

### PROGRAMMING EXAMPLE Nested Loops

The body of a loop can contain any sort of statements. In particular, you can have a loop statement within the body of a larger loop statement. For example, the program in Listing 4.4 uses a while loop to compute the average of a list of nonnegative scores. The program asks the user to enter all the scores followed by a negative sentinel value to mark the end of the data. This while loop is placed inside a do-while loop so that the user can repeat the entire process for another exam, and another, until the user wishes to end the

### Self-Test Questions

Provide students with the opportunity to practice skills learned in the chapter. Answers at the end of each chapter give immediate feedback.

### **SELF-TEST QUESTIONS**

28. Given the class Species as defined in Listing 5.19, why does the following program cause an error message?

```
public class SpeciesEqualsDemo
public static void main(String[] args)
   Species s1, s2; s1.
   setSpecies("Klingon ox", 10, 15);
   s2.setSpecies("Klingon ox", 10, 15);
   if (s1 == s2)
       System.out.println("Match with ==.");
       System.out.println("Do Not match with ==.")
```

- 29. After correcting the program in the previous question, what output does the program produce?
- 30. What is the biggest difference between a parameter of a primitive type and a parameter of a class type?
- 31. Given the class Species, as defined in Listing 5.19, and the class

### **Asides**

Give short commentary on relevant topics.

### **ASIDE** Use of the Terms Parameter and Argument

Our use of the terms parameter and argument is consistent with common usage. We use *parameter* to describe the definition of the data type and variable inside the header of a method and argument to describe items passed into a method when it is invoked. However, people often use these terms interchangeably. Some people use the term parameter both for what we call a formal parameter and for what we call an argument. Other people use the term argument both for what we call a formal parameter and for what we call an argument. When you see the term parameter or argument in other books, you must figure out its exact meaning from the context.

# **Brief Contents**

Chapter 1	Introduction to Computers and Java 37
Chapter 2	Basic Computation 85
Chapter 3	Flow of Control: Branching 175
Chapter 4	Flow of Control: Loops 237
Chapter 5	Defining Classes and Methods 305
Chapter 6	More About Objects and Methods 419
Chapter 7	Arrays 513
Chapter 8	Inheritance, Polymorphism, and Interfaces 621
Chapter 9	Exception Handling 709
Chapter 10	Streams, File I/O, and Networking 785
Chapter 11	Recursion 867
Chapter 12	Dynamic Data Structures and Generics 919
Appendices	1 0 1 7 00
	1 Getting Java 997
	2 Running Applets 998

- 3 Protected and Package Modifiers 1000
- 4 The DecimalFormat Class 1001
- 5 Javadoc 1005
- 6 Differences Between C++ and Java 1008
- 7 Unicode Character Codes 1012
- 8 Introduction to Java 8 Functional Programming 1013
- 9 The Iterator Interface 1017
- **10** Cloning 1019
- 11 Java Reserved Keywords 1023

Credits 1024 Index 1027

The following chapters, along with an index to their contents, are on the book's Website:

**Chapter 13** Window Interfaces Using Swing

**Chapter 14** Applets and HTML

**Chapter 15** More Swing

# **Contents**

1.1 COMPUTER BASICS 38
Hardware and Memory 39
Programs 42
Programming Languages, Compilers, and Interpreters 43
Java Bytecode 45
Class Loader 47
1.2 A SIP OF JAVA 48
History of the Java Language 48
Applications and Applets 49
A First Java Application Program 50
Writing, Compiling, and Running a Java Program 55
1.3 PROGRAMMING BASICS 57
Object-Oriented Programming 57
Algorithms 61
Testing and Debugging 63
Software Reuse 64
1.4 GRAPHICS SUPPLEMENT 66
A Sample JavaFX Application 67
Size and Position of Figures 70
Drawing Ovals and Circles 71
Drawing Arcs 73
Chapter 2 Basic Computation 85
2.1 VARIABLES AND EXPRESSIONS 86
Variables 87
Data Types 89

Chapter 1 Introduction to Computers and Java 37

Java Identifiers 91
Assignment Statements 93
Simple Input 96
Simple Screen Output 98

Constants 98

Named Constants 100

Assignment Compatibilities 101

Type Casting 103

Arithmetic Operators 106

Parentheses and Precedence Rules 109

Specialized Assignment Operators 110

Case Study: Vending Machine Change 112

Increment and Decrement Operators 117

More About the Increment and Decrement Operators 118

### 2.2 THE CLASS String 119

String Constants and Variables 119

Concatenation of Strings 120

String Methods 121

String Processing 123

Escape Characters 126

The Unicode Character Set 127

### 2.3 KEYBOARD AND SCREEN I/O 129

Screen Output 129

Keyboard Input 132

Other Input Delimiters (Optional) 137

Formatted Output with printf (Optional) 139

### 2.4 DOCUMENTATION AND STYLE 141

Meaningful Variable Names 141

Comments 142

Indentation 145

Using Named Constants 145

### 2.5 GRAPHICS SUPPLEMENT 147

Style Rules Applied to a JavaFX Application 148

Introducing the Class JOptionPane 150

Reading Input as Other Numeric Types 159

Programming Example: Change-Making Program

with Windowing I/O 160

# **Chapter 3** Flow of Control: Branching 175

### 3.1 THE if-else STATEMENT 176

The Basic if-else Statement 177

Boolean Expressions 184

Comparing Strings 189

Nested if-else Statements 194

Multibranch if-else Statements 196

Programming Example: Assigning Letter Grades 198

Case Study: Body Mass Index 201

The Conditional Operator (Optional) 204

The exit Method 204

### 3.2 THE TYPE boolean 205

Boolean Variables 206

Precedence Rules 207

Input and Output of Boolean Values 210

### 3.3 THE switch STATEMENT 212

Enumerations 218

### 3.4 GRAPHICS SUPPLEMENT 219

Specifying a Drawing Color 220

A Dialog Box for a Yes-or-No Question 224

# **Chapter 4** Flow of Control: Loops 237

### 4.1 JAVA LOOP STATEMENTS 238

The while Statement 239

The do-while Statement 242

Programming Example: Bug Infestation 247

Programming Example: Nested Loops 253

The for Statement 255

Declaring Variables Within a for Statement 261

Using a Comma in a for Statement (Optional) 262

The for-each Statement 264

### 4.2 PROGRAMMING WITH LOOPS 264

The Loop Body 265

Initializing Statements 266

Controlling the Number of Loop Iterations 267

Case Study: Using a Boolean Variable to End a Loop 269

Programming Example: Spending Spree 271

The break Statement and continue Statement in Loops

(Optional) 274

Loop Bugs 277

Tracing Variables 279

Assertion Checks 281

### 4.3 GRAPHICS SUPPLEMENT 283

Programming Example: A Multiface JavaFX Application 283

Drawing Text 288

## **Chapter 5** Defining Classes and Methods 305

#### 5.1 CLASS AND METHOD DEFINITIONS 307

Class Files and Separate Compilation 309

Programming Example: Implementing a Dog Class 309

Instance Variables 310

Methods 313

Defining void Methods 316

Defining Methods That Return a Value 317

Programming Example: First Try at Implementing a Species Class 322

The Keyword this 326

Local Variables 328

Blocks 330

Parameters of a Primitive Type 331

### 5.2 INFORMATION HIDING AND ENCAPSULATION 337

Information Hiding 338

Precondition and Postcondition Comments 338

The public and private Modifiers 340

Programming Example: A Demonstration of Why Instance

Variables Should Be Private 343

Programming Example: Another Implementation of a Class

of Rectangles 344

Accessor Methods and Mutator Methods 346

Programming Example: A Purchase Class 350

Methods Calling Methods 354

Encapsulation 360

Automatic Documentation with javadoc 363

UML Class Diagrams 364

### 5.3 OBJECTS AND REFERENCES 365

Variables of a Class Type 366

Defining an equals Method for a Class 371

Programming Example: A Species Class 375

Boolean-Valued Methods 378

Case Study: Unit Testing 380

Parameters of a Class Type 382

Programming Example: Class-Type Parameters Versus

Primitive-Type Parameters 386

### 5.4 GRAPHICS SUPPLEMENT 390

The GraphicsContext Class 390

Programming Example: Multiple Faces, but with a Helping

Method 394

Adding Labels to a JavaFX Application 398

### **Chapter 6** More About Objects and Methods 419

### 6.1 CONSTRUCTORS 421

Defining Constructors 421

Calling Methods from Constructors 430

Calling a Constructor from Other Constructors (Optional) 433

#### 6.2 STATIC VARIABLES AND STATIC METHODS 435

Static Variables 435

Static Methods 436

Dividing the Task of a main Method into Subtasks 443

Adding a main Method to a Class 444

The Math Class 446

Wrapper Classes 449

### 6.3 WRITING METHODS 455

Case Study: Formatting Output 455

Decomposition 461

Addressing Compiler Concerns 462

Testing Methods 464

### 6.4 OVERLOADING 466

Overloading Basics 466

Overloading and Automatic Type Conversion 469

Overloading and the Return Type 472

Programming Example: A Class for Money 474

### 6.5 INFORMATION HIDING REVISITED 481

Privacy Leaks 481

### 6.6 ENUMERATION AS A CLASS 485

### **6.7 PACKAGES** 487

Packages and Importing 488
Package Names and Directories 489
Name Clashes 492

### 6.8 GRAPHICS SUPPLEMENT 493

Adding Buttons 493 Adding Icons 493

# Chapter 7 Arrays 513

### 7.1 ARRAY BASICS 515

Creating and Accessing Arrays 516 Array Details 519 The Instance Variable Length 522 More About Array Indices 525 Initializing Arrays 528

### 7.2 ARRAYS IN CLASSES AND METHODS 530

Case Study: Sales Report 530
Indexed Variables as Method Arguments 538
Entire Arrays as Arguments to a Method 541
Arguments for the Method main 542
Array Assignment and Equality 543
Methods That Return Arrays 546

### 7.3 PROGRAMMING WITH ARRAYS AND CLASSES 550

Programming Example: A Specialized List Class 550

Partially Filled Arrays 558

### 7.4 SORTING AND SEARCHING ARRAYS 560

Selection Sort 560 Other Sorting Algorithms 564 Searching an Array 566

### 7.5 MULTIDIMENSIONAL ARRAYS 567

Multidimensional-Array Basics 568 Multidimensional-Array Parameters and Returned Values 571 Java's Representation of Multidimensional Arrays 574 Ragged Arrays (*Optional*) 575 *Programming Example:* Employee Time Records 577

### 7.6 GRAPHICS SUPPLEMENT 583

Layout Panes 583
Text Areas, Text Fields and Combining Layouts 591
Drawing Polygons 596

# Chapter 8 Inheritance, Polymorphism, and Interfaces 621

### 8.1 INHERITANCE BASICS 622

Derived Classes 624

Overriding Method Definitions 628

Overriding Versus Overloading 629

The final Modifier 629

Private Instance Variables and Private Methods of a Base Class 630

UML Inheritance Diagrams 632

### 8.2 PROGRAMMING WITH INHERITANCE 635

Constructors in Derived Classes 635
The this Method—Again 637
Calling an Overridden Method 637
Programming Example: A Derived Class of a Derived Class 638
Another Way to Define the equals Method in Undergraduate 643
Type Compatibility 643
The Class Object 648
A Better equals Method 650

### 8.3 POLYMORPHISM 652

Dynamic Binding and Inheritance 652 Dynamic Binding with toString 655

### 8.4 INTERFACES AND ABSTRACT CLASSES 657

Class Interfaces 657
Java Interfaces 658
Implementing an Interface 659

An Interface as a Type 661 Extending an Interface 664 Case Study: Character Graphics 665 Case Study: The Comparable Interface 678 Abstract Classes 682 8.5 GRAPHICS SUPPLEMENT 684

Event-Driven Programming 685 Event Handling in a Separate Class 686 Event Handling in the Main GUI Application Class 689 Event Handling in an Anonymous Inner Class 691 Programming Example: Adding Numbers 694

#### Chapter 9 Exception Handling 709

### 9.1 BASIC EXCEPTION HANDLING 710

Exceptions in Java 711 Predefined Exception Classes 721

### 9.2 DEFINING YOUR OWN EXCEPTION CLASSES 723

### 9.3 MORE ABOUT EXCEPTION CLASSES 733

Declaring Exceptions (Passing the Buck) 733 Kinds of Exceptions 736 Errors 738 Multiple Throws and Catches 739 The finally Block 745 Rethrowing an Exception (Optional) 746 Case Study: A Line-Oriented Calculator 747

### 9.4 GRAPHICS SUPPLEMENT 759

Additional User Interface Controls and Shapes 759 Images and Shapes 763 Handling Mouse Events 765 The Timeline Class 769

#### Chapter 10 Streams, File I/O, and Networking 785

### 10.1 AN OVERVIEW OF STREAMS AND FILE I/O 787

The Concept of a Stream 787 Why Use Files for I/O? 788 Text Files and Binary Files 788

33

# 10.2 TEXT-FILE I/O 790 Creating a Text File 790 Appending to a Text File 796 Reading from a Text File 798 10.3 TECHNIQUES FOR ANY FILE 801 The Class File 801 Programming Example: Reading a File Name from the Keyboard 801 Using Path Names 803 Methods of the Class File 804 Defining a Method to Open a Stream 806 Case Study: Processing a Comma-Separated Values File 808 10.4 BASIC BINARY-FILE I/O 811 Creating a Binary File 811 Writing Primitive Values to a Binary File 813 Writing Strings to a Binary File 816 Some Details About writeUTF 817 Reading from a Binary File 818 The Class EOFException 824 Programming Example: Processing a File of Binary Data 826 10.5 BINARY-FILE I/O WITH OBJECTS AND ARRAYS 831 Binary-File I/O with Objects of a Class 831 Some Details of Serialization 835 Array Objects in Binary Files 836 10.6 NETWORK COMMUNICATION WITH STREAMS 839 10.7 GRAPHICS SUPPLEMENT 845 Programming Example: A JavaFX GUI for Manipulating Files 845 Chapter 11 Recursion 867 11.1 THE BASICS OF RECURSION 868 Case Study: Digits to Words 871 How Recursion Works 876 Infinite Recursion 880

Recursive Methods Versus Iterative Methods 882 Recursive Methods That Return a Value 884

11.2 PROGRAMMING WITH 1	RECURSION	888
-------------------------	-----------	-----

Programming Example: Insisting That User Input Be Correct 888

Case Study: Binary Search 890

Programming Example: Merge Sort—A Recursive Sorting

Method 898

### 11.3 GRAPHICS SUPPLEMENT 902

Lambda Functions and Event Handlers 902

### Chapter 12 Dynamic Data Structures and Generics 919

### 12.1 ARRAY-BASED DATA STRUCTURES 921

The Class ArrayList 922

Creating an Instance of ArrayList 922

Using the Methods of ArrayList 924

Programming Example: A To-Do List 928

Parameterized Classes and Generic Data Types 931

### 12.2 THE JAVA COLLECTIONS FRAMEWORK 931

The Collection Interface 931

The Class HashSet 932

The Map Interface 934

The Class HashMap 934

#### 12.3 LINKED DATA STRUCTURES 937

The Class LinkedList 937

Linked Lists 938

Implementing the Operations of a Linked List 941

A Privacy Leak 948

Inner Classes 949

Node Inner Classes 950

Iterators 950

The Java Iterator Interface 962

Exception Handling with Linked Lists 962

Variations on a Linked List 964

Other Linked Data Structures 966

### 12.4 **GENERICS** 967

The Basics 967

Programming Example: A Generic Linked List 970

#### 12.5 GRAPHICS SUPPLEMENT 975

Building JavaFX Applications with the Scene Builder 975 Where to Go from Here 981

#### **APPENDICES**

- 1 Getting Java 997
- 2 Running Applets 998
- 3 Protected and Package Modifiers 1000
- 4 The DecimalFormat Class 1001 Other Pattern Symbols 1002
- 5 Javadoc 1005

Commenting Classes for Use with javadoc 1005 Running javadoc 1006

6 Differences Between C++ and Java 1008

Primitive Types 1008

Strings 1008

Flow of Control 1008

Testing for Equality 1009

main Method (Function) and Other Methods 1009

Files and Including Files 1009

Class and Method (Function) Definitions 1010

No Pointer Types in Java 1010

Method (Function) Parameters 1010

Arrays 1010

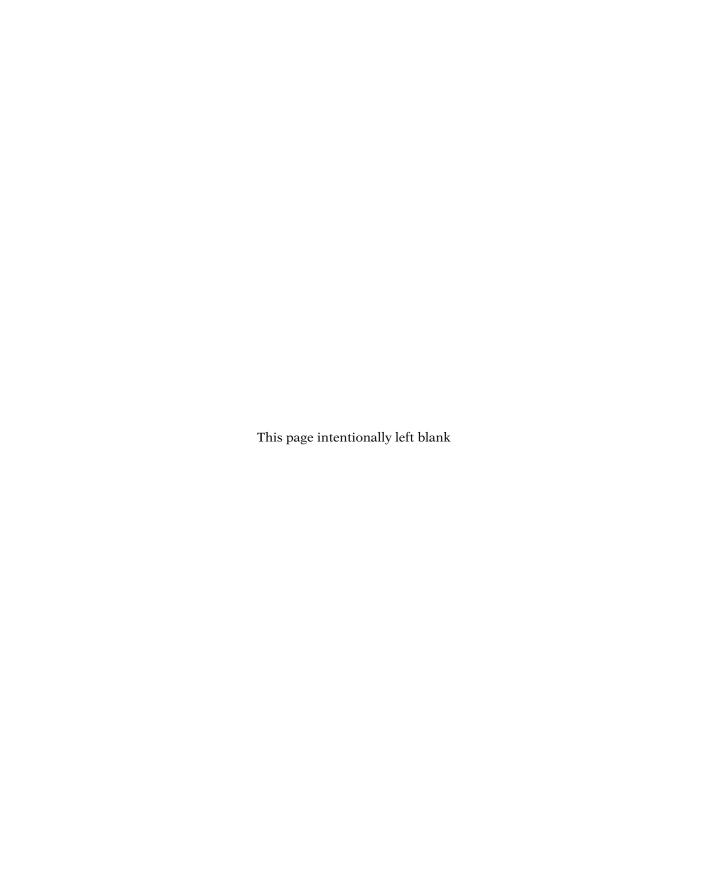
Garbage Collection 1011

Other Comparisons 1011

- 7 Unicode Character Codes 1012
- 8 Introduction to Java 8 Functional Programming 1013
- 9 The Iterator Interface 1017
- **10** Cloning 1019
- 11 Java Reserved Keywords 1023

CREDITS 1024

**INDEX** 1027



# Introduction to Computers and Java

#### 1.1 COMPUTER BASICS 38

Hardware and Memory 39
Programs 42
Programming Languages, Compilers, and Interpreters 43
Java Bytecode 45
Class Loader 47

#### **1.2 A SIP OF JAVA** 48

History of the Java Language 48
Applications and Applets 49
A First Java Application Program 50
Writing, Compiling, and Running a Java
Program 55

#### 1.3 PROGRAMMING BASICS 57

Object-Oriented Programming 57
Algorithms 61
Testing and Debugging 63
Software Reuse 64

#### 1.4 GRAPHICS SUPPLEMENT 66

A Sample JavaFX Application 67
Size and Position of Figures 70
Drawing Ovals and Circles 71
Drawing Arcs 73

It is by no means hopeless to expect to make a machine for really very difficult mathematical problems. But you would have to proceed step-by-step. I think electricity would be the best thing to rely on.

-CHARLES SANDERS PEIRCE (1839-1914)

#### INTRODUCTION

This chapter gives you a brief overview of computer hardware and software. Much of this introductory material applies to programming in any language, not just to programming in Java. Our discussion of software will include a description of a methodology for designing programs known as object-oriented programming. Section 1.2 introduces the Java language and explains a sample Java program.

Section 1.4 is the first of a number of graphics supplements that end each of the first ten chapters and provide an introduction to the graphics capabilities of the Java language. These graphics supplements are interdependent, and each one uses the Java topics presented in its chapter.

#### **OBJECTIVES**

After studying this chapter, you should be able to

- Give a brief overview of computer hardware and software
- Give an overview of the Java programming language
- Describe the basic techniques of program design in general and objectoriented programming in particular
- Describe JavaFX and some graphics basics

## **PREREQUISITES**

This first chapter does *not* assume that you have had any previous programming experience, but it does assume that you have access to a computer. To get the full value from the chapter, and from the rest of this book, you should have a computer that has the Java language installed, so that you can try out what you are learning. Appendix 1 describes how to obtain and install a free copy of the Java language for your computer.

## **1.1** COMPUTER BASICS

The Analytical Engine has no pretensions whatever to originate anything. It can do whatever we know how to order it to perform. It can follow analysis; but it has no power of anticipating any analytical relations or truths. Its province is to assist us in making available what we are already acquainted with.

—ADA AUGUSTA, Countess of Lovelace (1815–1852)

Computer systems consist of hardware and software. The hardware is the physical machine. A set of instructions for the computer to carry out is called a program. All the different kinds of programs used to give instructions to the computer are collectively referred to as software. In this book, we will discuss software, but to understand software, it helps to know a few basic things about computer hardware.

Hardware and software make up a computer system

## **Hardware and Memory**

Most computers available today have the same basic components, configured in basically the same way. They all have input devices, such as a keyboard and a mouse. They all have output devices, such as a display screen and a printer. They also have several other basic components, usually housed in some sort of cabinet, where they are not so obvious. These other components store data and perform the actual computing.

The CPU, or central processing unit, or simply the processor, is the device inside your computer that follows a program's instructions. Currently, one of the better-known processors is the Intel®Core™i7 processor. The processor can carry out only very simple instructions, such as moving numbers or other data from one place in memory to another and performing some basic arithmetic operations like addition and subtraction. The power of a computer comes from its speed and the intricacies of its programs. The basic design of the hardware is conceptually simple.

A computer's memory holds data for the computer to process, and it holds the result of the computer's intermediate calculations. Memory exists in two basic forms, known as main memory and auxiliary memory. Main memory holds the current program and much of the data that the program is manipulating. You most need to be aware of the nature of the main memory when you are writing programs. The information stored in main memory typically is volatile, that is, it disappears when you shut down your computer. In contrast, the data in auxiliary memory, or secondary memory, exists even when the computer's power is off. All of the various kinds of disks—including hard disk drives, flash drives, compact discs (CDs), and digital video discs (DVDs) are auxiliary memory.

To make this more concrete, let's look at an example. You might have heard a description of a personal computer (PC) as having, say, 1 gigabyte of RAM and a 200-gigabyte hard drive. RAM—short for random access memory—is the main memory, and the hard drive is the principal—but not the only—form of auxiliary memory. A byte is a quantity of memory. So 1 gigabyte of RAM is approximately 1 billion bytes of memory, and a 200-gigabyte hard drive has approximately 200 billion bytes of memory. What exactly is a byte? Read on.

The computer's main memory consists of a long list of numbered bytes. The number of a byte is called its **address**. A **byte** is the smallest addressable unit of memory. A piece of data, such as a number or a keyboard character, can

The CPU, or central processing unit, or processor, performs the instructions in a program

Main memory is volatile; auxiliary memory is not

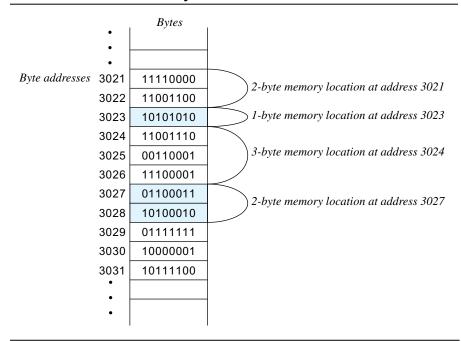
Main memory consists of addressable eight-bit bytes

Groups of adjacent bytes can serve as a single memory location be stored in one of these bytes. When the computer needs to recover the data later, it uses the address of the byte to find the data item.

A byte, by convention, contains eight digits, each of which is either 0 or 1. Actually, any two values will do, but the two values are typically written as 0 and 1. Each of these digits is called a **binary digit** or, more typically, a **bit**. A byte, then, contains eight bits of memory. Both main memory and auxiliary memory are measured in bytes.

Data of various kinds, such as numbers, letters, and strings of characters, is encoded as a series of 0s and 1s and placed in the computer's memory. As it turns out, one byte is just large enough to store a single keyboard character. This is one of the reasons that a computer's memory is divided into these eight-bit bytes instead of into pieces of some other size. However, storing either a string of characters or a large number requires more than a single byte. When the computer needs to store a piece of data that cannot fit into a single byte, it uses several adjacent bytes. These adjacent bytes are then considered to be a single, larger **memory location**, and the address of the first byte is used as the address of the entire memory location. Figure 1.1 shows how a typical computer's main memory might be divided into memory locations. The addresses of these larger locations are not fixed by the hardware but depend on the program using the memory.

FIGURE 1.1 Main Memory



Recall that main memory holds the current program and much of its data. Auxiliary memory is used to hold data in a more or less permanent form. Auxiliary memory is also divided into bytes, but these bytes are grouped into much larger units known as **files**. A file can contain almost any sort of data, such as a program, an essay, a list of numbers, or a picture, each in an encoded form. For example, when you write a Java program, you will store the program in a file that will typically reside in some kind of disk storage. When you use the program, the contents of the program file are copied from auxiliary memory to main memory.

A file is a group of bytes stored in auxiliary memory

You name each file and can organize groups of files into **directories**, or **folders**. *Folder* and *directory* are two names for the same thing. Some computer systems use one name, and some use the other.

A directory, or folder, contains groups of files

## FAQ<sup>1</sup> Why just 0s and 1s?

Computers use 0s and 1s because it is easy to make an electrical device that has only two stable states. However, when you are programming, you normally need not be concerned about the encoding of data as 0s and 1s. You can program as if the computer directly stored numbers, letters, or strings of characters in memory.

There is nothing special about calling the states zero and one. We could just as well use any two names, such as A and B or true and false. The important thing is that the underlying physical device has two stable states, such as on and off or high voltage and low voltage. Calling these two states zero and one is simply a convention, but it's one that is almost universally followed.

#### **RECAP** Bytes and Memory Locations

A computer's main memory is divided into numbered units called bytes. The number of a byte is called its address. Each byte can hold eight binary digits, or bits, each of which is either 0 or 1. To store a piece of data that is too large to fit into a single byte, the computer uses several adjacent bytes. These adjacent bytes are thought of as a single, larger memory location whose address is the address of the first of the adjacent bytes.

<sup>&</sup>lt;sup>1</sup> FAQ stands for "frequently asked question."

## **Programs**

A program is a set of computer instructions

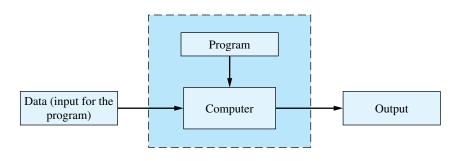
You probably have some idea of what a program is. You use programs all the time. For example, text editors and word processors are programs. As we mentioned earlier, a program is simply a set of instructions for a computer to follow. When you give the computer a program and some data and tell the computer to follow the instructions in the program, you are **running**, or **executing**, the program on the data.

Figure 1.2 shows two ways to view the running of a program. To see the first way, ignore the dashed lines and blue shading that form a box. What's left is what really happens when you run a program. In this view, the computer has two kinds of input. The program is one kind of input; it contains the instructions that the computer will follow. The other kind of input is the data for the program. It is the information that the computer program will process. For example, if the program is a spelling-check program, the data would be the text that needs to be checked. As far as the computer is concerned, both the data and the program itself are input. The output is the result—or results—produced when the computer follows the program's instructions. If the program checks the spelling of some text, the output might be a list of words that are misspelled.

This first view of running a program is what really happens, but it is not always the way we think about running a program. Another way is to think of the data as the input to the program. In this second view, the computer and the program are considered to be one unit. Figure 1.2 illustrates this view by surrounding the combined program–computer unit with a dashed box and blue shading. When we take this view, we think of the data as input to the program and the results as output from the program. Although the computer is understood to be there, it is presumed just to be something that assists the program. People who write programs—that is, **programmers**—find this second view to be more useful when they design a program.

Your computer has more programs than you might think. Much of what you consider to be "the computer" is actually a program—that is, software—rather than hardware. When you first turn on a computer, you are already

FIGURE 1.2 Running a Program



running and interacting with a program. That program is called the **operating system**. The operating system is a kind of supervisory program that oversees the entire operation of the computer. If you want to run a program, you tell the operating system what you want to do. The operating system then retrieves and starts the program. The program you run might be a text editor, a browser to surf the World Wide Web, or some program that you wrote using the Java language. You might tell the operating system to run the program by using a mouse to click an icon, by choosing a menu item, or by typing in a simple command. Thus, what you probably think of as "the computer" is really the operating system. Some common operating systems are Microsoft Windows, Apple's (Macintosh) Mac OS, Linux, and UNIX.

An operating system is a program that supervises a computer's operation

#### FAQ What exactly is software?

The word *software* simply means programs. Thus, a software company is a company that produces programs. The software on your computer is just the collection of programs on your computer.

# Programming Languages, Compilers, and Interpreters

Most modern programming languages are designed to be relatively easy for people to understand and use. Such languages are called **high-level languages**. Java is a high-level language. Most other familiar programming languages, such as Visual Basic, C++, C#, COBOL, Python, and Ruby, are also high-level languages. Unfortunately, computer hardware does not understand high-level languages. Before a program written in a high-level language can be run, it must be translated into a language that the computer can understand.

The language that the computer can directly understand is called **machine language**. **Assembly language** is a symbolic form of machine language that is easier for people to read. So assembly language is almost the same thing as machine language, but it needs some minor additional translation before it can run on the computer. Such languages are called **low-level languages**.

The translation of a program from a high-level language, like Java, to a low-level language is performed entirely or in part by another program. For some high-level languages, this translation is done as a separate step by a program known as a **compiler**. So before you run a program written in a high-level language, you must first run the compiler on the program. When you do this, you are said to **compile** the program. After this step, you can run the resulting machine-language program as often as you like without compiling it again.

The terminology here can get a bit confusing, because both the input to the compiler program and the output from the compiler program are Java is a highlevel language

Computers execute a lowlevel language called machine language

Compile once, execute often

Compilers translate source code into object code programs. Everything in sight is a program of some kind or other. To help avoid confusion, we call the input program, which in our case will be a Java program, the **source program**, or **source code**. The machine-language program that the compiler produces is often called the **object program**, or **object code**. The word **code** here just means a program or a part of a program.

## **RECAP Compiler**

A compiler is a program that translates a program written in a high-level language, such as Java, into a program in a simpler language that the computer can more or less directly understand.

Interpreters translate and execute portions of code at a time Some high-level languages are translated not by compilers but rather by another kind of program called an **interpreter**. Like a compiler, an interpreter translates program statements from a high-level language to a low-level language. But unlike a compiler, an interpreter executes a portion of code right after translating it, rather than translating the entire program at once. Using an interpreter means that when you run a program, translation alternates with execution. Moreover, translation is done each time you run the program. Recall that compilation is done once, and the resulting object program can be run over and over again without engaging the compiler again. This implies that a compiled program generally runs faster than an interpreted one.

#### **RECAP** Interpreter

An interpreter is a program that alternates the translation and execution of statements in a program written in a high-level language.

One disadvantage of the processes we just described for translating programs written in most high-level programming languages is that you need a different compiler or interpreter for each type of language or computer system. If you want to run your source program on three different types of computer systems, you need to use three different compilers or interpreters. Moreover, if a manufacturer produces an entirely new type of computer system, a team of programmers must write a new compiler or interpreter for that computer system. This is a problem, because these compilers and interpreters are large programs that are expensive and time-consuming to write. Despite this cost, many high-level-language compilers and interpreters work this way. Java, however, uses a slightly different and much more versatile

approach that combines a compiler and an interpreter. We describe Java's approach next.

## Java Bytecode

The Java compiler does not translate your program into the machine language for your particular computer. Instead, it translates your Java program into a language called **bytecode**. Bytecode is not the machine language for any particular computer. Instead, bytecode is a machine language for a hypothetical computer known as a **virtual machine**. A virtual machine is not exactly like any particular computer, but is similar to all typical computers. Translating a program written in bytecode into a machine-language program for an actual computer is quite easy. The program that does this translation is a kind of interpreter called the **Java Virtual Machine**, or **JVM**. The JVM translates and runs the Java bytecode.

To run your Java program on your computer, you proceed as follows: First, you use the compiler to translate your Java program into bytecode. Then you use the particular JVM for your computer system to translate each bytecode instruction into machine language and to run the machine-language instructions. The whole process is shown in Figure 1.3.

Modern implementations of the JVM use a Just-in-Time (JIT), compiler. The JIT compiler reads the bytecode in chunks and compiles entire chunks to native machine language instructions as needed. The compiled machine language instructions are remembered for future use so a chunk needs to be compiled only once. This model generally runs programs faster than the interpreter model, which repeatedly translates the next bytecode instruction to machine code.

It sounds as though Java bytecode just adds an extra step to the process. Why not write compilers that translate directly from Java to the machine language for your particular computer system? That could be done, and it is what is done for many other programming languages. Moreover, that technique would produce machine-language programs that typically run faster. However, Java bytecode gives Java one important advantage, namely, portability. After you compile your Java program into bytecode, you can run that bytecode on any computer. When you run your program on another computer, you do not need to recompile it. This means that you can send your bytecode over the Internet to another computer and have it run easily on that computer regardless of the computer's operating system. That is one of the reasons Java is good for Internet applications.

Portability has other advantages as well. When a manufacturer produces a new type of computer system, the creators of Java do not have to design a new Java compiler. One Java compiler works on every computer. Of course, every type of computer must have its own bytecode interpreter—the JVM—that translates bytecode instructions into machine-language instructions for that particular computer, but these interpreters are simple programs compared to a compiler. Thus, Java can be added to a new computer system very quickly and very economically.

A compiler translates Java code into bytecode

The JVM is an interpreter that translates and executes bytecode

Java bytecode runs on any computer that has a JVM

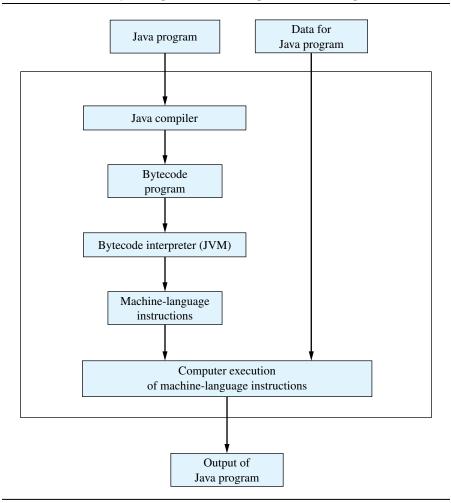


FIGURE 1.3 Compiling and Running a Java Program

## **RECAP Bytecode**

The Java compiler translates your Java program into a language called bytecode. This bytecode is not the machine language for any particular computer, but it is similar to the machine language of most common computers. Bytecode is easily translated into the machine language of a given computer. Each type of computer will have its own translator—called an interpreter—that translates from bytecode instructions to machine-language instructions for that computer.

Knowing about Java bytecode is important, but in the day-to-day business of programming, you will not even be aware that it exists. You normally will give two commands, one to compile your Java program into bytecode and one to run your program. The **run command** tells the bytecode interpreter to execute the bytecode. This run command might be called "run" or something else, but it is unlikely to be called "interpret." You will come to think of the run command as running whatever the compiler produces, and you will not even think about the translation of bytecode to machine language.

#### FAQ Why is it called bytecode?

Programs in low-level languages, such as bytecode and machine-language code, consist of instructions, each of which can be stored in a few bytes of memory. Typically, one byte of each instruction contains the operation code, or opcode, which specifies the operation to be performed. The notion of a one-byte opcode gave rise to the term bytecode.

#### **Class Loader**

A Java program is seldom written as one piece of code all in one file. Instead, it typically consists of different pieces, known as **classes**. We will talk about classes in detail later, but thinking of them as pieces of code is sufficient for now. These classes are often written by different people, and each class is compiled separately. Thus, each class is translated into a different piece of bytecode. To run your program, the bytecode for these various classes must be connected together. The connecting is done by a program known as the **class loader**. This connecting is typically done automatically, so you normally need not be concerned with it. In other programming languages, the program corresponding to the Java class loader is called a *linker*.

For now, think of a class as a piece of code



#### **SELF-TEST QUESTIONS**

Answers to the self-test questions appear at the end of each chapter.

- 1. What are the two kinds of memory in a computer?
- 2. What is software?
- 3. What data would you give to a program that computes the sum of two numbers?

- 4. What data would you give to a program that computes the average of all the quizzes you have taken in a course?
- 5. What is the difference between a program written in a high-level language, a program in machine language, and a program expressed in Java bytecode?
- 6. Is Java a high-level language or a low-level language?
- 7. Is Java bytecode a high-level language or a low-level language?
- 8. What is a compiler?
- 9. What is a source program?
- 10. What do you call a program that translates Java bytecode into machine-language instructions?

#### 1.2 A SIP OF JAVA

"New Amsterdam, madame," replied the Prince, "and after that the Sunda Islands and beautiful Java with its sun and palm trees."

—HENRY DE VERE STACPOOLE, The Beach of Dreams

In this section, we describe some of the characteristics of the Java language and examine a simple Java program. This introduction is simply an overview and a presentation of some terminology. We will begin to explore the details of Java in the next chapter.

## History of the Java Language

Java is widely viewed as a programming language for Internet applications. However, this book, and many other people, views Java as a general-purpose programming language that can be used without any reference to the Internet. At its birth, Java was neither of these things, but it eventually evolved into both.

The history of Java goes back to 1991, when James Gosling and his team at Sun Microsystems began designing the first version of a new programming language that would become Java—though it was not yet called that. This new language was intended for programming home appliances, like toasters and TVs. That sounds like a humble engineering task, but in fact it's a very challenging one. Home appliances are controlled by a wide variety of computer processors (chips). The language that Gosling and his team were designing had to work on all of these different processors. Moreover, a home appliance is typically an inexpensive item, so no manufacturer would be willing to invest

large amounts of time and money into developing complicated compilers to translate the appliance-language programs into a language the processor could understand. To solve these challenges, the designers wrote one piece of software that would translate an appliance-language program into a program in an intermediate language that would be the same for all appliances and their processors. Then a small, easy-to-write and hence inexpensive program would translate the intermediate language into the machine language for a particular appliance or computer. The intermediate language was called bytecode. The plan for programming appliances using this first version of Java never caught on with appliance manufacturers, but that was not the end of the story.

In 1994, Gosling realized that his language—now called Java—would be ideal for developing a Web browser that could run programs over the Internet. The Web browser was produced by Patrick Naughton and Jonathan Payne at Sun Microsystems. Originally called WebRunner and then HotJava, this browser is no longer supported. But that was the start of Java's connection to the Internet. In the fall of 1995, Netscape Communications Corporation decided to make the next release of its Web browser capable of running Java programs. Other companies associated with the Internet followed suit and have developed software that accommodates Java programs.

#### FAQ Why is the language named Java?

The question of how Java got its name does not have a very interesting answer. The current custom is to name programming languages in pretty much the same way that parents name their children. The creator of the programming language simply chooses any name that sounds good to her or him. The original name of the Java language was Oak. Later the creators realized that there already was a computer language named Oak, so they needed another name, and Java was chosen. One hears conflicting explanations of the origin of the name Java. One traditional, and perhaps believable, story is that the name was thought of during a long and tedious meeting while the participants drank coffee, and the rest, as they say, is history.

## **Applications and Applets**

This book focuses on Java applications. An **application** is just a regular program. Another kind of program is a Java applet. An **applet** sounds as though it would be a little apple, but the name is meant to convey the idea of

Applications are regular programs

Applets run within a Web browser

a little application. Applets and applications are almost identical. The difference is that an application is meant to be run on your computer, like any other program, whereas an applet is meant to be sent to another location on the Internet and run there from a web browser. Oracle is transitioning away from Java applets in favor of technologies such as JavaScript and HTML5. As a result we will only cover applets in Chapter 14, which is available online.

## A First Java Application Program

Our first Java program is shown in Listing 1.1. Below the program, we show a sample of the screen output that might be produced when a person runs and interacts with the program. The person who interacts with a program is called the **user**. The text typed in by the user is shown in color. If you run this program—and you should do so—both the text displayed by the program and the text you type will appear in the same color on your computer screen.

The user might or might not be the programmer, that is, the person who wrote the program. As a student, you often are both the programmer and the user, but in a real-world setting, the programmer and user are generally different people. This book is teaching you to be the programmer. One of the first things you need to learn is that you cannot expect the users of your program to know what you want them to do. For that reason, your program must give the user understandable instructions, as we have done in the sample program.

At this point, we just want to give you a feel for the Java language by providing a brief, informal description of the sample program shown in Listing 1.1. *Do not worry if some of the details of the program are not completely clear on this first reading.* This is just a preview of things to come. In Chapter 2, we will explain the details of the Java features used in the program.

The first line

```
import java.util.Scanner;
```

tells the compiler that this program uses the class Scanner. Recall that for now, we can think of a class as a piece of software that we can use in a program. This class is defined in the package java.util, which is short for "Java utility." A **package** is a library of classes that have already been defined for you.

The remaining lines define the class FirstProgram, extending from the first open brace ({}) to the last close brace ({}):

```
public class FirstProgram
{
    . . .
}
```

A user runs and interacts with a program

A package is a library of classes

#### LISTING 1.1 A Sample Java Program

```
Gets the Scanner class from the
import java.util.Scanner;
                                         package (library) java.util
                                       Name of the class—your choice. "This program
public class FirstProgram
                                      should be in a file named FirstProgram.java"
    public static void main(String[] args)
         System.out.println("Hello out there."); ← Sends output to screen
         System.out.println("I will add two numbers for you.");
         System.out.println("Enter two whole numbers on a line:");
                                   Says that n1 and n2 are variables
         int n1, n2;
                                   that hold integers (whole numbers)
                                                         Readies the program
         Scanner keyboard = new Scanner(System.in); for keyboard input
         n1 = keyboard.nextInt();
                                                 Reads one whole number
         n2 = keyboard.nextInt();
                                                from the keyboard
         System.out.print1n("The sum of those two numbers is");
         System.out.print1n(n1 + n2);
    }
}
```

#### Sample Screen Output

```
Hello out there.
I will add two numbers for you.
Enter two whole numbers on a line:
12 30
The sum of those two numbers is
42
```

Within these braces are typically one or more parts called **methods**. Every Java application has a method called main, and often other methods. The definition of the method main extends from another open brace to another close brace:

A class contains methods

Every application has a main method

```
public static void main(String[] args)
{
    . . .
}
```

The words public static void will have to remain a mystery for now, but they are required. Chapters 5 and 6 will explain these details.

Any **statements**, or instructions, within a method define a task and make up the **body** of the method. The first three statements in our main method's body are the first actions this program performs:

```
System.out.println("Hello out there.");
System.out.println("I will add two numbers for you.");
System.out.println("Enter two whole numbers on a line:");
```

Each of these statements begins with System.out.println and causes the quoted characters given within the parentheses to be displayed on the screen on their own line. For example,

```
System.out.println("Hello out there.");
causes the line
Hello out there.
```

to be written to the screen.

For now, you can consider System.out.println to be a funny way of saying "Display what is shown in parentheses." However, we can tell you a little about what is going on here and introduce some terminology. Java programs use things called **software objects** or, more simply, **objects** to perform actions. The actions are defined by methods. System.out is an object used to send output to the screen; println is the method that performs this action for the object System.out. That is, println sends what is within its parentheses to the screen. The item or items inside the parentheses are called **arguments** and provide the information the method needs to carry out its action. In each of these first three statements, the argument for the method println is a string of characters between quotes. This argument is what println writes to the screen.

An object performs an action when you **invoke**, or **call**, one of its methods. In a Java program, you write such a **method call**, or **method invocation**, by writing the name of the object, followed by a period—called a **dot** in computer jargon—followed by the method name and some parentheses that might or might not contain arguments.

The next line of the program in Listing 1.1,

```
int n1, n2;
```

says that n1 and n2 are the names of variables. A **variable** is something that can store a piece of data. The int says that the data must be an integer, that is, a whole number; int is an example of a **data type**. A data type specifies a set of possible values and the operations defined for those values. The values of a particular data type are stored in memory in the same format.

Objects perform actions when you call its methods

Variables store data

A data type specifies a set of values and their operations The next line

```
Scanner keyboard = new Scanner(System.in);
```

enables the program to accept, or **read**, data that a user enters at the keyboard. We will explain this line in detail in Chapter 2.<sup>2</sup>

Next, the line

```
n1 = keyboard.nextInt();
```

A program gets, or reads, data from a user

reads a number that is typed at the keyboard and then stores this number in the variable n1. The next line is almost the same except that it reads another number typed at the keyboard and stores this second number in the variable n2. Thus, if the user enters the numbers 12 and 30, as shown in the sample output, the variable n1 will contain the number 12, and the variable n2 will contain the number 30.

Finally, the statements

```
System.out.println("The sum of those two numbers is");
System.out.println(n1 + n2);
```

display an explanatory phrase and the sum of the numbers stored in the variables n1 and n2. Note that the second line contains the **expression** n1 + n2 rather than a string of characters in quotes. This expression computes the sum of the numbers stored in the variables n1 and n2. When an output statement like this contains a number or an expression whose value is a number, the number is displayed on the screen. So in the sample output shown in Listing 1.1, these two statements produce the lines

```
The sum of those two numbers is 42
```

Notice that each invocation of println displays a separate line of output.

The only thing left to explain in this first program are the semicolons at the end of certain lines. The semicolon acts as ending punctuation, like a period in an English sentence. A semicolon ends an instruction to the computer.

Of course, Java has precise rules for how you write each part of a program. These rules form the **grammar** for the Java language, just as the rules for the English language make up its grammar. However, Java's rules are more precise. The grammatical rules for any language, be it a programming language or a natural language, are called the **syntax** of the language.

Syntax is the set of grammatical rules for a language

<sup>&</sup>lt;sup>2</sup> As you will see in the next chapter, you can use some other name in place of keyboard, but that need not concern us now. Anyway, keyboard is a good word to use here.

#### **RECAP** Invoking (Calling) a Method

A Java program uses objects to perform actions that are defined by methods. An object performs an action when you invoke, or call, one of its methods. You indicate this in a program by writing the object name, followed by a period—called a dot—then the method name, and finally a pair of parentheses that can contain arguments. The arguments are information for the method.

#### **EXAMPLES:**

```
System.out.println("Hello out there.");
n1 = keyboard.nextInt();
```

In the first example, System.out is the object, println is the method, and "Hello out there." is the argument. When a method requires more than one argument, you separate the arguments with commas. A method invocation is typically followed by a semicolon.

In the second example, keyboard is the object and nextInt is the method. This method has no arguments, but the parentheses are required nonetheless.

#### FAQ Why do we need an import for input but not for output?

The program in Listing 1.1 needs the line

```
import java.util.Scanner;
```

to enable keyboard input, such as the following:

```
n1 = keyboard.nextInt();
```

Why don't we need a similar import to enable screen output such as

```
System.out.println("Hello out there.");
```

The answer is rather dull. The package that includes definitions and code for screen output is imported automatically into a Java program.

# SELF-TEST QUESTIONS

11. What would the following statement, when used in a Java program, display on the screen?

```
System.out.println("Java is great!");
```

12. Write a statement or statements that can be used in a Java program to display the following on the screen:

```
Java for one.
Java for all.
```

- 13. Suppose that mary is an object that has the method increaseAge. This method takes one argument, an integer. Write an invocation of the method increaseAge by the object mary, using the argument 5.
- 14. What is the meaning of the following line in the program in Listing 1.1?

```
n1 = keyboard.nextInt();
```

15. Write a complete Java program that uses System.out.println to display the following to the screen when the program is run:

```
Hello World!
```

Your program does nothing else. Note that you do not need to fully understand all the details of the program in order to write it. You can simply follow the model of the program in Listing 1.1. (You do want to understand all the details eventually, but that may take a few more chapters.)

## Writing, Compiling, and Running a Java Program

A Java program is divided into smaller parts called classes. Each program can consist of any number of class definitions. Although we wrote only one class—FirstProgram—for the program in Listing 1.1, in fact, the program uses two other classes: System and Scanner. However, these two classes are provided for you by Java.

Writing a Java program

You can write a Java class by using a simple text editor. For example, you could use Notepad in a Windows environment or TextEdit on a Macintosh system. Normally, each class definition you write is in a separate file. Moreover, the name of that file must be the name of the class, with .java added to the end. For example, the class FirstProgram must be in a file named FirstProgram.java.

Each class is in a file whose name ends in . java

Before you can run a Java program, you must translate its classes into a language that the computer can understand. As you saw earlier in this chapter,

this translation process is called compiling. As a rule, you do not need to compile classes like Scanner that are provided for you as part of Java. You normally need compile only the classes that you yourself write.

Compiling a Java program

To compile a Java class using the free Java system distributed by Oracle®, you use the command javac followed by the name of the file containing the class. For example, to compile a class named MyClass that is in a file named MyClass.java, you give the following command to the operating system:

Use the command javac to compile

javac MyClass.java

Thus, to compile the class in Listing 1.1, you would give the following command:

javac FirstProgram.java

Bytecode is in a file whose name ends in .class

When you compile a Java class, the translated version of the class—its bytecode—is placed in a file whose name is the name of the class followed by .class. So when you compile a class named MyClass in the file MyClass. java, the resulting bytecode is stored in a file named MyClass .class. When you compile the file named FirstProgram.java, the resulting bytecode is stored in a file named FirstProgram.class.

Although a Java program can involve any number of classes, you run only the class that you think of as the program. This class will contain a main method beginning with words identical to or very similar to

```
public static void main(String[] args)
```

These words will likely, but not always, be someplace near the beginning of the file. The critical words to look for are public static void main. The remaining portion of the line might use somewhat different wording.

You run a Java program by giving the command java, followed by the name of the class you think of as the program. For example, to run the program in Listing 1.1, you would give the following one-line command:

java FirstProgram

Note that you write the class name, such as FirstProgram, not the name of the file containing the class or its bytecode. That is, you omit any .java or .class ending. When you run a Java program, you are actually running the Java bytecode interpreter on the compiled version of your program.

The easiest way to write, compile, and run a Java program is to use an **integrated development environment**, or **IDE**. An IDE combines a text editor with menu commands for compiling and running a Java program. IDEs such as BlueJ, Eclipse, and NetBeans are free and available for Windows, Mac OS, and other systems. Appendix 1 provides links to these IDEs and other resources for writing Java programs.

VideoNote
Compiling a Java program

Use the command java to execute

# FAQ I tried to run the sample program in Listing 1.1. After I typed two numbers on a line, nothing happened. Why?

When you type a line of data at the keyboard for a program to read, you will see the characters you type, but the Java program does not actually read your data until you press the Enter (Return) key. Always press the Enter key when you have finished typing a line of input data at the keyboard.



#### **SELF-TEST QUESTIONS**

- 16. Suppose you define a class named YourClass in a file. What name should the file have?
- 17. Suppose you compile the class YourClass. What will be the name of the file containing the resulting bytecode?

#### 1.3 PROGRAMMING BASICS

'The time has come,' the Walrus said, 'To talk of many things: Of shoes—and ships—and sealing wax— Of cabbages—and kings . . . '

—LEWIS CARROLL, Through the Looking-Glass

Programming is a creative process. We cannot tell you exactly how to write a program to do whatever task you might want it to perform. However, we can give you some techniques that experienced programmers have found to be extremely helpful. In this section, we discuss some basics of these techniques. They apply to programming in almost any programming language and are not particular to Java.

## **Object-Oriented Programming**

Java is an **object-oriented programming** language, abbreviated **OOP**. What is OOP? The world around us is made up of objects, such as people, automobiles, buildings, trees, shoes, ships, sealing wax, cabbages, and kings. Each of these objects has the ability to perform certain actions, and each action can affect some of the other objects in the world. OOP is a programming methodology that views a program as similarly consisting of objects that can act alone or

Software objects act and interact

interact with one another. An object in a program—that is, a software object—might represent a real-world object, or it might be an abstraction.

For example, consider a program that simulates a highway interchange so that traffic flow can be analyzed. The program would have an object to represent each automobile that enters the interchange, and perhaps other objects to simulate each lane of the highway, the traffic lights, and so on. The interactions among these objects can lead to a conclusion about the design of the interchange.

The values of an object's attributes define its state

Object-oriented programming comes with its own terminology. An object has characteristics, or **attributes**. For example, an automobile object might have attributes such as its name, its current speed, and its fuel level. The values of an object's attributes give the object a **state**. The actions that an object can take are called **behaviors**. As we saw earlier, each behavior is defined by a piece of Java code called a method.

A class is a blueprint for objects

Objects of the same kind are said to have the same data type and belong to the same class. A **class** defines a kind of object; it is a blueprint for creating objects. The data type of an object is the name of its class. For example, in a highway simulation program, all the simulated automobiles might belong to the same class—probably called Automobile—and so their data type is Automobile.

All objects of a class have the same attributes and behaviors. Thus, in a simulation program, all automobiles have the same behaviors, such as moving forward and moving backward. This does not mean that all simulated automobiles are identical. Although they have the same attributes, they can have different states. That is, a particular attribute can have different values among the automobiles. So we might have three automobiles having different makes and traveling at different speeds. All this will become clearer when we begin to write Java classes.

As you will see, this same object-oriented methodology can be applied to any sort of computer program and is not limited to simulation programs. Object-oriented programming is not new, but its use in applications outside of simulation programs did not become popular until the early 1990s.

## **RECAP** Objects, Methods, and Classes

An object is a program construction that has data—called attributes—associated with it and that can perform certain actions known as behaviors. A class defines a type or kind of object. It is a blueprint for defining the objects. All objects of the same class have the same kinds of data and the same behaviors. When the program is run, each object can act alone or interact with other objects to accomplish the program's purpose. The actions performed by objects are defined by methods.

#### FAQ What if I know some other programming language?

If Java is your first programming language, you can skip the answer to this question. If you know some other programming language, the discussion here may help you to understand objects in terms of things you already know about. If that other programming language is object oriented, such as C++, C#, Python, or Ruby, you have a good idea of what objects, methods, and classes are. They are basically the same in all object-oriented programming languages, although some other languages might use another term to mean the same thing as *method*. If your familiarity is with an older programming language that does not use objects and classes, you can think of objects in terms of other, older programming constructs. For example, if you know about variables and functions or procedures, you can think of an object as a variable that has multiple pieces of data and its own functions or procedures. Methods are really the same thing as what are called *functions* or *procedures* in older programming languages.

Object-oriented programming uses classes and objects, but it does not use them in just any old way. There are certain design principles that must be followed. The following are three of the main design principles of objectoriented programming:

OOP design principles

Encapsulation Polymorphism Inheritance

Encapsulation sounds as though it means putting things into a capsule or, to say it another way, packaging things up. This intuition is basically correct. The most important part of encapsulation, however, is not simply that things are put into a capsule, but that only part of what is in the capsule is visible. When you produce a piece of software, you should describe it in a way that tells other programmers how to use it, but that omits all the details of how the software works. Note that encapsulation hides the fine detail of what is inside the "capsule." For this reason, encapsulation is often called information hiding.

Encapsulation packages and hides detail

The principles of encapsulation apply to programming in general, not just to object-oriented programming. But object-oriented languages enable a programmer not only to realize these principles but also to enforce them. Chapter 5 will develop the concept of encapsulation further.

**Polymorphism** comes from a Greek word meaning "many forms." The basic idea of polymorphism is that it allows the same program instruction to mean different things in different contexts. Polymorphism commonly occurs in English, and its use in a programming language makes the programming

language more like a human language. For example, the English instruction "Go play your favorite sport" means different things to different people. To one person, it means to play baseball. To another person, it means to play soccer.

Polymorphism also occurs in everyday tasks.<sup>3</sup> Imagine a person who whistles for her pets to come to dinner. Her dog runs, her bird flies, and her fish swim to the top of their tank. They all respond in their own way. The come-to-dinner whistle doesn't tell the animals how to come to dinner, just to come. Likewise when you press the "on" button on your laptop, your iPod, or your toothbrush, each of them responds appropriately. In a programming language such as Java, polymorphism means that one method name, used as an instruction, can cause different actions, depending on the kinds of objects that perform the action. For example, a method named showOutput might display the data in an object. But the number of data items it displays and their format depend on the kind of object that carries out the action. We will explain polymorphism more fully in Chapter 8.

Polymorphism enables objects to behave appropriately

Inheritance organizes related classes

Inheritance is a way of organizing classes. You can define common attributes and behaviors once and have them apply to a whole collection of classes. By defining a general class, you can use inheritance later to define specialized classes that add to or revise the details of the general class.

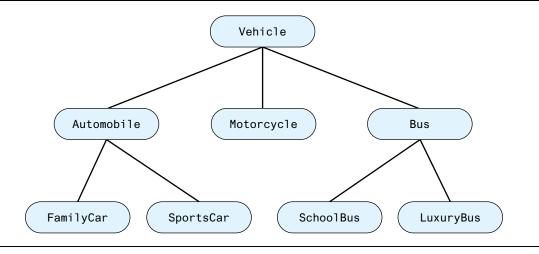
An example of such a collection of classes is shown in Figure 1.4. At each level, the classifications become more specialized. The class Vehicle has certain properties, like possessing wheels. The classes Automobile, Motorcycle, and Bus "inherit" the property of having wheels, but add more properties or restrictions. For example, an Automobile object has four wheels, a Motorcycle object has two wheels, and a Bus object has at least four wheels. Inheritance enables the programmer to avoid the repetition of programming instructions for each class. For example, everything that is true of every object of type Vehicle, such as "has wheels," is described only once, and it is inherited by the classes Automobile, Motorcycle, and Bus. Without inheritance, each of the classes Automobile, Motorcycle, Bus, SchoolBus, LuxuryBus, and so forth would have to repeat descriptions such as "has wheels." Chapter 8 will explain inheritance more fully.

## **RECAP Object-Oriented Programming**

Object-oriented programming, or OOP, is a programming methodology that defines objects whose behaviors and interactions accomplish a given task. OOP follows the design principles of encapsulation, polymorphism, and inheritance.

<sup>&</sup>lt;sup>3</sup> The examples here are based on those by Carl Alphonce in "Pedagogy and Practice of Design Patterns and Objects First: A One-Act Play." *ACM SIGPLAN Notices* 39, 5 (May 2004), 7–14.

FIGURE 1.4 An Inheritance Hierarchy



## **Algorithms**

Objects have behaviors that are defined by methods. You as a programmer need to design these methods by giving instructions for carrying out the actions. The hardest part of designing a method is not figuring out how to express your solution in a programming language. The hardest part is coming up with a plan or strategy for carrying out the action. This strategy is often expressed as something called an algorithm.

An algorithm is like a recipe

An **algorithm** is a set of directions for solving a problem. To qualify as an algorithm, the directions must be expressed so completely and so precisely that somebody can follow them without having to fill in any details or make any decisions that are not fully specified in the instructions. An algorithm can be written in English, a programming language such as Java, or in **pseudocode**, which is a combination of English and a programming language.

Algorithms are often written in pseudocode

An example may help to clarify the notion of an algorithm. Our first sample algorithm finds the total cost of a list of items. For example, the list of items might be a shopping list that includes the price of each item. The algorithm would then compute the total cost of all the items on the list. The algorithm is as follows:

#### Algorithm to compute the total cost of a list of items

- 1. Write the number 0 on the blackboard.
- 2. Do the following for each item on the list:
  - Add the cost of the item to the number on the blackboard.
  - Replace the old number on the blackboard with the result of this addition.
- 3. Announce that the answer is the number written on the blackboard.



Most algorithms need to store some intermediate results. This algorithm uses a blackboard to store intermediate results. If the algorithm is written in the Java language and run on a computer, intermediate results are stored in the computer's memory.

#### **RECAP** Algorithm

An algorithm is a set of directions for solving a problem. To qualify as an algorithm, the directions must be expressed completely and precisely.

#### **RECAP Pseudocode**

Pseudocode is a mixture of English and Java. When using pseudocode, you simply write each part of the algorithm in whatever language is easiest for you. If a part is easier to express in English, you use English. If another part is easier to express in Java, you use Java.



## **SELF-TEST QUESTIONS**

- 18. What is a method?
- 19. What is the relationship between classes and objects?
- 20. Do all objects of the same class have the same methods?
- 21. What is encapsulation?
- 22. What is information hiding?
- 23. What is polymorphism?
- 24. What is inheritance?
- 25. What is an algorithm?
- 26. What is pseudocode?
- 27. What attributes would you want for an object that represents a song?
- 28. Write an algorithm that counts the number of values that are odd in a list of integers.

## **Testing and Debugging**

The best way to write a correct program is to carefully design the necessary objects and the algorithms for the objects' methods. Then you carefully translate everything into a programming language such as Java. In other words, the best way to eliminate errors is to avoid them in the first place. However, no matter how carefully you proceed, your program might still contain some errors. When you finish writing a program, you should test it to see whether it performs correctly and then fix any errors you find.

A mistake in a program is called a **bug**. For this reason, the process of eliminating mistakes in your program is called **debugging**. There are three commonly recognized kinds of bugs or errors: syntax errors, run-time errors, and logic errors. Let's consider them in that order.

A **syntax error** is a grammatical mistake in your program. You must follow very strict grammatical rules when you write a program. Violating one of these rules—for example, omitting a required punctuation mark—is a syntax error. The compiler will detect syntax errors and provide an error message indicating what it thinks the error is. If the compiler says you have a syntax error, you probably do. However, the compiler is only guessing at what the error is, so it could be incorrect in its diagnosis of the problem.

Syntax errors are grammatical mistakes

#### **RECAP Syntax**

The syntax of a programming language is the set of grammatical rules for the language—that is, the rules for the correct way to write a program or part of a program. The compiler will detect syntax errors in your program and provide its best guess as to what is wrong.

An error that is detected when your program is run is called a **run-time error**. Such an error will produce an error message. For example, you might accidentally try to divide a number by zero. The error message might not be easy to understand, but at least you will know that something is wrong. Sometimes the error message can even tell you exactly what the problem is.

If the underlying algorithm for your program contains a mistake, or if you write something in Java that is syntactically correct but logically wrong, your program could compile and run without any error message. You will have written a valid Java program, but you will not have written the program you wanted. The program will run and produce output, but the output will be incorrect. In this case, your program contains a **logic error**. For example, if you were to mistakenly use a plus sign instead of a minus sign, you would make a logic error. You could compile and run your program with no error messages, but the program would give the wrong output. Sometimes a logic error will lead to a run-time error that produces an error message. But often a logic error

Run-time errors occur during execution

Logic errors are conceptual mistakes in the program or algorithm will not give you any error messages. For this reason, logic errors are the hardest kind of error to locate.

## **GOTCHA** Coping with "Gotchas"

Any programming language has details that can trip you up in ways that are surprising or hard to deal with. These sorts of problems are often called pitfalls, but a more colorful term is *gotchas*. A gotcha is like a trap waiting to catch you. When you get caught in the trap, the trap has "got you" or, as it is more commonly pronounced, "gotcha."

In this book, we have "Gotcha" sections like this one that warn you about many of the most common pitfalls and tell you how to avoid them or cope with them.

#### **GOTCHA** Hidden Errors

Just because your program compiles and runs without any errors and even produces reasonable-looking output does not mean that your program is correct. You should always run your program with some test data that gives predictable output. To do this, choose some data for which you can compute the correct results, either by using pencil and paper, by looking up the answer, or by some other means. Even this testing does not guarantee that your program is correct, but the more testing you do, the more confidence you can have in your program.



## **SELF-TEST QUESTIONS**

- 29. What is a syntax error?
- 30. What is a logic error?
- 31. What kinds of errors are likely to produce error messages that will alert you to the fact that your program contains an error?
- 32. Suppose you write a program that is supposed to compute the day of the week (Sunday, Monday, and so forth) on which a given date (like December 1, 2014) will fall. Now suppose that you forget to account for leap years. Your program will then contain an error. What kind of program error is it?

#### **Software Reuse**

When you first start to write programs, you can easily get the impression that you must create each program entirely from scratch. However, typical software is not produced this way. Most programs contain some components that

Don't let a gotcha get you



already exist. Using such components saves time and money. Furthermore, existing components have probably been used many times, so they likely are better tested and more reliable than newly created software.

For example, a highway simulation program might include a new highway object to model a new highway design but would probably model automobiles by using an automobile class that was already designed for some other program. To ensure that the classes you use in your programs are easily reusable, you must design them to be reusable. You must specify exactly how objects of that class interact with other objects. This is the principle of encapsulation that we mentioned earlier. But encapsulation is not the only principle you must follow. You must also design your class so that the objects are general and not specific to one particular program. For example, if your program requires that all simulated automobiles move only forward, you should still include a reverse in your automobile class, because some other simulation may require automobiles to back up. We will return to the topic of reusability after we learn more details about the Java language and have some examples to work with.

Besides reusing your own classes, you can and will use classes that Java provides. For example, we have already used the standard classes Scanner AND System to perform input and output. Java comes with a collection of many classes known as the Java Class Library, sometimes called the Java Application Programming Interface, or API. The classes in this collection are organized into packages. As you saw earlier, the class Scanner, for example, is in the package java.util. From time to time we will mention or use classes within the Java Class Library. You should become familiar with the documentation provided for the Java Class Library on the Oracle® Web site. At this writing, the link to this documentation is https://docs.oracle.com/javase/8/docs/api/java/util/Scanner.html. Figure 1.5 gives an example of this documentation.

Java provides a library of classes for you

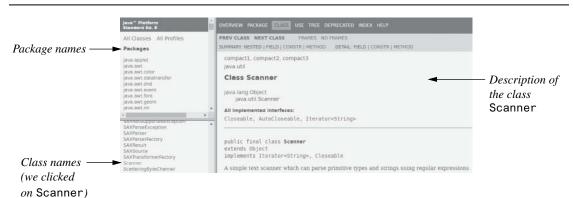


FIGURE 1.5 The Documentation for the Class Scanner

#### **1.4** GRAPHICS SUPPLEMENT

Have a nice day.

—COMMON FAREWELL

Each of Chapters 1 through 10 has a graphics section like this one that describes how to write programs that include various kinds of graphics displays. We typically will display the graphics inside a JavaFX application.

Since some people prefer to delay coverage of graphics until after a programmer, such as yourself, has mastered the more elementary material, you may skip these supplements without affecting your understanding of the rest of the book. In order to cover graphics this early, we will have to resort to some "magic formulas"—that is, code that we will tell you how to use but not fully explain until later in the book. These graphics supplements do build on each other. If you want to cover the graphics supplement in one chapter, you will need to first read all or most of the graphics supplements in previous chapters.

The material on graphics presented here uses classes, objects, and methods. You know that objects are entities that store data and can take actions. In this section, we will use objects only for taking actions, and we will use only one kind of object. Our objects will have various methods that can draw figures—such as ovals—inside a display.

The methods used to display graphics and graphical user interfaces (GUI) in Java have gone through several evolutions since Java's introduction in 1996. The first toolkit to display GUIs in Java was the Abstract Window Toolkit, or AWT. AWT was implemented using platform-specific code. The successor to AWT is Swing. Swing is written in Java, which provides platform independence. Swing is complementary to AWT rather than a replacement. A typical Java program written using Swing would incorporate libraries from both AWT and Swing. While there are still many Java programs written today using Swing, the most recent graphics toolkit for Java is JavaFX.

JavaFX is a set of packages that allow Java programmers to create rich graphics and media applications. Potential applications include GUI interfaces, 2D and 3D games, animations, visual effects, touch-enabled applications, and multimedia applications. At the time of this writing, JavaFX 8 is the latest version. JavaFX has several advantages over other graphical libraries, including hardware-accelerated graphics and a high-performance media engine. At some point, JavaFX will replace Swing as the standard library for creating graphical interfaces. However, both JavaFX and Swing are expected to be included in Java distributions for the foreseeable future.

Due to the historical progression from AWT to Swing to JavaFX, you may find it helpful to learn a bit about AWT and Swing. Sometimes you will see references to the older toolkits in the context of a newer toolkit. Swing is covered in the online chapter.

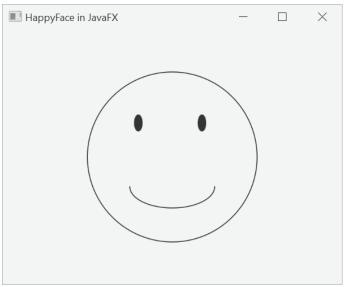
## A Sample JavaFX Application

Listing 1.2 contains a JavaFX application that draws a happy face. Let's examine the code by going through it section by section.

#### LISTING 1.2 Drawing a Happy Face

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.shape.ArcType;
public class HappyFace extends Application
   public static void main(String[] args)
   {
      launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
       Group root = new Group();
       Scene scene = new Scene(root);
       Canvas canvas = new Canvas (400, 300);
       GraphicsContext gc = canvas.getGraphicsContext2D();
       gc.stroke0val(100, 50, 200, 200);
       gc.fill0val(155, 100, 10, 20);
       gc.fill0val(230, 100, 10, 20);
       gc.strokeArc(150, 160, 100, 50, 180, 180, ArcType.OPEN);
       root.getChildren().add(canvas);
       primaryStage.setTitle("HappyFace in JavaFX");
       primaryStage.setScene(scene);
       primaryStage.show();
   }
}
```

#### Program Output



#### The section

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.shape.ArcType;
```

says that the application uses a number of library packages in the JavaFX library. They include classes for Application, Canvas, Scene, Group, Stage, GraphicsContext, and ArcType. These are all components of JavaFX that will be described in more detail later in the book.

The line

```
public class HappyFace extends Application
```

begins the class definition for the program. It is named HappyFace. The words extends Application indicate that we are defining a JavaFX application, as opposed to some other kind of class. Although you need not worry about further details yet, we are using inheritance to create the class HappyFace based upon an existing class Application.

The application contains two methods—main and start. The main method is where a Java program normally begins.

```
public static void main(String[] args)
{
    launch(args);
}
```

In the sample program shown in Listing 1.1, most of our program code was entered in the main method. This is how we will write most of our Java programs. However, a JavaFX application is different. A JavaFX program begins execution in the start method. The main method is ignored in a correctly deployed JavaFX application. However, it is common to include main and a call to launch as a fallback, which will end up launching the JavaFX program and the start method.

For a JavaFX application, programs begin in the start method.

```
@Override
public void start(Stage primaryStage) throws Exception
```

For now, you can ignore the <code>@Override</code> and the <code>throws</code> Exception code. What you do need to know is that this method is invoked automatically when the JavaFX application is run. JavaFX uses the metaphor of a stage and scenes, just like the stage and scene of a theater.

A JavaFX application begins in the start method

The next four lines set up a canvas on a scene for you to draw simple graphics.

```
Group root = new Group();
Scene scene = new Scene(root);
Canvas canvas = new Canvas(400, 300);
GraphicsContext gc = canvas.getGraphicsContext2D();
```

At this point, we can now use drawing operations on the canvas. The method invocation

```
gc.stroke0val(100, 50, 200, 200);
```

draws the big circle that forms the outline of the face. The first two numbers tell where on the screen the circle is drawn. The method stroke0va1, as you may have guessed, draws ovals. The last two numbers give the width and height of the oval. To obtain a circle, you make the width and height the same size, as we have done here. The units for these numbers are called *pixels*, and we will describe them shortly.

The two method invocations

```
gc.fill0val(155, 100, 10, 20);
gc.fill0val(230, 100, 10, 20);
```

draw the two eyes. The eyes are "real" ovals that are taller than they are wide. Also notice that the method is called fillOval, not strokeOval, which means it draws an oval that is filled in.

The next invocation

```
gc.strokeArc(150, 160, 100, 50, 180, 180, ArcType.OPEN);
```

draws the mouth. We will explain the meaning of all these arguments in the next section.

Finally, the block

```
root.getChildren().add(canvas);
primaryStage.setTitle("HappyFace in JavaFX");
primaryStage.setScene(scene);
primaryStage.show();
```

sets a title for the window and does some bookkeeping to set the stage and display the window.

## Size and Position of Figures

All measurements within a screen display are given not in inches or centimeters but in pixels. A **pixel**—short for picture element—is the smallest length your screen is capable of showing. A pixel is not an absolute unit of length like an inch or a centimeter. The size of a pixel can be different on different screens, but it will always be a small unit. You can think of your computer screen as being covered by small squares, each of which can be any color. You cannot show anything smaller than one of these squares. A pixel is one of these squares, but when used as measure of length, a pixel is the length of the side of one of these squares. If you have shopped for a digital camera, you have undoubtedly heard the term *pixel* or *megapixel*. The meaning of the word *pixel* when used in Java applets is the same as its meaning when describing pictures from a digital camera. A **megapixel** is just a million pixels.

Figure 1.6 shows the **coordinate system** used to position figures inside of an applet or other kind of Java window-like display. Think of the large rectangle as outlining the drawing area that is displayed on the screen. The coordinate system assigns two numbers to each point inside the rectangle. The numbers are known as the **x-coordinate** and the **y-coordinate** of the point. The **x-coordinate** is the number of pixels from the left edge of the rectangle to the point. The **y-coordinate** is the number of pixels from the top edge of the rectangle to the point. The coordinates are usually written within parentheses and separated by a comma, with the *x*-coordinate first. So the point marked with a blue dot in Figure 1.6 has the coordinates (100, 50); 100 is the *x*-coordinate and 50 is the *y*-coordinate.

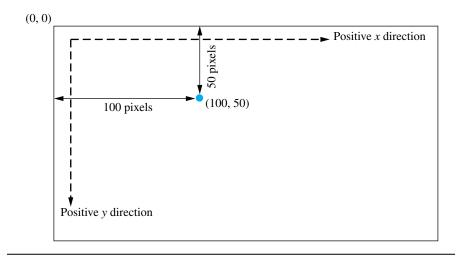
Each coordinate in this system is greater than or equal to zero. The x-coordinate gets larger as you go to the right from point (0, 0). The y-coordinate gets larger as you go down from point (0, 0). If you have studied x- and y-coordinates in a math class, these are the same, with one change. In other coordinate systems, the y-coordinates increase as they go up from point (0, 0).

A pixel is the

smallest length shown on a screen A coordinate system positions points on the screen

<sup>&</sup>lt;sup>4</sup> Strictly speaking, a pixel need not be a square but could be rectangular. However, we do not need to go into such fine detail here.

FIGURE 1.6 Screen Coordinate System



You position a rectangle in this graphical coordinate system at coordinates (x, y) by placing its upper left corner at the point (x, y). For example, the rectangle given by the dashed blue lines in Figure 1.7 is positioned at point (100, 50), which is marked with a black X. You position a figure that is not a rectangle at point (x, y) by first enclosing it in an imaginary rectangle that is as small as possible but still contains the figure and then by placing the upper left corner of this enclosing rectangle at (x, y). For example, in Figure 1.7 the oval is also positioned at point (100, 50). If the applet contains only an oval and no rectangle, only the oval shows on the screen. But an imaginary rectangle is still used to position the oval.

### **Drawing Ovals and Circles**

The oval in Figure 1.7 is drawn by the Java statement

```
gc.stroke0val(100, 50, 90, 50);
```

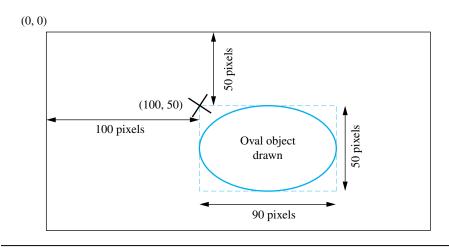
The first two numbers are the *x*- and *y*-coordinates of the upper left corner of the imaginary rectangle that encloses the oval. That is, these two numbers are the coordinates of the position of the figure drawn by this statement. The next two numbers give the width and height of the rectangle containing the oval (and thus the width and height of the oval itself). If the width and height are equal, you get a circle.

Now let's return to the statements in the body of the method paint:

```
gc.stroke0val(100, 50, 200, 200);
gc.fill0val(155, 100, 10, 20);
gc.fill0val(230, 100, 10, 20);
```

StrokeOval and fillOval draw ovals or circles

FIGURE 1.7 The Oval Drawn by gc.strokeOval (100, 50, 90, 50)



In each case, the first two numbers are the x- and y-coordinates of the upper left corner of an imaginary rectangle that encloses the figure being drawn. The first statement draws the outline of the face at position (100, 50). Since the width and height—as given by the last two arguments—have the same value, 200, we get a circle whose diameter is 200. The next two statements draw filled ovals for the eyes positioned at the points (155, 100) and (230, 100). The eyes are each 10 pixels wide and 20 pixels high. The results are shown in Listing 1.2.

### **RECAP** The Methods StrokeOval and fillOval

### **SYNTAX**

```
gc.stroke0val(x, y, Width, Height);
gc.fill0val(x, y, Width, Height);
```

The method stroke0val draws the outline of an oval that is *Width* pixels wide and *Height* pixels high. The oval is placed so that the upper left corner of a tightly enclosing rectangle is at the point (x, y).

The method filloval draws the same oval as stroke0val but fills it in.

### **Drawing Arcs**

Arcs, such as the smile on the happy face in Listing 1.2, are specified as a portion of an oval. For example, the following statement from Listing 1.2 draws the smile on the happy face:

```
gc.strokeArc(150, 160, 100, 50, 180, 180, ArcType.OPEN);
```

The first two arguments give the position of an invisible rectangle. The upper left corner of this rectangle is at the point (150, 160). The next two arguments specify the size of the rectangle; it has width 100 and height 50. Inside this invisible rectangle, imagine an invisible oval with the same width and height as the invisible rectangle. The next two arguments specify the portion of this invisible oval that is made visible. In this example, the bottom half of the oval is visible and forms the smile. Let's examine these next two arguments more closely.

The fifth argument of strokeArc specifies a start angle in degrees. The last argument specifies how many degrees of the oval's arc will be made visible. The rightmost end of the oval's horizontal equator is at zero degrees. As you move along the oval's edge in a counterclockwise direction, the degrees increase in value. For example, Figure 1.8a shows a start angle of 0 degrees; we measure 90 degrees along the oval in a counterclockwise direction, making one quarter of the oval visible. Conversely, as you move along the oval in a clockwise direction, the degrees decrease in value. For example, in Figure 1.8b, we start at 0 and move –90 degrees in a clockwise direction, making a different quarter of the oval visible. If the last argument is 360, you move counterclockwise through 360 degrees, making the entire oval visible, as Figure 1.8c shows.

drawArc draws part of an oval

### **RECAP** strokeArc

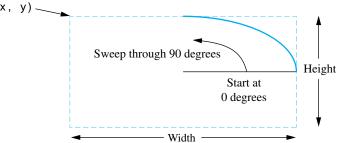
### **SYNTAX**

gc.strokeArc(x, y, Width, Height, StartAngle, ArcAngle, ArcType);

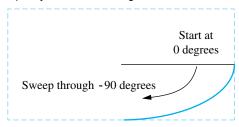
Draws an arc that is part of an oval placed so the upper left corner of a tightly enclosing rectangle is at the point (x, y). The oval's width and height are *Width* and *Height*, both in pixels. The portion of the arc drawn is given by *StartAngle* and *ArcAngle*, both given in degrees. The rightmost end of the oval's horizontal equator is at 0 degrees. You measure positive angles in a counterclockwise direction and negative angles in a clockwise direction. Beginning at *StartAngle*, you measure *ArcAngle* degrees along the oval to form the arc. ArcType can be ArcType.OPEN, ArcType.CHORD, or ArcType ROUND. Figure 1.8 gives some examples of arcs.

### FIGURE 1.8 Specifying an Arc

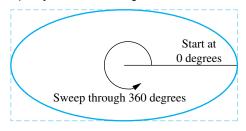
(a) gc.strokeArc(x, y, width, height, 0, 90, ArcType.OPEN);



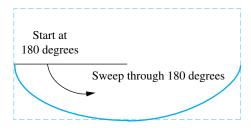
(b) gc.strokeArc(x, y, width, height, 0, -90, ArcType.OPEN);



(c) gc.strokeArc(x, y, width, height, 0, 360, ArcType.OPEN);



(d) gc.strokeArc(x, y, width, height, 180, 180, ArcType.OPEN);



### FAQ What is Graphics Context gc?

The identifier gc names an object that does the drawing. Note that gc is a "dummy variable" that stands for an object that Java supplies to do the drawing. You need not use the identifier gc, but you do need to be consistent. If you change one occurrence of gc to, say, pen, you must change all occurrences of gc to pen. Thus, the method start shown in Listing 1.2 could be written as follows:

```
GraphicsContext pen = canvas.getGraphicsContext2D();
pen.strokeOval(100, 50, 200, 200);
pen.fillOval(155, 100, 10, 20);
pen.fillOval(230, 100, 10, 20);
pen.strokeArc(150, 160, 100, 50, 180, 180, ArcType.OPEN);
```

This definition and the one given in Listing 1.2 are equivalent.

Finally, Figure 1.8d illustrates an arc that begins at 180 degrees, so it starts on the left end of the invisible oval. The sixth argument is also 180, so the arc is made visible through 180 degrees in the counterclockwise direction, or halfway around the oval. Finally, the last argument specifies the type of arc. Use ArcType.OPEN to leave an open arc that is not connected. Use ArcType. CHORD to close the arc by drawing a line segment from the start to the end. Use ArcType.ROUND to close the arc by drawing line segments from the start to the center to the end of the segment. The smile on the happy face in Listing 1.2 uses ArcType.OPEN.

### **SELF-TEST QUESTIONS**

- 33. How would you change the JavaFX application in Listing 1.2 so that the eyes are circles instead of ovals?
- 34. How would you change the program in Listing 1.2 so that the face frowns? (*Hint:* Turn the smile upside down by changing the arguments in the call to the method strokeArc.)



### CHAPTER SUMMARY

A computer's main memory holds the program that is currently executing, and it also holds many of the data items that the program is manipulating. A computer's main memory is divided into a series of numbered locations called bytes. This memory is volatile: The data it holds disappears when the computer's power is off.

- A computer's auxiliary memory is used to hold data in a more or less permanent way. Its data remains even when the computer's power is off. Hard disk drives, flash drives, CDs, and DVDs are examples of auxiliary memory.
- A compiler is a program that translates a program written in a high-level language like Java into a program written in a low-level language. An interpreter is a program that performs a similar translation, but unlike a compiler, an interpreter executes a portion of code right after translating it, rather than translating the entire program at once.
- The Java compiler translates your Java program into a program in the bytecode language. When you give the command to run your Java program, this bytecode program is both translated into machine-language instructions and executed by an interpreter called the Java Virtual Machine.
- An object is a program construct that performs certain actions. These actions, or behaviors, are defined by the object's methods. The characteristics, or attributes, of an object are determined by its data, and the values of these attributes give the object a state.
- Object-oriented programming is a methodology that views a program as consisting of objects that can act alone or interact with one another. A software object might represent a real-world object, or it might be an abstraction.
- Three of the main principles of object-oriented programming are encapsulation, polymorphism, and inheritance.
- A class is a blueprint for the attributes and behaviors of a group of objects. The class defines the type of these objects. All objects of the same class have the same methods.
- In a Java program, a method invocation is written as the object name, followed by a period (called a dot), the method name, and, finally, the arguments in parentheses.
- An algorithm is a set of directions for solving a problem. To qualify as an algorithm, the directions must be expressed so completely and precisely that somebody could follow them without having to fill in any details or make any decisions that are not fully specified in the directions.
- Pseudocode is a combination of English and a programming language. It is used to write an algorithm's directions.
- The syntax of a programming language is the set of grammatical rules for the language. These rules dictate whether a statement in the language is correct. The compiler will detect errors in a program's syntax.

- You can write JavaFX applications that display pictures on the computer screen.
- The method stroke0val draws the outline of an oval. The method filloval draws the same oval as stroke0val but fills it in. The method strokeArc draws an arc that is part of an oval.

### **Exercises**

- 1. How does the programmer's view of executing a program differ from the computer's?
- 2. When you turn a computer on, what kind of program do you interact with first? What is it called?
- 3. Two programs, X and Y, are translated using an interpreter and a compiler, respectively. Which program will run faster and why?
- 4. How does a source program differ from an object program in Java?
- 5. How does a class loader differ from a linker?
- 6. Write a statement or statements that can be used in a Java program to display the following on the screen:

Welcome

То

Iava

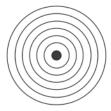
7. What would the following statements, when used in a Java program, display on the screen?

```
int a = 10;
int a2 = 100;
System.out.println(a2);
System.out.println (" is square of ");
System.out.println(a);
```

- 8. Write statements that can be used in a Java program to read two numbers, as entered at the keyboard, and display their difference on the screen.
- 9. Given a person's year of birth, the Election Wizard can compute the year in which they will be eligible to vote (assuming the eligibility age to be 18 years). Write statements that can be used in a Java program to perform this computation for the Election Wizard.
- 10. Write statements that can be used in a Java program to read two integers and display the number of integers that lie between them, including the integers themselves. For example, four integers are between 3 and 6: 3, 4, 5, and 6.
- 11. A memory address starts with 2313. Each subsequent value uses three bytes as location. For instance, the second value takes memory

addresses 2316, 2317, and 2318. What memory addresses will be taken by:

- a. 5th value?
- b. 10th value?
- c. 13th value?
- 12. Find the documentation for the Java Class Library on the Oracle® Web site. (At this writing, the link to this documentation is https://docs.oracle.com/javase/8/docs/api/.) Then find the description for the class Scanner. How many methods are described in the section entitled "Method Summary"?
- 13. Self-Test Question 27 asked you to think of some attributes for a song object. What attributes would you want for an object that represents a play list containing many songs?
- 14. What behaviors might a song have? What behaviors might a play list have? Contrast the difference in behavior between the two kinds of objects.
- 15. What attributes and behaviors would an object representing a mobile sim card have?
- 16. Suppose that you have a number x that is greater than 1. Write an algorithm that computes the largest integer k such that  $2^k$  is less than or equal to x.
- 17. Write an algorithm that finds the minimum value in a list of values.
- 18. Write statements that can be used in a JavaFX application to draw a dart board showing concentric circular rings and a bull's eye. (The bull's eye should be a filled circle.)



Graphics

**Graphics** 

**Graphics** 

- 19. Find the documentation for the class Graphics Context in the JavaFX Class Library. (See Exercise 12.) Learn how to use the method strokeRect. Then write statements that can be used in a JavaFX application to draw a square containing a circle. The circle's diameter and the square's side should be equal in size.
- 20. Write statements that can be used in a JavaFX application to draw the outline of a crescent moon.

### PRACTICE PROGRAMS

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

1. Obtain a copy of the Java program shown in Listing 1.1 from the Web at the location given in the preface. Name the file FirstProgram.java.

- Compile the program so that you receive no compiler error messages. Then run the program.
- 2. Modify the Java program described in Practice Program 1 so that it adds three numbers instead of two. Compile the program so that you receive no compiler error messages. Then run the program.
- 3. The following program has syntax errors that prevent the program from compiling. Find and fix the errors.

```
import java.util.Scanner;
public class SyntaxErrorRev
{
   public static void main(String[] args)
   {
      System.out.println("Enter the length and width of rectangle");
      System.out.println(-to calculate its area);
      Scanner keyboard = Scanner(System.in);
      int l = keyboard.nextInt();
      int w = keyboard.nextInt();
      area = l * w;
      System.out.println("The area of the rectangle is " area);
   }
}
```

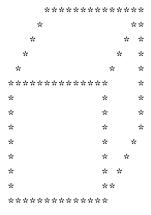
4. The following program will compile but it has run-time errors. Find and fix the errors.

```
import java.util.Scanner;
public class SemanticErrorRev
{
 public static void main(String[] args)
    int subject1, subject2, subject3, subject4;
   System.out.println("Enter the marks in four subjects as
   whole numbers ");
   System.out.println(" so as to compute the sum and the
   average of the student ");
   Scanner keyboard = new Scanner(System.in);
    subject1 = keyboard.nextInt();
    subject2 = keyboard.nextInt();
    subject3 = keyboard.nextInt();
    subject4 = keyboard.nextInt();
    int sum = subject1 + subject2 + subject3 + subject4;
   System.out.println("The total marks in four subjects are "
    + sum);
    int avg = subject1 + subject2 + subject3 + subject4;
   System.out.println("The average marks of the student is
    " + avg);
 }
}
```

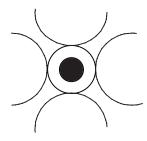
### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

1. Write a Java program that displays the following picture. (*Hint*: Write a sequence of println statements that display lines of asterisks and blanks.)



- 2. Write a complete program for the problem described in Exercise 9.
- 3. Write a complete program for the problem described in Exercise 10.
- 4. Write a JavaFX application similar to the one in Listing 1.2 that displays a picture of a snowman. (*Hint:* Draw three circles, one above the other. Make the circles progressively smaller from bottom to top. Make the top circle a happy face.)
- 5. Write a JavaFX application for the problem described in Exercise 18.
- 6. Write a JavaFX application that displays the following pattern:



### **Answers to Self-Test Questions**

- 1. Main memory and auxiliary memory.
- 2. Software is just another name for programs.



Graphics

Graphics

**Graphics** 

- 3. The two numbers to be added.
- 4. All the grades on all the quizzes you have taken in the course.
- 5. A high-level-language program is written in a form that is easy for a human being to write and read. A machine-language program is written in a form the computer can execute directly. A high-level-language program must be translated into a machine-language program before the computer can execute it. Java bytecode is a low-level language that is similar to the machine language of most common computers. It is relatively easy to translate a program expressed in Java bytecode into the machine language of almost any computer.
- 6. Java is a high-level language.
- 7. Java bytecode is a low-level language.
- 8. A compiler translates a high-level-language program into a low-level-language program such as a machine-language program or a Java bytecode program. When you compile a Java program, the compiler translates your Java program into a program expressed in Java bytecode.
- 9. A source program is the high-level-language program that is input to a compiler.
- 10. The Java Virtual Machine is a program that translates Java bytecode instructions into machine-language instructions. The JVM is a kind of interpreter.
- 11. Java is great!
- 12. System.out.println("Java for one.");
   System.out.println("Java for all.");
- 13. mary.increaseAge(5);
- 14. The statement reads a whole number typed in at the keyboard and stores it in the variable n1.

Some details, such as identifier names, may be different in your program. Be sure you compile and run your program.

16. The file containing the class YourClass should be named YourClass. java.

- 17. YourClass.class.
- 18. A method defines an action that an object is capable of performing.
- 19. A class is a blueprint for creating objects. All objects in the same class have the same kind of data and the same methods.
- 20. Yes, all objects of the same class have the same methods.
- 21. Encapsulation is the process of hiding all the details of an object that are unnecessary to using the object. Put another way, encapsulation is the process of describing a class or object by giving only enough information to allow a programmer to use the class or object.
- 22. Information hiding is another term for encapsulation.
- 23. In a programming language, such as Java, polymorphism means that one method name, used as an instruction, can cause different actions, depending on the kind of object performing the action.
- 24. Inheritance is a way of organizing classes. You can define a general class having common attributes and behaviors, and then use inheritance to define specialized classes that add to or revise the details of the general class.
- 25. An algorithm is a set of directions for solving a problem. To qualify as an algorithm, the directions must be expressed so completely and precisely that somebody could follow them without having to fill in any details or make any decisions that are not fully specified in the directions.
- 26. Pseudocode is a mixture of English and Java that you can use to write the steps of an algorithm.
- 27. A song object could have the following attributes: title, composer, date, performer, album title.
- 28. Algorithm to count the odd integers in a list of integers:
  - 1. Write the number 0 on the blackboard.
  - 2. Do the following for each odd integer on the list:
    - Add 1 to the number on the blackboard.
    - Replace the old number on the blackboard with the result of this addition.
  - 3. Announce that the answer is the number written on the blackboard.
- 29. A syntax error is a grammatical mistake in a program. When you write a program, you must adhere to very strict grammatical rules. If you violate one of these rules by omitting a required punctuation mark, for example, you make a syntax error.

- 30. A logic error is a conceptual error in a program or its algorithm. If your program runs and gives output, but the output is incorrect, you have a logic error.
- 31. Syntax errors and run-time errors.
- 32. A logic error.
- 33. Change the following lines

```
gc.fillOval(155, 100, 10, 20);
gc.fillOval(230, 100, 10, 20);
to
gc.fillOval(155, 100, 10, 10);
gc.fillOval(230, 100, 10, 10);
```

The last two numbers on each line are changed from 10, 20 to 10, 10. You could also use some other number, such as 20, and write 20, 20 in place of 10, 10.

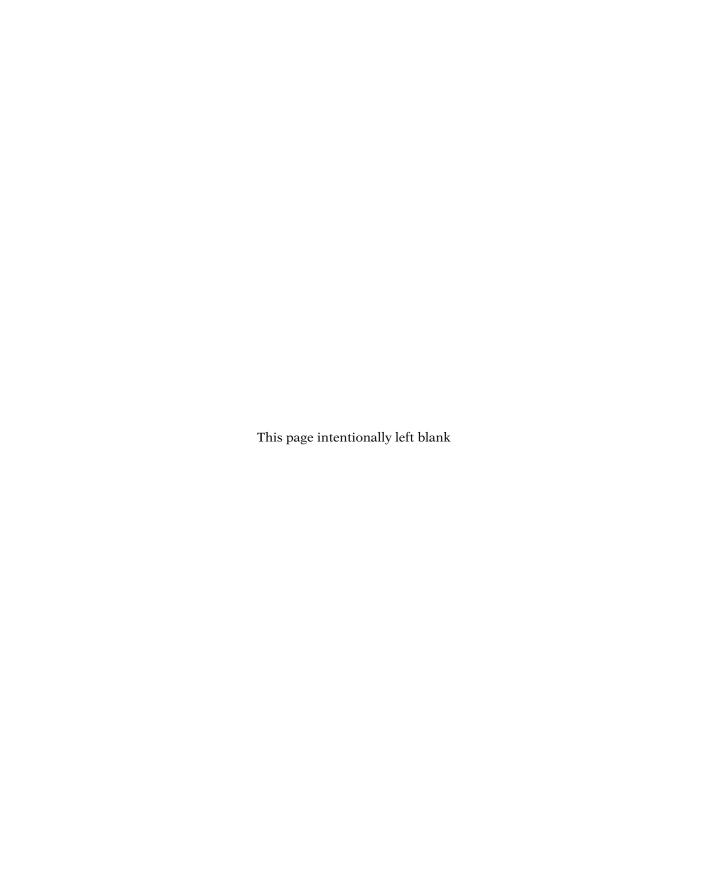
34. Change the following line

```
gc.strokeArc(150, 160, 100, 50, 180, 180, ArcType.OPEN);
to
gc.strokeArc(150, 160, 100, 50, 180, -180, ArcType.OPEN);
```

The last number is changed from positive to negative. Other correct answers are possible. For example, the following is also acceptable:

```
gc.strokeArc(150, 160, 100, 50, 0, 180, ArcType.OPEN);
```

You could also change the first number 150 to a larger number in either of the above statements. Other correct answers are similar to what we have already described.



# Basic Computation

### 2.1 VARIABLES AND EXPRESSIONS 86

Variables 87 Data Types 89 Java Identifiers 91 Assignment Statements 93 Simple Input 96 Simple Screen Output 98 Constants 98 Named Constants 100 Assignment Compatibilities 101 Type Casting 103 Arithmetic Operators 106 Parentheses and Precedence Rules 109 Specialized Assignment Operators 110 Case Study: Vending Machine Change 112 Increment and Decrement Operators 117 More About the Increment and Decrement Operators 118

### 2.2 THE CLASS String 119

String Constants and Variables 119
Concatenation of Strings 120
String Methods 121
String Processing 123

Escape Characters 126
The Unicode Character Set 127

### 2.3 KEYBOARD AND SCREEN I/O 129

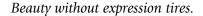
Screen Output 129
Keyboard Input 132
Other Input Delimiters (Optional) 137
Formatted Output with printf (Optional) 139

### **2.4 DOCUMENTATION AND STYLE** 141

Meaningful Variable Names 141 Comments 142 Indentation 145 Using Named Constants 145

### 2.5 GRAPHICS SUPPLEMENT 147

Style Rules Applied to a JavaFX Application 148
Introducing the Class J0ptionPane 150
Reading Input as Other Numeric Types 159
Programming Example: Change-Making Program with Windowing I/O 160



—RALPH WALDO EMERSON, The Conduct of Life, (1876)

In this chapter, we explain enough about the Java language to allow you to write simple Java programs. You do not need any programming experience to understand this chapter. If you are already familiar with some other programming language, such as Visual Basic, C, C++, or C#, much that is in Section 2.1 will already be familiar to you. However, even if you know the concepts, you should learn the Java way of expressing them.

### **OBJECTIVES**

After studying this chapter, you should be able to

- Describe the Java data types that are used for simple data like numbers and characters
- Write Java statements to declare variables and define named constants
- Write assignment statements and expressions containing variables and constants
- Define strings of characters and perform simple string processing
- Write Java statements that accomplish keyboard input and screen output
- Adhere to stylistic guidelines and conventions
- Write meaningful comments within a program
- Use the class JoptionPane to perform window-based input and output

### **PREREQUISITES**

If you have not read Chapter 1, you should read at least the section of Chapter 1 entitled "A First Java Application Program" to familiarize yourself with the notions of class, object, and method. Also, material from the graphics supplement in Chapter 1 is used in the section "Style Rules Applied to a Graphics Applet" in the graphics supplement of this chapter.

### 2.1 VARIABLES AND EXPRESSIONS

In this section, we explain how simple variables and arithmetic expressions are used in Java programs. Some of the terms used here were introduced in Chapter 1. We will, however, review them again.

### **Variables**

**Variables** in a program are used to store data such as numbers and letters. They can be thought of as containers of a sort. The number, letter, or other data item in a variable is called its **value**. This value can be changed, so that at one time the variable contains, say, 6, and at another time, after the program has run for a while, the variable contains a different value, such as 4.

A variable is a program component used to store or represent data

For example, the program in Listing 2.1 uses the variables number Of Baskets, eggsPerBasket, and total Eggs. When this program is run, the statement

```
eggsPerBasket = 6;
```

sets the value of eggsPerBasket to 6.

In Java, variables are implemented as memory locations, which we described in Chapter 1. Each variable is assigned one memory location. When the variable is given a value, the value is encoded as a string of 0s and 1s and is placed in the variable's memory location.

Variables represent memory locations

### LISTING 2.1 A Simple Java Program

```
public class EggBasket
   public static void main(String[] args)
   {
                                                                 Variable
      int numberOfBaskets, eggsPerBasket, totalEggs; 
                                                                 declarations
      numberOfBaskets = 10; ←
                                      Assianment statement
      eggsPerBasket = 6;
      totalEggs = numberOfBaskets * eggsPerBasket;
      System.out.println("If you have");
      System.out.println(eggsPerBasket + " eggs per basket and");
      System.out.println(numberOfBaskets + " baskets, then");
      System.out.println("the total number of eggs is " + totalEggs);
   }
}
```

### Sample Screen Output

```
If you have
6 eggs per basket and
10 baskets, then
the total number of eggs is 60
```

Choose meaningful variable names

You should choose variable names that are helpful. The names should suggest the variables' use or indicate the kind of data they will hold. For example, if you use a variable to count something, you might name it count. If the variable is used to hold the speed of an automobile, you might call the variable speed. You should almost never use single-letter variable names like x and y. Somebody reading the statement

```
x = y + z;
```

would have no idea of what the program is really adding. The names of variables must also follow certain spelling rules, which we will detail later in the section "Java Identifiers."

Before you can use a variable in your program, you must state some basic information about each one. The compiler—and so ultimately the computer—needs to know the name of the variable, how much computer memory to reserve for the variable, and how the data item in the variable is to be coded as strings of 0s and 1s. You give this information in a variable declaration. Every variable in a Java program must be declared before it is used for the first time.

A variable declaration tells the computer what type of data the variable will hold. That is, you declare the variable's data type. Since different types of data are stored in the computer's memory in different ways, the computer must know the type of a variable so it knows how to store and retrieve the value of the variable from the computer's memory. For example, the following line from Listing 2.1 declares numberOfBaskets, eggsPerBasket, and totalEggs to be variables of data type int:

```
int numberOfBaskets, eggsPerBasket, totalEggs;
```

A variable declaration consists of a type name, followed by a list of variable names separated by commas. The declaration ends with a semicolon. All the variables named in the list are declared to have the same data type, as given at the start of the declaration.

If the data type is int, the variable can hold whole numbers, such as 42, –99, 0, and 2001. A whole number is called an **integer**. The word int is an abbreviation of *integer*. If the type is double, the variable can hold numbers having a decimal point and a fractional part after the decimal point. If the type is char, the variables can hold any one character that appears on the computer keyboard.

Every variable in a Java program must be declared before the variable can be used. Normally, a variable is declared either just before it is used or at the start of a section of your program that is enclosed in braces {}. In the simple programs we have seen so far, this means that variables are declared either just before they are used or right after the lines

```
public static void main(String[] args)
```

Declare variables before using them

### **RECAP** Variable Declarations

In a Java program, you must declare a variable before it can be used. A variable declaration has the following form:

### **SYNTAX**

```
Type Variable_1, Variable_2, . . .;
```

### **EXAMPLES**

```
int styleNumber, numberOfChecks, numberOfDeposits;
double amount, interestRate;
char answer;
```

### **Data Types**

As you have learned, a data type specifies a set of values and their operations. In fact, the values have a particular data type because they are stored in memory in the same format and have the same operations defined for them.

A data type specifies a set of values and operations

### **REMEMBER** Syntactic Variables

When you see something in this book like *Type*, *Variable\_1*, or *Variable\_2* used to describe Java syntax, these words do not literally appear in your Java code. They are **syntactic variables**, which are a kind of blank that you fill in with something from the category that they describe. For example, *Type* can be replaced by int, double, char, or any other type name. *Variable\_1* and *Variable\_2* can each be replaced by any variable name.

Java has two main kinds of data types: class types and primitive types. As the name implies, a **class type** is a data type for objects of a class. Since a class is like a blueprint for objects, the class specifies how the values of its type are stored and defines the possible operations on them. As we implied in the previous chapter, a class type has the same name as the class. For example, quoted strings such as "Java is fun" are values of the class type String, which is discussed later in this chapter.

Variables of a **primitive type** are simpler than objects (values of a class type), which have both data and methods. A value of a primitive type is an indecomposable value, such as a single number or a single letter. The types int, double, and char are examples of primitive types.

Class types and primitive types

Type Name	Kind of Value	Memory Used	Range of Values
byte	Integer	1 byte	-128 to 127
short	Integer	2 bytes	-32,768 to 32,767
int	Integer	4 bytes	-2,147,483,648 to 2,147,483,647
long	Integer	8 bytes	-9,223,372,036,854,775,808 to 9,223,372,036,854,775,807
float	Floating-point	4 bytes	$\pm 3.40282347 \times 10^{+38}$ to $\pm 1.40239846 \times 10^{-45}$
double	Floating-point	8 bytes	$\pm 1.79769313486231570 \times 10^{+308}$ to $\pm 4.94065645841246544 \times 10^{-324}$
char	Single character (Unicode)	2 bytes	All Unicode values from 0 to 65,535
boolean		1 or more bytes	True or false

### FIGURE 2.1 Primitive Types

Figure 2.1 lists all of Java's primitive types. Four types are for integers, namely, byte, short, int, and long. The only differences among the various integer types are the range of integers they represent and the amount of computer memory they use. If you cannot decide which integer type to use, use the type int.

A number having a fractional part—such as the numbers 9.99, 3.14159, -5.63, and 5.0—is called a **floating-point number**. Notice that 5.0 is a floating-point number, not an integer. If a number has a fractional part, even if the fractional part is zero, it is a floating-point number. As shown in Figure 2.1, Java has two data types for floating-point numbers, float and double. For example, the following code declares two variables, one of type float and one of type double:

```
float cost;
double capacity;
```

As with integer types, the differences between float and double involve the range of their values and their storage requirements. If you cannot decide between the types float and double, use double.

The primitive type char is used for single characters, such as letters, digits, or punctuation. For example, the following declares the variable symbol to be of type char, stores the character for uppercase *A* in symbol, and then displays *A* on the screen:

```
char symbol;
symbol = 'A';
System.out.println(symbol);
```

A floating-point number has a fractional part In a Java program, we enclose a single character in single quotes, as in 'A'. Note that there is only one symbol for a single quote. The same quote symbol is used on both sides of the character. Finally, remember that uppercase letters and lowercase letters are different characters. For example, 'a' and 'A' are two different characters.

Single quotes enclose a character

The last primitive type we have to discuss is the type boolean. This data type has two values, true and false. We could, for example, use a variable of type boolean to store the answer to a true/false question such as "Is eggCount less than 12?" We will have more to say about the data type boolean in the next chapter. Although a boolean requires only 1 bit of storage, in practice 1 or more bytes is used, depending upon the context. This is because the CPU is designed to read 1 or more bytes at a time, so it is actually more time consuming to access an individual bit.

All primitive type names in Java begin with a lowercase letter. In the next section, you will learn about a convention in which class type names—that is, the names of classes—begin with an uppercase letter.

Although you declare variables for class types and primitive types in the same way, these two kinds of variables store their values using different mechanisms. Chapter 5 will explain class type variables in more detail. In this chapter and the next two, we will concentrate on primitive types. We will occasionally use variables of a class type before Chapter 5, but only in contexts where they behave pretty much the same as variables of a primitive type.

### **Java Identifiers**

The technical term for a name in a programming language, such as the name of a variable, is an **identifier**. In Java, an identifier (a name) can contain only letters, digits 0 through 9, and the underscore character (\_). The first character in an identifier cannot be a digit. In particular, no name can contain a space or any other character such as a dot (period) or an asterisk (\*). There is no limit to the length of an identifier. Well, in practice, there is a limit, but Java has no official limit and will accept even absurdly long names. Java is **case sensitive**. That is, uppercase and lowercase letters are considered to be different characters. For example, Java considers mystuff, myStuff, and MyStuff to be three different identifiers, and you could have three different variables with these three names. Of course, writing variable names that differ only in their capitalization is a poor programming practice, but the Java compiler would happily accept them. Within these constraints, you can use any name you want for a variable, a class, or any other item you define in a Java program. But there are some style guidelines for choosing names.

Java is case sensitive

<sup>&</sup>lt;sup>1</sup> Java does allow the dollar sign (\$) to appear in an identifier, treating it as a letter. But such identifiers have a special meaning. It is intended to identify code generated by a machine, so you should not use the \$ symbol in your identifiers.

Our somewhat peculiar use of uppercase and lowercase letters, such as numberOfBaskets, deserves some explanation. It would be perfectly legal to use NumberOfBaskets or number\_of\_baskets instead of numberOfBaskets, but these other names would violate some well-established conventions about how you should use uppercase and lowercase letters. Under these conventions, we write the names of variables using only letters and digits. We "punctuate" multiword names by using uppercase letters—since we cannot use spaces. The following are all legal names that follow these conventions:

Legal identifiers

inputStream YourClass CarWash hotCar theTimeOfDay

Notice that some of these legal names start with an uppercase letter and others, such as hotCar, start with a lowercase letter. We will always follow the convention that the names of classes start with an uppercase letter, and the names of variables and methods start with a lowercase letter.

The following identifiers are all illegal in Java, and the compiler will complain if you use any of them:

Illegal identifiers

prenhall.com go-team Five\* 7eleven

The first three contain illegal characters, either a dot, a hyphen, or an asterisk. The last name is illegal because it starts with a digit.

Some words in a Java program, such as the primitive types and the word if, are called **keywords** or **reserved words**. They have a special predefined meaning in the Java language and cannot be used as the names of variables, classes, or methods, or for anything other than their intended meaning. All Java keywords are entirely in lowercase. A full list of these keywords appears in Appendix 11, which is online, and you will learn them as we go along. The program listings in this book show keywords, such as public, class, static, and void, in a special color. The text editors within an IDE often identify keywords in a similar manner.

Some other words, such as main and println, have a predefined meaning but are not keywords. That means you can change their meaning, but it is a bad idea to do so, because it could easily confuse you or somebody else reading your program.

Java keywords have special meanings

### **RECAP Identifiers (Names)**

The name of something in a Java program, such as a variable, class, or method, is called an identifier. It must not start with a digit and may contain only letters, digits 0 through 9, and the underscore character (\_). Uppercase and lowercase letters are considered to be different characters. (The symbol \$ is also allowed, but it is reserved for special purposes, and so you should not use \$ in a Java name.)

Although it is not required by the Java language, the common practice, and the one followed in this book, is to start the names of classes with uppercase letters and to start the names of variables and methods with lowercase letters. These names are usually spelled using only letters and digits.

### **GOTCHA** Java Is Case Sensitive

Do not forget that Java is case sensitive. If you use an identifier, like myNumber, and then in another part of your program you use the spelling MyNumber, Java will not recognize them as being the same identifier. To be seen as the same identifier, they must use exactly the same capitalization.

# FAQ Why should I follow naming conventions? And who sets the rules?

By following naming conventions, you can make your programs easier to read and to understand. Typically, your supervisor or instructor determines the conventions that you should follow when writing Java programs. However, the naming conventions that we just gave are almost universal among Java programmers. We will mention stylistic conventions for other aspects of a Java program as we go forward. Sun Microsystems provides its own conventions on its Web site. While the company suggests that all Java programmers follow these conventions, not everyone does.

## **Assignment Statements**

The most straightforward way to give a variable a value or to change its value is to use an **assignment statement**. For example, if answer is a variable of type int and you want to give it the value 42, you could use the following assignment statement:

```
answer = 42;
```

The equal sign, =, is called the **assignment operator** when it is used in an assignment statement. It does not mean what the equal sign means in other contexts. The assignment statement is an order telling the computer to change the value stored in the variable on the left side of the assignment operator to the value of the **expression** on the right side. Thus, an assignment statement always consists of a single variable followed by the assignment operator (the equal sign) followed by an expression. The assignment statement ends with a semicolon. So assignment statements take the form

An assignment statement gives a value to a variable

Variable = Expression;

The expression can be another variable, a number, or a more complicated expression made up by using **arithmetic operators**, such as + and -, to combine variables and numbers. For example, the following are all examples of assignment statements:

```
amount = 3.99;
firstInitial = 'B';
score = numberOfCards + handicap;
eggsPerBasket = eggsPerBasket - 2;
```

All the names, such as amount, score, and numberOfCards, are variables. We are assuming that the variable amount is of type double, firstInitial is of type char, and the rest of the variables are of type int.

When an assignment statement is executed, the computer first evaluates the expression on the right side of the assignment operator (=) to get the value of the expression. It then uses that value to set the value of the variable on the left side of the assignment operator. You can think of the assignment operator as saying, "Make the value of the variable equal to what follows."

For example, if the variable number 0fCards has the value 7 and handicap has the value 2, the following assigns 9 as the value of the variable score:

```
score = numberOfCards + handicap;
```

In the program in Listing 2.1, the statement

\* means multiply

```
totalEggs = numberOfBaskets * eggsPerBasket;
```

is another example of an assignment statement. It tells the computer to set the value of totalEggs equal to the number in the variable numberOfBaskets multiplied by the number in the variable eggsPerBasket. The asterisk character (\*) is the symbol used for multiplication in Java.

Note that a variable can meaningfully occur on both sides of the assignment operator and can do so in ways that might at first seem a little strange. For example, consider

The same variable can occur on both sides of the =

```
count = count + 10;
```

This does not mean that the value of count is equal to the value of count plus 10, which, of course, is impossible. Rather, the statement tells the computer to add 10 to the *old* value of count and then make that the *new* value of count. In effect, the statement will increase the value of count by 10. Remember that when an assignment statement is executed, the computer first evaluates the expression on the right side of the assignment operator and then makes that result the new value of the variable on the left side of the assignment operator. As another example, the following assignment statement will decrease the value of eggsPerBasket by 2:

```
eggsPerBasket = eggsPerBasket - 2;
```

### **RECAP** Assignment Statements Involving Primitive Types

An assignment statement that has a variable of a primitive type on the left side of the equal sign causes the following action: First, the expression on the right side of the equal sign is evaluated, and then the variable on the left side of the equal sign is set to this value.

### **SYNTAX**

```
Variable = Expression;

EXAMPLE

score = goals - errors;
interest = rate * balance;
number = number + 5;
```

### PROGRAMMING TIP Initialize Variables

A variable that has been declared, but that has not yet been given a value by an assignment statement (or in some other way), is said to be **uninitialized**. If the variable is a variable of a class type, it literally has no value. If the variable has a primitive type, it likely has some default value. However, your program will be clearer if you explicitly give the variable a value, even if you are simply reassigning the default value. (The exact details on default values have been known to change and should not be counted on.)

One easy way to ensure that you do not have an uninitialized variable is to initialize it within the declaration. Simply combine the declaration and an assignment statement, as in the following examples:

You can initialize a variable when you declare it

```
int count = 0;
double taxRate = 0.075;
char grade = 'A';
int balance = 1000, newBalance;
```

Note that you can initialize some variables and not initialize others in a declaration.

Sometimes the compiler may complain that you have failed to initialize a variable. In most cases, that will indeed be true. Occasionally, though, the compiler is mistaken in giving this advice. However, the compiler will not compile your program until you convince it that the variable in question is initialized. To make the compiler happy, initialize the variable when you declare it, even if the variable will be given another value before it is used for anything. In such cases, you cannot argue with the compiler.

### **RECAP** Combining a Variable Declaration and an Assignment

You can combine the declaration of a variable with an assignment statement that gives the variable a value.

### **SYNTAX**

```
Type Variable_1 = Expression_1, Variable_2 = Expression_2,
...;

EXAMPLES

int numberSeen = 0, increment = 5;
double height = 12.34, prize = 7.3 + increment;
char answer = 'y';
```

### **Simple Input**

In Listing 2.1, we set the values of the variables eggsPerBasket and numberOfBaskets to specific numbers. It would make more sense to obtain the values needed for the computation from the user, so that the program could be run again with different numbers. Listing 2.2 shows a revision of the program in Listing 2.1 that asks the user to enter numbers as input at the keyboard.

We use the class Scanner, which Java supplies, to accept keyboard input. Our program must import the definition of the Scanner class from the package java.util. Thus, we begin the program with the following statement:

```
import java.util.Scanner;
```

The following line sets things up so that data can be entered from the keyboard:

```
Scanner keyboard = new Scanner(System.in);
```

This line must appear before the first statement that takes input from the keyboard. That statement in our example is

```
eggsPerBasket = keyboard.nextInt();
```

This assignment statement gives a value to the variable eggsPerBasket. The expression on the right side of the equal sign, namely

```
keyboard.nextInt()
```

reads one int value from the keyboard. The assignment statement makes this int value the value of the variable eggsPerBasket, replacing any value that the variable might have had. When entering numbers at the keyboard, the user must either separate multiple numbers with one or more spaces or place each number on its own line. Section 2.3 will explain such keyboard input in detail.

Use the standard class Scanner to accept keyboard input

### LISTING 2.2 A Program with Keyboard Input

```
Gets the Scanner class from the
import java.util.Scanner; <</pre>
                                     package (library) java.util
public class EggBasket2
   public static void main(String[] args)
   {
      int numberOfBaskets, eggsPerBasket, totalEggs;
                                                             Sets up things so the program
                                                             can accept keyboard input
      Scanner keyboard = new Scanner(System.in);
      System.out.println("Enter the number of eggs in each basket:");
      eggsPerBasket = keyboard.nextInt(); -
                                                               Reads one whole number
      System.out.println("Enter the number of baskets:");
                                                              from the keyboard
      numberOfBaskets = keyboard.nextInt();
      totalEggs = numberOfBaskets * eggsPerBasket;
      System.out.println("If you have");
      System.out.println(eggsPerBasket + " eggs per basket and");
      System.out.println(numberOfBaskets + " baskets, then");
      System.out.println("the total number of eggs is " + totalEggs);
      System.out.println("Now we take two eggs out of each basket.");
      eggsPerBasket = eggsPerBasket - 2;
      totalEggs = numberOfBaskets * eggsPerBasket;
      System.out.println("You now have");
      System.out.println(eggsPerBasket + " eggs per basket and");
      System.out.println(numberOfBaskets + " baskets.");
      System.out.println("The new total number of eggs is " + totalEggs);
   }
}
```

### Sample Screen Output

```
Enter the number of eggs in each basket:

6
Enter the number of baskets:

10
If you have
6 eggs per basket and
10 baskets, then
the total number of eggs is 60
Now we take two eggs out of each basket.
You now have
4 eggs per basket and
10 baskets.
The new total number of eggs is 40
```

### Simple Screen Output

Now we will give you a brief overview of screen output—just enough to allow you to write and understand programs like the one in Listing 2.2. System is a class that is part of the Java language, and out is a special object within that class. The object out has println as one of its methods. It may seem strange to write System.out.println to call a method, but that need not concern you at this point. Chapter 6 will provide some details about this notation.

So

```
System.out.println(eggsPerBasket + "eggs per basket.");
```

displays the value of the variable eggsPerBasket followed by the phrase eggs per basket. Notice that the + symbol does not indicate arithmetic here. It denotes another kind of "and." You can read the preceding Java statement as an instruction to display the value of the variable eggsPerBasket and then to display the string "eggs per basket."

Section 2.3 will continue the discussion of screen output.

### **Constants**

A variable can have its value changed. That is why it is called a variable: Its value *varies*. A number like 2 cannot change. It is always 2. It is never 3. In Java, terms like 2 or 3.7 are called **constants**, or **literals**, because their values do not change.

Constants need not be numbers. For example, 'A', 'B', and '\$' are three constants of type char. Their values cannot change, but they can be used in an assignment statement to change the value of a variable of type char. For example, the statement

```
firstInitial = 'B';
```

changes the value of the char variable firstInitial to 'B'.

There is essentially only one way to write a constant of type char, namely, by placing the character between single quotes. On the other hand, some of the rules for writing numeric constants are more involved. Constants of integer types are written the way you would expect them to be written, such as 2, 3, 0, -3, or 752. An integer constant can be prefaced with a plus sign or a minus sign, as in +12 and -72. Numeric constants cannot contain commas. The number 1,000 is *not* correct in Java. Integer constants cannot contain a decimal point. A number with a decimal point is a floating-point number.

Floating-point constant numbers may be written in either of two forms. The simple form is like the everyday way of writing numbers with digits after the decimal point. For example, 2.5 is a floating-point constant. The other, slightly more complicated form is similar to a notation commonly used in mathematics and the physical sciences, **scientific notation**. For instance, consider the number 865000000.0. This number can be expressed more clearly in the following scientific notation:

A constant does not change in value

Java's e notation is like scientific notation

Java has a similar notation, frequently called either **e notation** or **floating-point notation**. Because keyboards have no way of writing exponents, the 10 is omitted and both the multiplication sign and the 10 are replaced by the letter e. So in Java,  $8.65 \times 10^8$  is written as  $8.65 \times 10^8$ . The e stands for *exponent*, since it is followed by a number that is thought of as an exponent of 10. This form and the less convenient form 865000000.0 are equivalent in a Java program. Similarly, the number  $4.83 \times 10^{-4}$ , which is equal to 0.000483, could be written in Java as either 0.000483 or 4.83e-4. Note that you also could write this number as 0.483e-3 or 48.3e-5. Java does not restrict the position of the decimal point.

The number before the e may contain a decimal point, although it doesn't have to. The number after the e cannot contain a decimal point. Because multiplying by 10 is the same as moving the decimal point in a number, you can think of a positive number after the e as telling you to move the decimal point that many digits to the right. If the number after the e is negative, you move the decimal point that many digits to the left. For example, 2.48e4 is the same number as 24800.0, and 2.48e-2 is the same number as 0.0248.



### FAQ What is "floating" in a floating-point number?

Floating-point numbers got their name because, with the e notation we just described, the decimal point can be made to "float" to a new location by adjusting the exponent. You can make the decimal point in 0.000483 float to after the 4 by expressing this number as the equivalent expression 4.83e-4. Computer language implementers use this trick to store each floating-point number as a number with exactly one digit before the decimal point (and some suitable exponent). Because the implementation always floats the decimal point in these numbers, they are called floating-point numbers. Actually, the numbers are stored in another base, such as 2 or 16, rather than as the decimal (base 10) numbers we used in our example, but the principle is the same.

# **FAQ** Is there an actual difference between the constants 5 and 5.0?

The numbers 5 and 5.0 are conceptually the same number. But Java considers them to be different. Thus, 5 is an integer constant of type int, but 5.0 is a floating-point constant of type double. The number 5.0 contains a fractional part, even though the fraction is 0. Although you might see the numbers 5 and 5.0 as having the same value, Java stores them differently. Both integers and floating-point numbers contain a finite number of digits when stored in a computer, but only integers are considered exact quantities. Because floating-point numbers have a fractional portion, they are seen as approximations.

# **GOTCHA** Imprecision in Floating-Point Numbers

Floating-point numbers are stored with a limited amount of precision and so are, for all practical purposes, only approximate quantities. For example, the fraction one third is equal to

```
0.3333333 . . .
```

where the three dots indicate that the 3s go on forever. The computer stores numbers in a format somewhat like the decimal representation on the previously displayed line, but it has room for only a limited number of digits. If it can store only ten digits after the decimal, then one third is stored as

```
0.333333333 (and no more 3s)
```

This number is slightly smaller than one third and so is only approximately equal to one third. In reality, the computer stores numbers in binary notation, rather than in base 10, but the principles are the same and the same sorts of things happen.

Not all floating-point numbers lose accuracy when they are stored in the computer. Integral values like 29.0 can be stored exactly in floating-point notation, and so can some fractions like one half. Even so, we usually will not know whether a floating-point number is exact or an approximation. When in doubt, assume that floating-point numbers are stored as approximate quantities.

### **Named Constants**

Java provides a mechanism that allows you to define a variable, initialize it, and moreover fix the variable's value so that it cannot be changed. The syntax is

```
public static final Type Variable = Constant;
```

For example, we can give the name PI to the constant 3.14159 as follows:

```
public static final double PI = 3.14159;
```

You can simply take this as a long, peculiarly worded way of giving a name (like PI) to a constant (like 3.14159), but we can explain most of what is on this line. The part

```
double PI = 3.14159;
```

simply declares PI as a variable and initializes it to 3.14159. The words that precede this modify the variable PI in various ways. The word public says that there are no restrictions on where you can use the name PI. The word static will have to wait until Chapter 6 for an explanation; for now, just be sure to include it. The word final means that the value 3.14159 is the final value assigned to PI or, to phrase it another way, that the program is not allowed to change the value of PI.

Name important constants

The convention for naming constants is to use all uppercase letters, with an underscore symbol (\_) between words. For example, in a calendar program, you might define the following constant:

```
public static final int DAYS_PER_WEEK = 7;
```

Although this convention is not required by the definition of the Java language, most programmers adhere to it. Your programs will be easier to read if you can readily identify variables, constants, and so forth.

### **RECAP Named Constants**

To define a name for a constant, write the keywords public static final in front of a variable declaration that includes the constant as the initializing value. Place this declaration within the class definition but outside of any method definitions, including the main method.

### **SYNTAX**

```
public static finalType Variable = Constant;
```

### **EXAMPLES**

Although it is not required, most programmers spell named constants using all uppercase letters, with an underscore to separate words.

## **Assignment Compatibilities**

As the saying goes, "You can't put a square peg in a round hole," and you can't put a double value like 3.5 in a variable of type int. You cannot even put the double value 3.0 in a variable of type int. You cannot store a value of one type in a variable of another type unless the value is somehow converted to match the type of the variable. However, when dealing with numbers, this conversion will sometimes—but not always—be performed automatically for you. The conversion will always be done when you assign a value of an integer type to a variable of a floating-point type, such as

```
double doubleVariable = 7;
```

Slightly more subtle assignments, such as the following, also perform the conversion automatically:

```
int intVariable = 7;
double doubleVariable = intVariable;
```

More generally, you can assign a value of any type in the following list to a variable of any type that appears further down in the list:

```
byte \rightarrow short \rightarrow int \rightarrow long \rightarrow float \rightarrow double
```

For example, you can assign a value of type long to a variable of type float or to a variable of type double (or, of course, to a variable of type long), but you cannot assign a value of type long to a variable of type byte, short, or int. Note that this is not an arbitrary ordering of the types. As you move down the list from left to right, the types become more precise, either because they allow larger values or because they allow decimal points in the numbers. Thus, you can store a value into a variable whose type allows more precision than the type of the value allows.

In addition, you can assign a value of type char to a variable of type int or to any of the numeric types that follow int in our list of types. This particular assignment compatibility will be important when we discuss keyboard input. However, we do not advise assigning a value of type char to a variable of type int except in certain special cases.<sup>2</sup>

If you want to assign a value of type double to a variable of type int, you must change the type of the value using a type cast, as we explain in the next section.

### **RECAP** Assignment Compatibilities

You can assign a value of any type on the following list to a variable of any type that appears further down on the list:

```
byte \rightarrow short \rightarrow int \rightarrow long \rightarrow float \rightarrow double
```

In particular, note that you can assign a value of any integer type to a variable of any floating-point type.

It is also legal to assign a value of type char to a variable of type int or to any of the numeric types that follow int in our list of types.

A value can be assigned to a variable whose type allows more precision

<sup>&</sup>lt;sup>2</sup> Readers who have used certain other languages, such as C or C++, may be surprised to learn that you cannot assign a value of type char to a variable of type byte. This is because Java reserves two bytes of memory for each value of type char but naturally reserves only one byte of memory for values of type byte.

### **Type Casting**

The title of this section has nothing to do with the Hollywood notion of typecasting. In fact, it is almost the opposite. In Java—and in most programming languages—a **type cast** changes the data type of a value from its normal type to some other type. For example, changing the type of the value 2.0 from double to int involves a type cast. The previous section described when you can assign a value of one type to a variable of another type and have the type conversion occur automatically. In all other cases, if you want to assign a value of one type to a variable of another type, you must perform a type cast. Let's see how this is done in Java.

Suppose you have the following:

```
double distance = 9.0;
int points = distance; ← This assignment is illegal.
```

As the note indicates, the last statement is illegal in Java. You cannot assign a value of type double to a variable of type int, even if the value of type double happens to have all zeros after the decimal point and so is conceptually a whole number.

In order to assign a value of type double to a value of type int, you must place (int) in front of the value or the variable holding the value. For example, you can replace the preceding illegal assignment with the following and get a legal assignment:

```
int points = (int)distance; 			 This assignment is legal.
```

A type cast changes the data type of a value

The expression (int)distance is called a type cast. Neither distance nor the value stored in distance is changed in any way. But the value stored in points is the "int version" of the value stored in distance. If the value of distance is 25.36, the value of (int)distance is 25. So points contains 25, but the value of distance is still 25.36. If the value of distance is 9.0, the value assigned to points is 9, and the value of distance remains unchanged.

An expression like (int) 25.36 or (int)distance is an expression that *produces* an int value. A type cast does not change the value of the source variable. The situation is analogous to computing the number of (whole) dollars you have in an amount of money. If you have \$25.36, the number of dollars you have is 25. The \$25.36 has not changed; it has merely been used to produce the whole number 25.

For example, consider the following code:

Truncation discards the fractional part

The expression (int)dinnerBill produces the value 25, so the output of this code would be

```
The value of dinnerBillPlusTip is 30
```

But the variable dinnerBill still contains the value 25.36.

Be sure to note that when you type cast from a double to an int—or from any floating-point type to any integer type—the amount is not rounded. The part after the decimal point is simply discarded. This is known as **truncating**. For example, the following statements

```
double dinnerBill = 26.99;
int numberOfDollars = (int)dinnerBill;
```

set numberOfDollars to 26, not 27. The result is not rounded.

As we mentioned previously, when you assign an integer value to a variable of a floating-point type—double, for example—the integer is automatically type cast to the type of the variable. For example, the assignment statement

```
double point = 7;
is equivalent to
   double point = (double)7;
```

The type cast (double) is implicit in the first version of the assignment. The second version, however, is legal.

### **RECAP Type Casting**

In many situations, you cannot store a value of one type in a variable of another type unless you use a type cast that converts the value to an equivalent value of the target type.

### **SYNTAX**

```
(Type_Name) Expression
```

### **EXAMPLES**

```
double guess = 7.8;
int answer = (int)guess;
```

The value stored in answer will be 7. Note that the value is truncated, not rounded. Note also that the variable *guess* is not changed in any way; it still contains 7.8. The last assignment statement affects only the value stored in *answer*.

### ■ PROGRAMMING TIP Type Casting a Character to an Integer

Java sometimes treats values of type char as integers, but the assignment of integers to characters has no connection to the meaning of the characters. For example, the following type cast will produce the int value corresponding to the character '7':

```
char symbol = '7';
System.out.println((int)symbol);
```

You might expect the preceding to display 7, but it does not. It displays the number 55. Java, like all other programming languages, uses an arbitrary numbering of characters to encode them. Thus, each character corresponds to an integer. In this correspondence, the digits 0 through 9 are characters just like the letters or the plus sign. No effort was made to have the digits correspond to their intuitive values. Basically, they just wrote down all the characters and then numbered them in the order they were written down. The character '7' just happened to get 55. This numbering system is called the Unicode system, which we discuss later in the chapter. If you have heard of the ASCII numbering system, the Unicode system is the same as the ASCII system for the characters in the English language.

## **SELF-TEST QUESTIONS**

1. Which of the following may be used as variable names in Java?

```
rate1, 1stPlayer, myprogram.java, long, TimeLimit,
numberOfWindows
```

- 2. Can a Java program have two different variables with the names aVariable and avariable?
- 3. Give the declaration for a variable called count of type int. The variable should be initialized to zero in the declaration.
- 4. Give the declaration for two variables of type double. The variables are to be named rate and time. Both variables should be initialized to zero in the declaration.
- 5. Write the declaration for two variables called miles and flowRate. Declare the variable miles to be of type int and initialize it to zero in the declaration. Declare the variable flowRate to be of type double and initialize it to 50.56 in the declaration.
- 6. What is the normal spelling convention for named constants?
- 7. Give a definition for a named constant for the number of hours in a day.

- 8. Write a Java assignment statement that will set the value of the variable interest to the value of the variable balance multiplied by 0.05.
- 9. Write a Java assignment statement that will set the value of the variable interest to the value of the variable balance multiplied by the value of the variable rate. The variables are of type double.
- 10. Write a Java assignment statement that will increase the value of the variable count by 3. The variable is of type int.
- 11. What is the output produced by the following lines of program code?

```
char a, b;
a = 'b';
System.out.println(a);
b = 'c';
System.out.println(b);
a = b;
System.out.println(a);
```

12. In the Programming Tip entitled "Type Casting a Character to an Integer," you saw that the following does not display the integer 7:

```
char symbol = '7';
System.out.println((int)symbol);
```

Thus, (int)symbol does not produce the number corresponding to the digit in symbol. Can you write an expression that will work to produce the integer that intuitively corresponds to the digit in symbol, assuming that symbol contains one of the ten digits 0 through 9? (*Hint*: The digits do correspond to consecutive integers, so if (int)'7' is 55, then (int)'8' is 56.)

### **Arithmetic Operators**

In Java, you can perform arithmetic involving addition, subtraction, multiplication, and division by using the arithmetic operators +, -, \*, and /, respectively. You indicate arithmetic in basically the same way that you do in ordinary arithmetic or algebra. You can combine variables or numbers—known collectively as **operands**—with these operators and parentheses to form an **arithmetic expression**. Java has a fifth arithmetic operator, %, that we will define shortly.

The meaning of an arithmetic expression is basically what you expect it to be, but there are some subtleties about the type of the result and, occasionally, even about the value of the result. All five of the arithmetic operators can be used with operands of any of the integer types, any of the floating-point types, and even with operands of differing types. The type of the value produced depends on the types of the operands being combined.

An arithmetic expression combines operands, operators, and parentheses

Let's start our discussion with simple expressions that combine only two operands, that is, two variables, two numbers, or a variable and a number. If both operands are of the same type, the result is of that type. If one of the operands is of a floating-point type and the other is of an integer type, the result is of the floating-point type.

Operands in an arithmetic expression can have mixed data types

For example, consider the expression

```
amount + adjustment
```

If the variables amount and adjustment are both of type int, the result—that is, the value returned by the operation—is of type int. If either amount or adjustment, or both, are of type double, the result is of type double. If you replace the addition operator, +, with any of the operators -, \*, /, or %, the type of the result is determined in the same way.

Larger expressions using more than two operands can always be viewed as a series of steps, each of which involves only two operands. For example, to evaluate the expression

```
balance + (balance * rate)
```

you (or the computer) evaluate balance \* rate and obtain a number, and then you form the sum of that number and balance. This means that the same rule we used to determine the type of an expression containing two operands can also be used for more complicated expressions: If all of the items being combined are of the same type, the result is of that type. If some of the items being combined are of integer types and some are of floating-point types, the result is of a floating-point type.

Knowing whether the value produced has an integer type or a floating-point type is typically all that you need to know. However, if you need to know the exact type of the value produced by an arithmetic expression, you can find out as follows: The type of the result produced is one of the types used in the expression. Of all the types used in the expression, it is the one that appears rightmost in the following list:

```
byte \rightarrow short \rightarrow int \rightarrow long \rightarrow float \rightarrow double
```

Note that this is the same sequence as the one used to determine automatic type conversions.

The division operator (/) deserves special attention, because the type of the result can affect the value produced in a dramatic way. When you combine two operands with the division operator and at least one of the operands is of type double—or of some other floating-point type—the result is what you would normally expect of a division. For example, 9.0/2 has one operand of type double, namely, 9.0. Hence, the result is the type double number 4.5. However, when both operands are of an integer type, the result can be surprising. For example, 9/2 has two operands of type int, so it yields the type int result 4, not 4.5. The fraction after the decimal point is simply lost. Be sure to notice that when you divide two integers, the result *is not rounded*; the part

Integer division truncates the result

The % operator gets the remainder after division

after the decimal point is discarded—that is, truncated—no matter how large it is. So 11/3 is 3, not 3.6666.... Even if the fractional portion after the decimal point is zero, that decimal point and zero are still lost. Surprisingly, this seemingly trivial difference can be of some significance. For example, 8.0/2 evaluates to the type double value 4.0, which is only an approximate quantity. However, 8/2 evaluates to the int value 4, which is an exact quantity. The approximate nature of 4.0 can affect the accuracy of any further calculation that is performed using this result.

Java's fifth arithmetic operator is the **remainder operator**, or **modulus operator**, denoted by %. When you divide one number by another, you get a result (which some call a quotient) and a remainder—that is, the amount left over. The % operator gives you the remainder. Typically, the % operator is used with operands of integer types to recover something equivalent to the fraction after the decimal point. For example, 14 divided by 4 yields 3 with a remainder of 2, that is, with 2 left over. The % operation gives the remainder after doing the division. So 14/4 evaluates to 3, and 14 % 4 evaluates to 2, because 14 divided by 4 is 3 with 2 left over.

The % operator has more applications than you might at first suspect. It allows your program to count by 2s, 3s, or any other number. For example, if you want to perform a certain action only on even integers, you need to know whether a given integer is even or odd. An integer n is even if n % 2 is equal to 0, and the integer is odd if n % 2 is equal to 1. Similarly, if you want your program to do something with every third integer, you can have it step through all the integers, using an int variable n to store each one. Your program would then perform the action only when n % 3 is equal to 0.

# FAQ How does the % operator behave with floating-point numbers?

The remainder operator is usually used with integer operands, but Java does allow you to use it with floating-point operands. If n and d are floating-point numbers, n % d equals n - (d \* q), where q is the integer portion of n / d. Note that the sign of q is the same as the sign of n / d. For example, 6.5 % 2.0 is 0.5, -6.5 % 2.0 is -0.5, and 6.5 % -2.0 is 0.5.

Finally, notice that sometimes we use + and - as the sign of a number, while at other times + and - indicate addition and subtraction. In fact, Java always treats + and - as operators. A **unary operator** is an operator that has only one operand (one thing that it applies to), such as the operator - in the assignment statement

bankBalance = -cost;

A binary operator has two operands, such as the operators + and \* in

```
total = cost + (tax * discount);
```

Note that the same operator symbol can sometimes be used as both a unary operator and a binary operator. For example, the - and + symbols can serve as either binary or unary operators.

# **FAQ** Do spaces matter in an arithmetic expression?

The spaces in *any* Java statement usually do not matter. The only exception is when spaces appear within a pair of double quotes or single quotes. However, adding spaces in other situations can make a Java statement easier to read. For example, you should add a space both before and after any binary operator, as we have done in our examples.

#### Parentheses and Precedence Rules

Parentheses can be used to group items in an arithmetic expression in the same way that you use parentheses in algebra and arithmetic. With the aid of parentheses, you can tell the computer which operations to perform first, second, and so forth. For example, consider the following two expressions that differ only in the positioning of their parentheses:

```
(cost + tax) * discount
cost + (tax * discount)
```

To evaluate the first expression, the computer first adds cost and tax and then multiplies the result by discount. To evaluate the second expression, it multiplies tax and discount and then adds the result to cost. If you evaluate these expressions, using some numbers for the values of the variables, you will see that they produce different results.

If you omit the parentheses, the computer will still evaluate the expression. For example, the following assignment statement

```
total = cost + tax * discount;
is equivalent to
  total = cost + (tax * discount);
```

When parentheses are omitted, the computer performs multiplication before addition. More generally, when the order of operations is not determined by parentheses, the computer will perform the operations in an order specified by

#### FIGURE 2.2 Precedence Rules

#### Highest Precedence

First: the unary operators +, -, !, ++, and --

Second: the binary arithmetic operators \*, /, and %

Third: the binary arithmetic operators + and -

Lowest Precedence

Precedence rules and parentheses determine the order of operations the **precedence rules** shown in Figure 2.2.<sup>3</sup> Operators that are higher on the list are said to have **higher precedence**. When the computer is deciding which of two operations to perform first and the order is not dictated by parentheses, it begins with the operation having higher precedence and then performs the one having lower precedence. Some operators have equal precedence, in which case the order of operations is determined by where the operators appear in the expression. Binary operators of equal precedence are performed in left-to-right order. Unary operators of equal precedence are performed in right-to-left order.

These precedence rules are similar to the rules used in algebra. Except for some very standard cases, it is best to include the parentheses, even if the intended order of operations is the one indicated by the precedence rules, because the parentheses can make the expression clearer to a person reading the program code. Too many unnecessary parentheses can have the opposite effect, however. One standard case in which it is normal to omit parentheses is a multiplication within an addition. Thus,

```
balance = balance + (interestRate * balance);
```

would usually be written

```
balance = balance + interestRate * balance;
```

Both forms are acceptable, and the two forms have the same meaning.

Figure 2.3 shows some examples of how to write arithmetic expressions in Java and indicates in color some of the parentheses that you can normally omit.

# **Specialized Assignment Operators**

You can precede the simple assignment operator (=) with an arithmetic operator, such as +, to produce a kind of special-purpose assignment operator.



 $<sup>^3</sup>$  Figure 2.2 shows all the operators we will use in this chapter. More precedence rules will be given in Chapter 3.

FIGURE 2.3 Some Arithmetic E	Expressions	in Java
------------------------------	-------------	---------

Ordinary Math	Java (Preferred Form)	Java (Parenthesized)	
$rate^2 + delta$	rate * rate + delta	(rate * rate) + delta	
2(salary + bonus)	2 * (salary + bonus)	2 * (salary + bonus)	
$\frac{1}{time + 3mass}$	1 / (time + 3 * mass)	1 / (time + (3 * mass))	
$\frac{a-7}{t+9v}$	(a - 7) / (t + 9 * v)	(a - 7) / (t + (9 * v))	

For example, the following will increase the value of the variable amount by 5:

```
amount += 5;
```

This statement is really just shorthand for

```
amount = amount + 5;
```

This is hardly a big deal, but it can sometimes be handy.

You can do the same thing with any of the other arithmetic operators, -, \*, /, and %. For example, you could replace the line

You can combine an arithmetic operator with = as a shorthand notation

```
amount = amount * 25;
```

with

```
amount *= 25;
```

Although you might not care to use these special assignment operators right now, many Java programmers do use them, so you are likely to encounter them in other programmers' code.

# **SELF-TEST QUESTIONS**

13. What is the output produced by the following lines of program code?

```
int quotient = 7 / 3;
int remainder = 7 % 3;
System.out.println("quotient = " + quotient);
System.out.println("remainder = " + remainder);
```

14. What is the output produced by the following lines of program code?

```
double result = (1 / 2) * 2;
System.out.println("(1 / 2) * 2 equals " + result);
```

15. What is the output produced by the following code?

```
int result = 3 * 7 % 3 - 4 - 6;
System.out.println("result is " + result);
```

16. What is the output produced by the following code?

```
int result = 11;
result /= 2;
System.out.println("resu lt is " + result);
```

# **CASE STUDY** Vending Machine Change

Vending machines often have small computers to control their operation. In this case study, we will write a program that handles one of the tasks that such a computer would need to perform. The input and output will be performed via the keyboard and screen. To integrate this program into a vending machine computer, you would have to embed the code into a larger program that takes its data from some place other than the keyboard and sends its results to some place other than the screen, but that's another story. In this case study, the user enters an amount of change from 1 to 99 cents. The program responds by telling the user one combination of coins that equals that amount of change.

For example, if the user enters 55 for 55 cents, the program tells the user that 55 cents can be given as two quarters and one nickel—that is, two 25-cent coins and one 5-cent coin. Suppose we decide that the interaction between the user and the program should be like this:

```
Enter a whole number from 1 to 99. I will find a combination of coins that equals that amount of change.

87
87 cents in coins:
3 quarters
1 dime
0 nickels and
2 pennies
```

Actually writing a sample dialogue, as we did here, before coding the program will help us to solve our problem.

The program will need variables to store the amount of change and the number of each type of coin. So it will need at least the following variables:

```
int amount, quarters, dimes, nickels, pennies;
```

That takes care of some routine matters; now we are ready to tackle the heart of the problem.

Pseudocode (first try)

We need an algorithm to compute the number of each kind of coin. Suppose we come up with the following pseudocode:

Specify the task

Write down a sample dialogue

with the user

# Algorithm to compute the number of coins in amount cents:

- 1. Read the amount into the variable amount.
- 2. Set the variable quarters equal to the maximum number of quarters in amount.
- 3. Reset amount to the change left after giving out that many quarters.
- 4. Set the variable dimes equal to the maximum number of dimes in amount.
- 5. Reset amount to the change left after giving out that many dimes.
- 6. Set the variable nickels equal to the maximum number of nickels in amount.
- 7. Reset amount to the change left after giving out that many nickels.
- 8. pennies = amount;
- 9. Display the original amount and the numbers of each coin.

These steps look reasonable, but before we rush into code, let's try an example. If we have 87 cents, we set amount to 87. How many quarters are in 87? Three, so quarters becomes 3, and we have 87 – 3 \* 25, or 12, cents left in amount. We extract one dime and are left with 2 cents in amount. Thus, dimes is 1, nickels is 0, and pennies is 2.

Let's display our results. How much did we have originally? We look in amount and find 2. What happened to our 87? The algorithm changes the value of amount, but we need the original amount at the end so that we can display it. To fix the algorithm, we could either display the original value in amount before we change it or copy the original value into one more variable—called originalAmount. If we choose the latter approach, we can modify our pseudocode as follows:

Pseudocode (revised)

#### Algorithm to compute the number of coins in amount cents:

- 1. Read the amount into the variable amount.
- 2. originalAmount = amount;
- 3. Set the variable quarters equal to the maximum number of quarters in amount.
- 4. Reset amount to the change left after giving out that many quarters.
- 5. Set the variable dimes equal to the maximum number of dimes in amount.
- 6. Reset amount to the change left after giving out that many dimes.
- 7. Set the variable nickels equal to the maximum number of nickels in amount.
- 8. Reset amount to the change left after giving out that many nickels.
- 9. pennies = amount;
- 10. Display original Amount and the numbers of each coin.

We now need to produce Java code that does the same thing as our pseudocode. Much of it is routine. The first line of pseudocode simply calls for

Convert the pseudocode to Java code

prompting the user and then reading input from the keyboard. The following Java code corresponds to this first line of pseudocode:

```
System.out.println("Enter a whole number from 1 to 99.");
System.out.println("I will find a combination of coins");
System.out.println("that equals that amount of change.");
Scanner keyboard = new Scanner(System.in);
amount = keyboard.nextInt();
```

The next line of pseudocode, which sets the value of original Amount, is already Java code, so you need not do any translating.

Thus far, the main part of our program reads as follows:

```
public static void main(String[] args)
{
  int amount, originalAmount,
     quarters, dimes, nickels, pennies;
  System.out.println("Enter a whole number from 1 to 99.");
  System.out.println("I will find a combination of coins");
  System.out.println("that equals that amount of change.");
  Scanner keyboard = new Scanner(System.in);
  amount = keyboard.nextInt();
  originalAmount = amount;
```

Next, we need to translate the following to Java code:

- 3. Set the variable quarters equal to the maximum number of quarters in amount.
- 4. Reset amount to the change left after giving out that many quarters.

Let's think. In our earlier example, we had 87 cents. To get the number of quarters in 87 cents, we see how many times 25 goes into 87. That is, we divide 87 by 25 to get 3 with 12 left over. So quarters is 3. Since the remainder, 12, is less than 25, we don't have four quarters in 87 cents, only three. Ah! We realize that we can use the operators / and % for this kind of division. For example,

Use / and % with integers to solve our problem

```
87 / 25 is 3 (the maximum number of 25s in 87) 87 % 25 is 12 (the remainder)
```

Using amount instead of 87 gives us the following two statements:

```
quarters = amount / 25;
amount = amount % 25;
```

We can treat dimes and nickels in a similar way, so we get the following code:

```
dimes = amount / 10;
amount = amount % 10;
nickels = amount / 5;
amount = amount % 5;
```

The rest of the program coding is straightforward. Our final program is shown in Listing 2.3.

# LISTING 2.3 A Change-Making Program

```
import java.util.Scanner;
public class ChangeMaker
   public static void main(String[] args)
   {
      int amount, originalAmount,
         quarters, dimes, nickels, pennies;
      System.out.println("Enter a whole number from 1 to 99.");
      System.out.println("I will find a combination of coins");
      System.out.println("that equals that amount of change.");
      Scanner keyboard = new Scanner(System.in);
      amount = keyboard.nextInt();
      originalAmount = amount;
      quarters = amount / 25; 	←
                                         = 25 goes into 87 three times
      amount = amount % 25;
                                         with 12 left over.
                                         87 / 25 is 3.
      dimes = amount / 10;
      amount = amount % 10;
                                          87 % 25 is 12.
      nickels = amount / 5;
                                         87 cents is three quarters
      amount = amount % 5;
                                         with 12 cents left over.
      pennies = amount;
      System.out.println(originalAmount +
                          " cents in coins can be given as:");
      System.out.println(quarters + " quarters");
      System.out.println(dimes + " dimes");
      System.out.println(nickels + " nickels and");
      System.out.println(pennies + " pennies");
   }
}
```

#### Sample Screen Output

```
Enter a whole number from 1 to 99.

I will find a combination of coins that equals that amount of change.

87

87 cents in coins can be given as:
3 quarters
1 dimes
0 nickels and
2 pennies
```

Test your program using data that produces as many different kinds of results as you can think of

After writing a program, you need to test it on a number of different kinds of data. For our program, we should try data values that give zero for all possible coins, as well as other data, such as 25 and 26 cents, that produce results ranging from all quarters to quarters and another coin. For example, we could test our program on each of the following inputs: 0, 4, 5, 6, 10, 11, 25, 26, 35, 55, 65, 75, 76, and a number of other cases.

Although all our tests will be successful, the output does not exactly use correct grammar. For example, an input of 26 cents produces the output

26 cents in coins:

- 1 quarters
- 0 dimes
- 0 nickels and
- 1 pennies

The numbers are correct, but the labels would be better if they said 1 quarter instead of 1 quarters and 1 penny instead of 1 pennies. The techniques you need to produce this nicer-looking output will be presented in the next chapter. For now, let's end this project here. The output is correct and understandable.

# ■ PROGRAMMING TIP The Basic Structure of a Program

Many application programs, including the one we just wrote in the previous case study, have a similar basic structure. Their fundamental steps are like the advice once given to public speakers by Dale Carnegie (1888–1955): "Tell the audience what you're going to say, say it; then tell them what you've said." Programs often take the following steps:

- 1. Prepare: Declare variables and explain the program to the user.
- 2. Input: Prompt for and get input from the user.
- 3. Process: Perform the task at hand.
- 4. Output: Display the results.

This structure, which we can abbreviate as PIPO, is particularly true of our initial programs. Keeping these steps in mind can help you to organize your thoughts as you design and code your programs.

# **SELF-TEST QUESTION**

17. Consider the following statement from the program in Listing 2.3:

Suppose that you replaced the preceding line with the following:

How would this change the sample output given in Listing 2.3?

# **Increment and Decrement Operators**

Java has two special operators that are used to increase or decrease the value of a variable by 1. Since these operators are so specialized, both you and Java could easily get along without them. But they are sometimes handy, and they are of cultural significance because programmers use them. So to be "in the club," you should know how they work, even if you do not want to use them in your own programs.

The **increment operator** is written as two plus signs (++). For example, the following will increase the value of the variable count by 1:

Increment operator ++

```
count++;
```

This is a Java statement. If the variable count has the value 5 before this statement is executed, it will have the value 6 after the statement is executed. The statement is equivalent to

```
count = count + 1;
```

The **decrement operator** is similar, except that it subtracts 1 rather than adds 1 to the value of the variable. The decrement operator is written as two minus signs (--). For example, the following will decrease the value of the variable count by 1:

```
Decrement operator – –
```

```
count--;
```

If the variable count has the value 5 before this statement is executed, it will have the value 4 after the statement is executed. The statement is equivalent to

```
count = count - 1;
```

You can use the increment operator and the decrement operator with variables of any numeric type, but they are used most often with variables of integer types, such as the type int.

As you can see, the increment and decrement operators are really very specialized. Why does Java have such specialized operators? It inherited them from C++, and C++ inherited them from C. In fact, this increment operator is where the ++ came from in the name of the C++ programming language. Why was it added to the C and C++ languages? Because adding or subtracting 1 is a very common thing to do when programming.

# More About the Increment and Decrement Operators

Although we do not recommend doing so, the increment and decrement operators can be used in expressions. When used in an expression, these operators both change the value of the variable they are applied to and **return**, or produce, a value.

Be careful if you use the operators ++ and -- in expressions

In expressions, you can place the ++ or -- either before or after the variable, but the meaning is different, depending on where the operator is placed. For example, consider the code

```
int n = 3;
int m = 4;
int result = n * (++m);
```

After this code is executed, the value of n is unchanged at 3, the value of m is 5, and the value of result is 15. Thus, ++m both changes the value of m and returns that changed value to be used in the arithmetic expression.

In the previous example, we placed the increment operator before the variable. If we place it after the variable m, something slightly different happens. Consider the code

```
int n = 3;
int m = 4;
int result = n * (m++);
```

In this case, after the code is executed, the value of n is 3 and the value of m is 5, just as in the previous case, but the value of result is 12, not 15. What is the story?

The two expressions  $n^*(++m)$  and  $n^*(m++)$  both increase the value of m by 1, but the first expression increases the value of m before it does the multiplication, whereas the second expression increases the value of m after it does the multiplication. Both ++m and m++ have the same effect on the final value of m, but when you use them as part of an arithmetic expression, they give a different value to the expression.

The -- operator works in the same way when it is used in an arithmetic expression. Both --m and m-- have the same effect on the final value of m, but when you use them as part of an arithmetic expression, they give a different value to the expression. For --m, the value of m is decreased *before* its value is used in the expression, but for m--, the value of m is decreased *after* its value is used in the expression.

When an increment or decrement operator is placed before a variable, we get what is called the **prefix form**. When it is placed after a variable, we get a **postfix form**. Note that the increment and decrement operators can be applied only to variables. They cannot be applied to constants or to more complicated arithmetic expressions.



# **SELF-TEST QUESTION**

18. What output is produced by the following lines of program code?

```
int n = 2;
n++;
System.out.println("n is " + n);
n—;
System.out.println("n is " + n);
```

# 2.2 THE CLASS String

Words, words, mere words, no matter from the heart.

—WILLIAM SHAKESPEARE, Troilus and Cressida

Strings of characters, such as "Enter the amount:", are treated slightly differently than values of the primitive types. Java has no primitive type for strings. However, Java supplies a class called String that can be used to create and process strings of characters. In this section, we introduce you to the class String.

Classes are central to Java, and you will soon define and use your own classes. However, this discussion of the class String gives us an opportunity to review some of the notation and terminology used for classes that Chapter 1 introduced.

The class String comes with Java

# **String Constants and Variables**

You have already been using constants of type String. The quoted string

```
"Enter a whole number from 1 to 99."
```

which appears in the following statement from the program in Listing 2.3, is a string constant:

```
System.out.println("Enter a whole number from 1 to 99.");
```

A value of type String is one of these quoted strings. That is, a value of type String is a sequence of characters treated as a single item. A variable of type String can name one of these string values.

The following declares greeting to be the name for a String variable:

```
String greeting;
```

The next statement sets the value of greeting to the String value "Hello!":

```
greeting = "Hello!";
```

These two statements are often combined into one, as follows:

```
String greeting = "Hello!";
```

Once a String variable, such as greeting, has been given a value, you can display it on the screen as follows:

```
System.out.println(greeting);
```

This statement displays

Hello!

assuming that the value of greeting has been set as we just described.

A string can have any number of characters. For example, "Hello" has five characters. A string can even have zero characters. Such a string is called the **empty string** and is written as a pair of adjacent double quotes, like so:"". You will encounter the empty string more often than you might think. Note that the string " " is not empty: It consists of one blank character.

# **Concatenation of Strings**

You can connect—or join or paste—two strings together to obtain a larger string. This operation is called **concatenation** and is performed by using the + operator. When this operator is used with strings, it is sometimes called the **concatenation operator**. For example, consider the following code:

```
String greeting, sentence;
greeting = "Hello";
sentence = greeting + "my friend";
System.out.println(sentence);
```

This code sets the variable sentence to the string "Hellomy friend" and will write the following on the screen:

```
Hellomy friend
```

Notice that no spaces are added when you concatenate two strings by means of the + operator. If you wanted sentence set to "Hello my friend", you could change the assignment statement to

```
sentence = greeting + " my friend";
```

Notice the space before the word *my*.

You can concatenate any number of String objects by using the + operator. You can even use + to connect a String object to any other type of object. The result is always a String object. Java will figure out some way to

You can use + to join, or concatenate, strings together express any object as a string when you connect it to a string using the + operator. For simple things like numbers, Java does the obvious thing. For example,

```
String solution = "The answer is " + 42;
```

will set the String variable solution to the string "The answer is 42". This is so natural that it may seem as though nothing special is happening, but a conversion from one type to another does occur. The constant 42 is a number—not even an object—whereas "42" is a String object consisting of the character '4' followed by the character '2'. Java converts the number constant 42 to the string constant "42" and then concatenates the two strings "The answer is" and "42" to obtain the longer string "The answer is 42".

# **RECAP** Using the + Symbol with Strings

You can concatenate two strings by connecting them with the + operator.

#### **EXAMPLE**

```
String name = "Chiana";
String greeting = "Hi " + name;
System.out.println(greeting);
```

This sets greeting to the string "Hi Chiana" and then displays the following on the screen:

```
Hi Chiana
```

Note that we added a space at the end of "Hi" to separate the words in the output.

# **String Methods**

A String variable is not a simple variable, as a variable of type int is. A String variable is a variable of a class type that names a String object. Recall that an object has methods as well as data. For example, objects of the class String store data consisting of strings of characters, such as "Hello". The methods provided by the class String can be used to manipulate this data.

Most of the String methods return some value. For example, the method length returns the number of characters in a String object. So "Hello". length() returns the integer 5. That is, the value of "Hello".length() is 5, which we can store in an int variable as follows:

```
int n = "Hello".length( );
```

Call the method length to get the length of a string As you have learned, you call, or invoke, a method into action by writing the name of the object, followed by a dot, followed by the method name, and ending with parentheses. Although the object can be a constant, such as "Hello", it is more common to use a variable that names the object, as illustrated by the following:

```
String greeting = "Hello";
int n = greeting.length();
```

For some methods—such as length—no arguments are needed, so the parentheses are empty. For other methods, as you will see soon, some information must be provided inside the parentheses.

All objects of a class have the same methods, but each object can have different data. For example, the two String objects "Hello" and "Good-bye" have different data—that is, different strings of characters. However, they have the same methods. Thus, since we know that the String object "Hello" has the method length, we know that the String object "Good-bye" must also have the method length. All string objects have this method.

Spaces, special symbols, and repeated characters are all counted when computing the length of a string. For example, suppose we declare String variables as follows:

```
String command = "Sit Fido!";
String answer = "bow-wow";
```

Then command.length() returns 9 and answer.length() returns 7.

You can use a call to the method length anywhere that you can use a value of type int. For example, all of the following are legal Java statements:

Positions, or indices, in a string begin with 0

```
int count = command.length();
System.out.println("Length is " + command.length());
count = command.length() + 3;
```

Many of the methods for the class String depend on counting **positions** in the string. Positions in a string begin with 0, not with 1. In the string "Hi Mom", 'H' is in position 0, 'i' is in position 1, the blank character is in position 2, and so forth. A position is usually referred to as an **index** in computer parlance. So it would be more normal to say that 'H' is at index 0, 'i' is at index 1, and so on. Figure 2.4 illustrates how index positions are numbered in a string. The 12 characters in the string "Java is fun." have indices 0 through 11. The index of each character is shown above it in the figure.

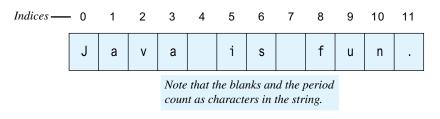
A substring is simply a portion of a string. For example, the string defined by

```
String phrase = "Java is fun.";
```

has a substring "fun" that begins at index 8. The method indexOf returns the index of a substring given as its argument. The invocation phrase. indexOf("fun") will return 8 because the 'f' in "fun" is at index 8. If the

A substring is a portion of a string

# FIGURE 2.4 String Indices



substring occurs more than once in a string, indexOf returns the index of the first occurrence of its substring argument.

Figure 2.5 describes some of the methods for the class String. In the next chapter, you will learn how to make use of methods such as equals and compareTo that compare strings. Other methods listed in this figure may become more useful to you in subsequent chapters. You can learn about additional String methods by consulting the documentation for the Java Class Library on the Oracle Web site.

# FAQ When calling a method, we write the name of an object and a dot before the method's name. What term do we use to refer to this object?

An object has methods. When you invoke one of these methods, the object receives the call and performs the actions of the method. Thus, the object is known as a **receiving object**, or **receiver**. Documentation, such as that in Figure 2.5, often describes the receiving object simply as **this object**.

#### FAQ What is whitespace?

Any characters that are not visible when displayed are collectively known as whitespace. Such characters include blanks, tabs, and new-line characters.

# **String Processing**

Technically, objects of type String cannot be changed. Notice that none of the methods in Figure 2.5 changes the value of a String object. The class String has more methods than those shown in Figure 2.5, but none of them lets you write statements that do things like "Change the fifth character in this

# FIGURE 2.5 Some Methods in the Class String

Method	Return Type	Example for String s = "Java";	Description
charAt (index)	char	c = s.charAt(2); // c='v'	Returns the character at <i>index</i> in the string. Index numbers begin at 0.
compareTo (a_string)	int	<pre>i = s.compareTo("C++"); // i is positive</pre>	Compares this string with <i>a_string</i> to see which comes first in lexicographic (alphabetic, with upper- before lowercase) ordering. Returns a negative integer if this string is first, zero if the two strings are equal, and a positive integer if <i>a_string</i> is first.
concat (a_string)	String	s2 = s.concat("rocks"); // s2 = "Javarocks"	Returns a new string with this string concatenated with $a\_string$ . You can use the + operator instead.
equals (a_string)	boolean	<pre>b = s.equals("Java"); // b = true</pre>	Returns true if this string and <i>a_string</i> are equal. Otherwise returns false.
equals IgnoreCase (a_string)	boolean	<pre>b = s.equals("java"); // b = true</pre>	Returns true if this string and <i>a_string</i> are equal, considering upper- and lowercase versions of a letter to be the same. Otherwise returns false.
index0f (a_string)	int	i = s.index0f("va"); // i = 2	Returns the index of the first occurrence of the substring <i>a_string</i> within this string or –1 if <i>a_string</i> is not found. Index numbers begin at 0.
lastIndexOf (a_string)	int	<pre>i = s.lastIndexOf("a"); // i = 3</pre>	Returns the index of the last occurrence of the substring $a\_string$ within this string or $-1$ if $a\_string$ is not found. Index numbers begin at 0.
length()	int	i = s.length(); // i = 4	Returns the length of this string.
toLower Case()	String	s2 = s.toLowerCase(); // s2 = "java"	Returns a new string having the same characters as this string, but with any uppercase letters converted to lowercase. This string is unchanged.
toUpper Case()	String	s2 = s.toUpperCase(); // s2 = "JAVA"	Returns a new string having the same characters as this string, but with any lowercase letters converted to uppercase. This string is unchanged.
replace (oldchar, newchar)	String	s2 = s.replace('a','o'); // s2 = "Jovo";	Returns a new string having the same characters as this string, but with each occurrence of <i>oldchar</i> replaced by <i>newchar</i> .
substring (start)	String	s2 = s.substring(2); // s2 = "va";	Returns a new string having the same characters as the substring that begins at index <i>start</i> through to the end of the string. Index numbers begin at 0.
substring (start,end)	String	<pre>s2 = s.substring(1,3); // s2 = "av";</pre>	Returns a new string having the same characters as the substring that begins at index <i>start</i> through to but not including the character at index <i>end</i> . Index numbers begin at 0.
trim( )	String	s = " Java "; s2 = s.trim(); // s2 = "Java"	Returns a new string having the same characters as this string, but with leading and trailing whitespace removed.

string to 'z'". This was done intentionally to make the implementation of the String class more efficient—that is, to make the methods execute faster and use less computer memory. Java has another string class, StringBuilder, that has methods for altering its objects. But we will not discuss this class here because we do not need it.

Although you cannot change the value of a String object, such as "Hello", you can still write programs that change the value of a String *variable*, which is probably all you want to do anyway. To make the change, you simply use an assignment statement, as in the following example:

```
String name = "D'Aargo";
name = "Ka " + name;
```

The assignment statement in the second line changes the value of the name variable from "D' Aargo" to "Ka D'Aargo". Listing 2.4 shows a sample program that performs some simple string processing and changes the value of a String variable. The backslash that appears within the argument to the println method is explained in the next section.



#### LISTING 2.4 Using the String Class

```
The meaning of \" is discussed
                                               in the section entitled "Escape
public class StringDemo
                                               Characters."
    public static void main(String[] args)
    {
        String sentence = "Text processing is hard!";
        int position = sentence.indexOf("hard");
        System.out.println(sentence);
        System.out.println("012345678901234567890123");
        System.out.println("The word \"hard\" starts at index "
                            + position);
        sentence = sentence.substring(0, position) + "easy!";
        sentence = sentence.toUpperCase();
        System.out.println("The changed string is:");
        System.out.println(sentence);
    }
}
```

#### Screen Output

```
Text processing is hard!
012345678901234567890123
The word "hard" starts at index 19
The changed string is:
TEXT PROCESSING IS EASY!
```

Quotes within quotes

# **GOTCHA** String Index Out of Bounds

The first character in a string is at index 0, not 1. So if a string contains n characters, the last character is at index n-1. Whenever you call a string method—such as charAt—that takes an index as an argument, the value of that index must be valid. That is, the index value must be greater than or equal to zero and less than the length of the string. An index value outside of this range is said to be **out of bounds** or simply **invalid**. Such an index will cause a run-time error.

# **Escape Characters**

Suppose you want to display a string that contains quotation marks. For example, suppose you want to display the following on the screen:

The word "Java" names a language, not just a drink!

The following statement will not work:

This will produce a compiler error message. The problem is that the compiler sees

```
"The word "
```

as a perfectly valid quoted string. Then the compiler sees Java", which is not anything valid in the Java language (although the compiler might guess that it is a quoted string with one missing quote or guess that you forgot a + sign). The compiler has no way to know that you mean to include the quotation marks as part of the quoted string, unless you tell it that you mean to do so. You tell the compiler that you mean to include the quote in the string by placing a backslash (\) before the troublesome character, like so:

Figure 2.6 lists some other special characters that are indicated with a backslash. These are often called **escape sequences** or **escape characters**, because they escape from the usual meaning of a character, such as the usual meaning of the double quote.

It is important to note that each escape sequence represents one character, even though it is written as two symbols. So the string "\"Hi\"" contains four characters—a quote, H, i, and another quote—not six characters. This point is significant when you are dealing with index positions.

Including a backslash in a quoted string is a little tricky. For example, the string "abc\def" is likely to produce the error message "Invalid escape character." To include a backslash in a string, you need to use two backslashes. The string "abc\\def", if displayed on the screen, would produce

An escape character requires two symbols to represent it

abc\def

# FIGURE 2.6 Escape Characters

- \" Double quote.
- \' Single quote.
- \\ Backslash.
- \n New line. Go to the beginning of the next line.
- \r Carriage return. Go to the beginning of the current line.
- \t Tab. Add whitespace up to the next tab stop.

The escape sequence  $\n$  indicates that the string starts a new line at the  $\n$ . For example, the statement

```
System.out.println("The motto is\nGo for it!");
```

will write the following two lines to the screen:

```
The motto is Go for it!
```

Including a single quote inside a quoted string, such as "How's this", is perfectly valid. But if you want to define a single quote as a constant, you need to use the escape character \', as in

```
char singleQuote = '\";
```

#### The Unicode Character Set

A character set is a list of characters, each associated with a standard number. The ASCII character set includes all the characters normally used on an English-language keyboard. (ASCII stands for American Standard Code for Information Interchange.) Each character in ASCII is represented as a 1-byte binary number. This encoding provides for up to 256 characters. Many programming languages other than Java use the ASCII character set.

The **Unicode** character set includes the entire ASCII character set, plus many of the characters used in languages other than English. A Unicode character occupies 2 bytes. This encoding provides more than 65,000 different characters.

To appeal to international users, the developers of Java adopted the Unicode character set. As it turns out, this is not likely to be a big issue if you are using an English-language keyboard. Normally, you can just program as though Java were using the ASCII character set, because the ASCII character set is a subset of the Unicode character set. The advantage of the Unicode character set is that it makes it easy to handle languages other than English. The disadvantage is that it sometimes requires more computer memory to store each character than it would if Java used only the ASCII character set. You can see the subset of the Unicode character set that is synonymous with the ASCII character set in the appendix of this book.

Unicode includes ASCII as a subset



# **SELF-TEST QUESTIONS**

19. What output is produced by the following statements?

```
String greeting = "How do you do";
System.out.println(greeting + "Seven of Nine.");
```

20. What output is produced by the following statements?

```
String test = "abcdefg";
System.out.println(test.length());
System.out.println(test.charAt(1));
```

21. What output is produced by the following statements?

```
String test = "abcdefg";
System.out.println(test.substring(3));
```

22. What output is produced by the following statement?

```
System.out.println("abc\ndef");
```

23. What output is produced by the following statement?

```
System.out.println("abc\\ndef");
```

24. What output is produced by the following statements?

```
String test = "Hello John";
test = test.toUpperCase();
System.out.println(test);
```

25. What is the value of the expression s1.equals(s2) after the following statements execute?

```
String s1 = "Hello John";
String s2 = "hello john";
```

26. What is the value of the expression s1.equals(s2) after the following statements execute?

```
String s1 = "Hello John";
String s2 = "hello john";
s1 = s1.toUpperCase();
s2 = s2.toUpperCase();
```

# 2.3 KEYBOARD AND SCREEN I/O

Garbage in, garbage out.

—PROGRAMMER'S SAYING

Input and output of program data are usually referred to as I/O. A Java program can perform I/O in many different ways. This section presents some very simple ways to handle text as either input typed at the keyboard or output sent to the screen. In later chapters, we will discuss more elaborate ways to do I/O.

# **Screen Output**

We have been using simple output statements since the beginning of this book. This section will summarize and explain what we have already been doing. In Listing 2.3, we used statements such as the following to send output to the display screen:

Earlier in this chapter, we noted that System is a standard class, out is a special object within that class, and out has println as one of its methods. Of course, you need not be aware of these details in order to use these output statements. You can simply consider System.out.println to be one peculiarly spelled statement. However, you may as well get used to this dot notation and the notion of methods and objects.

To use output statements of this form, simply follow the expression System.out.println with what you want to display, enclosed in parentheses, and then follow that with a semicolon. You can output strings of text in double quotes, like "Enter a whole number from 1 to 99" or "quarters"; variables, like quarters; numbers, like 5 or 7.3; and almost any other object or value. If you want to display more than one thing, simply place a + between the things you want to display. For example,

Use + to join the things you want to display

If the value of number is 7, the output will be

```
Lucky number = 13Secret number = 7
```

Notice that no spaces are added. If you want a space between the 13 and the word Secret in the preceding output—and you probably do—you should add a space at the beginning of the string

```
"Secret number = "
so that it becomes

"Secret number = "
```

Notice that you use double quotes, not single quotes, and that the left and right quotes are the same symbol. Finally, notice that you can place the statement on several lines if it is too long. However, you cannot break a line in the middle of a variable name or a quoted string. For readability, you should break the line before or after a + operator, and you should indent the continuation line.

You can also use the println method to display the value of a String variable, as illustrated by the following:

```
String greeting = "Hello Programmers!";
System.out.println(greeting);
```

This will cause the following to be written on the screen:

```
Hello Programmers!
```

Every invocation of println ends a line of output. For example, consider the following statements:

```
System.out.println("One, two, buckle my shoe.");
System.out.println("Three, four, shut the door.");
```

These two statements will cause the following output to appear on the screen:

```
One, two, buckle my shoe.
Three, four, shut the door.
```

If you want two or more output statements to place all of their output on a single line, use print instead of println. For example,

```
System.out.print("One, two,");
System.out.print(" buckle my shoe.");
System.out.print(" Three, four,");
System.out.println("shut the door.");
```

will produce the following output:

```
One, two, buckle my shoe. Three, four, shut the door.
```

Notice that a new line is not started until you use a println instead of a print. Notice also that the new line starts *after* the items specified in the println have been displayed. This is the only difference between print and println.

That is all you need to know in order to write programs with this sort of output, but we can still explain a bit more about what is happening. Consider the following statement:

```
System.out.println("The answer is " + 42);
```

The expression inside the parentheses should look familiar:

```
"The answer is " + 42
```

print versus
println

In our discussion of the class String in Section 2.2, we said that you could use the + operator to concatenate a string, such as "The answer is", and another item, such as the number constant 42. The + operator within a System.out. println statement is the same + operator that performs string concatenation. In the preceding example, Java converts the number constant 42 to the string "42" and then uses the + operator to obtain the string "The answer is 42". The System.out.println statement then displays this string. The println method always outputs strings. Technically speaking, it never outputs numbers, even though it looks as though it does.

#### **RECAP** println

You can display lines of text using the method System.out.println. The items of output can be quoted strings, variables, constants such as numbers, or almost any object you can define in Java.

#### **SYNTAX**

```
System.out.println (Output_1 + Output_2 + ... + Output_Last);
```

#### **EXAMPLES**

```
System.out.println("Hello out there!");
System.out.println("Area = " + theArea + " square inches");
```

#### **RECAP** println **Versus** print

System.out.println and System.out.print are almost the same method. The println method advances to a new line *after* it displays its output, whereas the print method does not. For example,

```
System.out.print("one");
System.out.print("two");
System.out.println("three");
System.out.print("four");
produces the following output:
  one two three
four
```

The output would look the same whether the last statement involved print or println. However, since our last statement uses print, subsequent output will appear on the same line as four.

# **Keyboard Input**

As we mentioned earlier in this chapter, you can use the class Scanner for handling keyboard input. This standard class is in the package <code>java.util</code>. To make Scanner available to your program, you write the following line near the beginning of the file containing your program:

```
import java.util.Scanner;
```

You use an object of the class Scanner to perform keyboard input. You create such an object by writing a statement in the following form:

```
Scanner Scanner_Object_Name = new Scanner(System.in);
```

where *Scanner\_Object\_Name* is any Java variable. For example, in Listing 2.3, we used the identifier keyboard for the *Scanner\_Object\_Name*, as follows:

```
Scanner keyboard = new Scanner(System.in);
```

We often use the identifier keyboard for our Scanner object because it suggests keyboard input. However, you may use other names instead. For example, you could use the variable scannerObject everywhere we use keyboard.

After you define a Scanner object, you can use methods of the class Scanner to read data typed at the keyboard. For example, the method invocation

```
keyboard.nextInt()
```

reads one int value typed at the keyboard and returns that int value. You can assign that value to a variable of type int, as follows:

```
int n1 = keyboard.nextInt();
```

What if you want to read a number of some type other than int? The method nextDouble works in exactly the same way as nextInt, except that it reads a value of type double. Scanner has similar methods for reading values of other numeric types.

The method next reads a word, as illustrated by the following statements:

```
String s1 = keyboard.next();
String s2 = keyboard.next();
```

If the input line is

```
plastic spoons
```

the string "plastic" is assigned to s1 and the string "spoons" is assigned to s2. Note that any two input values entered at the keyboard must be separated by whitespace characters such as one or more blanks or one or more line breaks or some combination of blanks and line breaks. In this context, the separators are called **delimiters**. For the method next, a word is any string of nonwhitespace characters delimited by whitespace characters.

If you want to read an entire line, you would use the method nextLine. For example,

```
String sentence = keyboard.nextLine();
```

nextInt reads an int value

nextDouble reads a double value

next reads a word

A delimiter is a separator in input data; by default, it is whitespace reads in one line of input and places the resulting string into the variable sentence. The end of an input line is indicated by the escape character '\n'. When you press the Enter (Return) key at the keyboard, you enter the '\n' character. On the screen, however, you simply see one line end and another begin. When nextLine reads a line of text, it reads this '\n' character, but the '\n' does not become part of the string value returned. So in the previous example, the string named by the variable sentence does not end with the '\n' character.

nextLine reads an entire line

Listing 2.5 shows a program that demonstrates the Scanner methods that we just introduced.

# LISTING 2.5 A Demonstration of Keyboard Input (part 1 of 2)

```
    Gets the Scanner

import java.util.Scanner;
                                class from the package
public class ScannerDemo
                                (library) java.util
    public static void main(String[] args)
                                                        Sets things up
    {
                                                        so the program
        Scanner keyboard = new Scanner(System.in);
                                                        can accept
                                                        keyboard input
        System.out.println("Enter two whole numbers");
       System.out.println("separated by one or more spaces:");
        int n1, n2;
                                             Reads one int value
        n1 = keyboard.nextInt();
                                            from the keyboard
       n2 = keyboard.nextInt();
        System.out.println("You entered " + n1 + " and " + n2);
       System.out.println("Next enter two numbers.");
       System.out.println("A decimal point is OK.");
        double d1, d2;
                                           Reads one double
        d1 = keyboard.nextDouble();
                                       value from the keyboard
       d2 = keyboard.nextDouble();
        System.out.println("You entered " + d1 + " and " + d2);
       System.out.println("Next enter two words:");
       String s1, s2;
                                               Reads one word
        s1 = keyboard.next();
                                               from the keyboard
        s2 = keyboard.next();
        System.out.println("You entered \"" +
                          s1 + "\" and \"" + s2 + "\""):
        the next Gotcha section.
       System.out.println("Next enter a line of text:");
        s1 = keyboard.nextLine();
                                                         Reads an entire line
       System.out.println("You entered: \"" + s1 + "\"");
}
                                                                         (continued)
```

# LISTING 2.5 A Demonstration of Keyboard Input (part 2 of 2)

# Sample Screen Output

```
Enter two whole numbers
separated by one or more spaces:
42 43
You entered 42 and 43
Next enter two numbers.
A decimal point is OK.
9.99 21
You entered 9.99 and 21.0
Next enter two words:
plastic spoons
You entered "plastic" and "spoons"
Next enter a line of text:
May the hair on your toes grow long and curly.
You entered "May the hair on your toes grow long and curly."
```

#### **RECAP Keyboard Input Using the Class Scanner**

You can use an object of the class Scanner to read input from the keyboard. To set things up, you place the following statement at the beginning of your program file:

```
import java.util.Scanner;
```

You also need a statement in the following form before the first statement involving keyboard input:

```
Scanner Scanner_Object_Name = new Scanner(System.in);
```

where Scanner\_Object\_Name is any Java identifier that is not a keyword. For example,

```
Scanner scannerObject = new Scanner(System.in);
```

The methods nextInt, nextDouble, and next read and return, respectively, a value of type int, a value of type double, and a word as the value of a String object. The method nextLine reads and returns the remainder of the current input line as a string. The terminating '\n' is read but not included in the string value returned.

(continued)

#### **SYNTAX**

```
Int_Variable= Scanner_Object_Name.nextInt();
 Double_Variable= Scanner_Object_Name.nextDouble()
 String_Variable= Scanner_Object_Name.next();
 String_Variable= Scanner_Object_Name.nextLine();
EXAMPLES
 int count = scannerObject.nextInt();
 double distance = scannerObject.nextDouble();
 String word = scannerObject.next();
 String wholeLine = scannerObject.nextLine();
```

Figure 2.7 lists some other methods in the class Scanner.

#### **REMEMBER Prompt for Input**

Your program should always display a prompt when it needs the user to enter some data as input, as in the following example:

```
System.out.println("Enter a whole number:");
```

#### GOTCHA Problems with the Methods next and nextLine



The methods next and nextLine of the class Scanner read text starting wherever the last keyboard reading left off. For example, suppose you create an object of the class Scanner as follows:

```
Scanner keyboard = new Scanner(System.in);
```

and suppose you continue with the following code:

```
int n = keyboard.nextInt();
String s1 = keyboard.nextLine();
String s2 = keyboard.nextLine();
```

Finally, assume that the corresponding input is typed at the keyboard, as follows:

```
42 is the answer
and don't you
forget it.
```

This will set the value of the variable n to 42, the variable s1 to "is the answer", and the variable s2 to "and don't you".

FIGURE 2.7 Some Methods in the Class Scanner

Method for Scanner kbd;	Return Type	Description	
next()	String	Returns the string value consisting of the next keyboard characters up to, but not including, the first delimiter character. The default delimiters are whitespace characters.	
nextLine()	String	Reads the rest of the current keyboard input line and returns the characters read as a value of type String. Note that the line terminator '\n' is read and discarded; it is not included in the string returned.	
nextInt()	int	Returns the next keyboard input as a value of type int.	
nextDouble()	double	Returns the next keyboard input as a value of type double.	
nextFloat()	float	Returns the next keyboard input as a value of type float.	
nextLong()	long	Returns the next keyboard input as a value of type long.	
nextByte()	byte	Returns the next keyboard input as a value of type byte.	
nextShort()	short	Returns the next keyboard input as a value of type short.	
nextBoolean()	boolean	Returns the next keyboard input as a value of type boolean. The values of true and false are entered as the words true and false. Any combination of uppercase and lowercase letters is allowed in spelling true and false.	
useDelimiter (Delimiter_Word)	Scanner	Makes the string <code>Delimiter_Word</code> the only delimiter used to separate input. Only the exact word will be a delimiter. In particular, blanks, line breaks, and other whitespace will no longer be delimiters unless they are a part of <code>Delimiter_Word</code> . This is a simple case of the use of the useDelimiter method. There are many ways to set the delimiters to various combinations of characters and words, but we will not go into them in this book.	

So far it may not seem as though there is any potential for problems, but suppose the input were instead

```
42 and don't you forget it.
```

Under these circumstances, you might expect that n is set to 42, s1 to "and don't you", and s2 to "forget it". But that is not what happens.

Actually, the value of the variable n is set to 42, the variable s1 is set to the empty string, and the variable s2 is set to "and don't you". The method

nextInt reads the 42 but does not read the end-of-line character '\n'. So the first nextLine invocation reads the rest of the line that contains the 42. There is nothing more on that line, except for '\n'. Thus, nextLine reads and discards the end-of-line character '\n' and then returns the empty string, which is assigned to s1. The next invocation of nextLine begins on the next line and reads "and don't you".

When combining methods that read numbers from the keyboard with methods that read strings, you sometimes have to include an extra invocation of nextLine to get rid of the end-of-line character '\n'. This problem is illustrated near the end of the program in Listing 2.5.

# **REMEMBER The Empty String**

Recall that an empty string has zero characters and is written as "". If the nextLine method executes, and the user simply presses the Enter (Return) key, the nextLine method returns the empty string.

# Other Input Delimiters (Optional)

When using the Scanner class for keyboard input, you can change the delimiters that separate keyboard input to almost any combination of characters and strings, but the details are a bit involved. In this book we will describe only one simple kind of delimiter change. We will tell you how to change the delimiters from whitespace to one specific delimiter string.

For example, suppose you create a Scanner object as follows:

```
Scanner keyboard2 = new Scanner(System.in);
```

You can change the delimiter for the object keyboard2 to "##" as follows:

```
keyboard2.useDelimiter("##");
```

After this invocation of the useDelimiter method, "##" will be the *only* input delimiter for the input object keyboard2. Note that whitespace will no longer be a delimiter for keyboard input involving keyboard2. So given the keyboard input

```
funny wo##rd ##
```

the following code would read the two strings "funny wo" and "rd":

```
System.out.println("Enter two words as a line of text:");
String s1 = keyboard2.next();
String s2 = keyboard2.next();
```

Note that no whitespace characters, not even line breaks, serve as an input delimiter once this change is made to keyboard2. Also note that you can have two different objects of the class Scanner with different delimiters in the same program. These points are illustrated by the program in Listing 2.6.

# LISTING 2.6 Changing Delimiters (Optional)

```
import java.util.Scanner;
public class DelimitersDemo
    public static void main(String[] args)
    {
                                                      keyboard1 and
        Scanner keyboard1 = new Scanner(System.in);
                                                      keyboard2 have
        Scanner keyboard2 = new Scanner(System.in);
                                                      different delimiters.
        keyboard2.useDelimiter("##");
        //The delimiters for keyboard1 are the whitespace
        //characters.
        //The only delimiter for keyboard2 is ##.
        String s1, s2;
        System.out.println("Enter a line of text with two words:");
        s1 = keyboard1.next();
        s2 = keyboard1.next();
        System.out.println("The two words are \"" + s1 +
                            "\" and \"" + s2 + "\"");
        System.out.println("Enter a line of text with two words");
        System.out.println("delimited by ##:");
        s1 = keyboard2.next();
        s2 = keyboard2.next();
        System.out.println("The two words are \"" + s1 +
                            "\" and \"" + s2 + "\"");
    }
}
```

# Sample Screen Output

```
Enter a line of text with two words:

funny wo##rd##

The two words are "funny" and "wo##rd##"

Enter a line of text with two words

delimited by ##:

funny wo##rd##

The two words are "funny wo" and "rd"
```

# Formatted Output with printf (Optional)

Starting with version 5.0, Java includes a method named printf that can be used to give output in a specific format. It is used in the same manner as the printf function in the C programming language. The method works like the print method except it allows you to add formatting instructions that specify things such as the number of digits to include after a decimal point. For example, consider the following:



This code outputs the following lines:

```
Price using println:19.5
Price using printf formatting: 19.50
```

Using println the price is output as "19.5" immediately after the colon because we did not add an additional space. Using printf the string after the colon is " 19.50" with a blank preceding the 19.50. In this simple example, the first argument to printf is a string known as the **format specifier** and the second argument is the number or other value to be output in that format.

The format specifier %6.2f says to output a floating-point number in a field (number of spaces) of width six (room for six characters) and to show exactly two digits after the decimal point. So, 19.5 is expressed as "19.50" in a field of width six. Because "19.50" only has five characters, a blank character is added to obtain the six-character string " 19.50". Any extra blank space is added to the front of the value output. If the output requires more characters than specified in the field (e.g., if the field in this case was set to 1 via %1.2f), then the field is automatically expanded to the exact size of the output (five in our example). The f in %6.2f means the output is a floating-point number, that is, a number with a decimal point.

Figure 2.8 summarizes some of the common format specifiers.

We can combine multiple format specifiers into a single string. For example, given

the output is: "Widgets sold:2 at \$19.50. Total = \$39.00". There are three blank spaces in front of "Widgets" to make a field of ten characters. Similarly, there are three blank spaces in front of the 2 to make a field of four characters. The 19.50 fits in exactly five characters and the last field for the total is expanded to five from one so it will fit the 39.00.

FIGURE 2.8 Selected Format Specifiers for System.out.printf

Format Specifier	Type of Output	Examples
%c	Character	A single character: %c
		A single character in a field of two spaces: %2c
%d	Decimal integer number	An integer: %d
		An integer in a field of 5 spaces: %5d
%f	Floating-point number	A floating-point number: %f
		A floating-point number with 2 digits after the decimal: %1.2f
		A floating-point number with 2 digits after the decimal in a field of 6 spaces: %6.2f
%e	Exponential floating- point number	A floating-point number in exponential format: %e
%s	String	A string formatted to a field of 10 spaces: %10s



# **SELF-TEST QUESTIONS**

27. Write Java statements that will cause the following to be written to the screen:

Once upon a time, there were three little programmers.

- 28. What is the difference between the methods System.out.println and System.out.print?
- 29. Write a complete Java program that reads a line of keyboard input containing two values of type int—separated by one or more spaces—and then displays the two numbers.
- 30. Write a complete Java program that reads one line of text containing exactly three words—separated by any kind or amount of whitespace—and then displays the line with spacing corrected as follows: The output has no space before the first word and exactly two spaces between each pair of adjacent words.

31. What output is produced by the following statements?

```
String s = "Hello" + "" + "Joe";
System.out.println(s);
```

# **2.4** DOCUMENTATION AND STYLE

"Don't stand there chattering to yourself like that," Humpty Dumpty said, looking at her for the first time, "but tell me your name and your business."

"My name is Alice, but—"

"It's a stupid name enough!" Humpty Dumpty interrupted impatiently. "What does it mean?"

"Must a name mean something?" Alice asked doubtfully.

"Of course it must," Humpty Dumpty said with a short laugh: "my name means the shape i am—and a good handsome shape it is too. With a name like yours, you might be any shape, almost."

—LEWIS CARROLL, Through the Looking-Glass

A program that gives the correct output is not necessarily a good program. Obviously, you want your program to give the correct output, but that is not the whole story. Most programs are used many times and are changed at some point either to fix bugs or to accommodate new demands by the user. If the program is not easy to read and understand, it will not be easy to change, and it might even be impossible to change with any realistic effort. Even if the program will be used only once, you should pay some attention to readability. After all, you will have to read the program to debug it.

In this section, we discuss four aspects of a program that help to make it more readable: meaningful names, comments, indentation, and named constants.

# **Meaningful Variable Names**

As we mentioned earlier in this chapter, the names x and y are almost never good variable names. The name you give to a variable should be suggestive of its intended use. If the variable holds a count of something, you might name it count. If the variable holds a tax rate, you might name it taxRate.

In addition to giving variables meaningful names and giving them names that the compiler will accept, you should choose names that follow the normal practice of programmers. That way, your code will be easier for others to read and to combine with their code, should you work on a project with more than one programmer. Typically, variable names are made up entirely of letters and digits. You start each name with a lowercase letter, as we have been doing so far. The practice of starting with a lowercase letter may look strange at first, but it is a convention that is commonly used, and you will quickly get used to it. We use names that start with an uppercase letter for something else, namely, for class names like String.

Name your variables to suggest their use

If the name consists of more than one word, "punctuate" it by using capital letters at the word boundaries, as in taxRate, numberOfTries, and timeLeft.

#### Comments

For example,

Write programs that are self-documenting

The documentation for a program tells what the program does and how it does it. The best programs are **self-documenting**. This means that, thanks to a very clean style and very well-chosen identifiers, what the program does and how it does it will be obvious to any programmer who reads the program. You should strive for such self-documenting programs, but your programs may also need a bit of additional explanation to make them completely clear. This explanation can be given in the form of comments.

Use comments to explain details

Comments are notes that you write into your program to help a person understand the program but that are ignored by the compiler. You can insert comments into a Java program in three ways. The first way is to use the two symbols // at the beginning of a comment. Everything after these symbols up to the end of the line is treated as a comment and is ignored by the compiler. This technique is handy for short comments, such as

// comment

```
String sentence; //Spanish version
```

If you want a comment of this form to span several lines, each line must contain the symbols // at the beginning of the comment.

The second kind of comment can more easily span multiple lines. Anything written between the matching symbol pairs /\* and \*/ is a comment and is ignored by the compiler.

/\* \*/ comment

```
/*
This program should only
be used on alternate Thursdays,
except during leap years, when it should
only be used on alternate Tuesdays.
*/
```

This is not a very likely comment, but it does illustrate the use of /\* and \*/.

Many text editors automatically highlight comments by showing them in a special color. In this book, we will also write comments in a different color, as illustrated by the following comment

```
/** */ comment
```

```
'^'
This program should only
be used on alternate Thursdays,
except during leap years, when it should
only be used on alternate Tuesdays.
*/
```

Notice that this comment uses two asterisks rather than one in the opening /\*\*. This is not required to make it a comment, but it is needed when we use a program named javadoc that automatically extracts documentation from Java software. We will discuss how to use javadoc later in this book, but we will start using the double asterisks now.

It is difficult to explain just when you should and should not insert a comment. Too many comments can be as bad as too few comments. With too many comments, the really important information can be lost in a sea of comments that just state the obvious. As we show you more Java features, we will mention likely places for comments. For now, you should normally need them in only two situations.

First, every program file should have an explanatory comment at its beginning. This comment should give all the important information about the file: what the program does, the name of the author, how to contact the author, and the date the file was last changed, as well as other information particular to your situation, such as course assignment number. This comment should be similar to the one shown at the top of Listing 2.7.

Second, you should write comments that explain any nonobvious details. For example, look at the program in Listing 2.7. Note the two variables named radius and area. Obviously, these two variables will hold the values for the radius and area of a circle, respectively. You should *not* include comments like the following:

```
double radius; //the radius of a circle ← A poor comment
```

However, something is not obvious. What units are used for the radius? Inches? Feet? Meters? Centimeters? You should add a comment that explains the units used, as follows:

```
double radius; //in inches
double area; //in square inches
```

These two comments are also shown in Listing 2.7.

# **REMEMBER Write Self-Documenting Code**

**Self-documenting** code uses well-chosen names and has a clear style. The program's purpose and workings should be obvious to any programmer who reads the program, even if the program has no comments. To the extent that it is possible, you should strive to make your programs self-documenting.

### LISTING 2.7 Comments and Indentation

```
import java.util.Scanner; <--</pre>
                                                          This import c an go after
                                                          the big comment if you prefer.
 Program to compute area of a circle.
 Author: Jane Q. Programmer.
 E-mail Address: janeg@somemachine.etc.etc.
 Programming Assignment 2.
 Last Changed: October 7, 2017.
public class CircleCalculation
                                                          The vertical lines indicate
                                                          the indenting pattern.
    public static void main(String[] args)
        double radius; //in inches
         double area; //in square inches
         Scanner keyboard = new Scanner(System.in);
         System.out.println("Enter the radius of a circle in inches:");
         radius = keyboard.nextDouble();
         area = 3.14159 * radius * radius;
         System.out.println("A circle of radius " + radius + " inches");
         System.out.println("has an area of " + area + " square inches.");
    }
                              Later in this chapter, we
}
                              will give an improved
                              version of this program.
```

## Sample Screen Output

```
Enter the radius of a circle in inches:
2.5
A circle of radius 2.5 inches
has an area of 19.6349375 square inches.
```

## **RECAP** Java Comments

There are three ways to add comments in Java:

- Everything after the two symbols // to the end of the line is a comment and is ignored by the compiler.
- Anything written between the symbol pairs /\* and \*/ is a comment and is ignored by the compiler.
- Anything written between the symbol pairs /\*\* and \*/ is a comment that is processed by the documentation program javadoc but is ignored by the compiler.

## **Indentation**

A program has a lot of structure. There are smaller parts within larger parts. For example, one part starts with

```
public static void main(String[] args)
{
```

The body of this main method begins with an open brace { and ends with a closing brace }. Within these braces are Java statements, which we indent by a consistent number of spaces.

The program in Listing 2.7 has three levels of indentation—as indicated by the vertical lines—that clearly show its **nested structure**. The outermost structure, which defines the class CircleCalculation, is not indented at all. The next level of nested structure—the main method—is indented. The body of that method is indented yet again.

Use consistent indentation to show a program's structure

We prefer to indent by four spaces for each level of indenting. Indenting more than that leaves too little room on the line for the statement itself, whereas a smaller indent might not show up well. Indenting two or three spaces is not unreasonable, but we find four spaces to be the clearest. If you are in a course, follow the rules given by your instructor. On a programming project, you likely will have a style sheet that dictates the number of spaces you should indent. In any event, you should indent consistently within any one program.

If a statement does not fit on one line, you can write it on two or more lines. However, when you write a single statement on more than one line, indent the second and all subsequent continuation lines more than the first line.

Although the levels of nesting shown in Listing 2.7 are delimited by braces, {}, that is not always the case. Regardless of whether there are any braces, you should still indent each level of nesting.

Indent each level of nesting

# **Using Named Constants**

Look again at the program in Listing 2.7. You probably recognize the number 3.14159 as the approximate value of pi, the number that is used in many calculations involving a circle and that is often written as PI. However, you might not be sure that 3.14159 is pi and not some other number. Somebody other than you might have no idea as to where the number 3.14159 came from. To avoid such confusion, you should always give a name to constants such as 3.14159 and use the name instead of writing out the number.

For example, you might give the number 3.14159 the name PI and define it as follows:

```
public static final double PI = 3.14159;
```

Then the assignment statement

```
area = 3.14159 * radius * radius;
```

could be written more clearly as

```
area = PI * radius * radius;
```

In Listing 2.8, we have rewritten the program from Listing 2.7 so that it uses the name PI as a defined name for the constant 3.14159. Note that the definition of PI is placed outside of the main method. Although named constants need not be defined near the beginning of a file, it is a good practice to place them there. That way, they will be handy if you need to correct their

# **LISTING 2.8** Naming a Constant

```
import java.util.Scanner;
Program to compute area of a circle.
Author: Jane Q. Programmer.
E-mail Address: janeq@somemachine.etc.etc.
Programming Assignment 2.
Last Changed: October 7, 2017.
*/
public class CircleCalculation2
    public static final double PI = 3.14159;
    public static void main(String[] args)
    {
        double radius; //in inches
        double area; //in square inches
        Scanner keyboard = new Scanner(System.in);
        System.out.println("Enter the radius of a circle in inches:");
        radius = keyboard.nextDouble();
        area = PI * radius * radius;
        System.out.println("A circle of radius " + radius + " inches");
        System.out.println("has an area of " + area + " square inches.");
                             Although it would not be as clear, it
                             is legal to place the definition of PI
                             here instead.
```

## Sample Screen Output

```
Enter the radius of a circle in inches:
2.5
A circle of radius 2.5 inches
has an area of 19.6349375 square inches.
```

values. For example, suppose you have a banking program that contains the named constant

```
public static final double MORTGAGE INTEREST RATE = 6.99;
```

and suppose the interest rate changes to 8.5 percent. You can simply change the value of the named constant to

```
public static final double MORTGAGE_INTEREST_RATE = 8.5;
```

You would then need to recompile your program, but you need not change anything else in it.

Using a named constant, like MORTGAGE\_INTEREST\_RATE, can save you a lot of work. To change the mortgage interest rate from 6.99 percent to 8.5 percent, you change only one number. If the program did not use a named constant, you would have to change every occurrence of 6.99 to 8.5. Although a text editor makes this task easy, this change might not be right. If some occurrences of 6.99 represent the mortgage interest rate, while other occurrences of 6.99 represent something else, you would have to decide just what each 6.99 means. That would surely produce confusion and probably introduce errors.

Name your constants to make your program clearer and easier to maintain

# **SELF-TEST QUESTIONS**

- 32. What are the kinds of comments in Java?
- 33. What is the output produced by the following Java code:

```
/**
   Code for Question 33 .
*/
System.out.println("One");
//System.out.println("Two");
System.out.println("And hit it!");
```

34. Although it is kind of silly, state legislatures have been known to pass laws that "change" the value of pi. Suppose you live in a state where, by law, the value of pi is exactly 3.14. How must you change the program in Listing 2.8 to make it comply with the law?

# **2.5** GRAPHICS SUPPLEMENT

```
It ain't over till it's over.
```

-YOGI BERRA

This section begins with a JavaFX application from Chapter 1 redone following the style rules discussed in this chapter. However, the rest of the section is devoted to the JOptionPane class. This class provides you with a way to use windowing for I/O in your Java programs.

Chapter 3 also has a small amount of material on JOptionPane. All the material on JOptionPane in this chapter and in Chapter 3 is independent of the other material in this book. You may cover the material on JOptionPane whether you cover the other material in the other graphics supplements or not. You can also omit the material on JOptionPane and still cover the other material in the graphics supplements.

# Style Rules Applied to a JavaFX Application

Listing 2.9 revises the program that appears in Listing 1.2 of Chapter 1, adding named constants for all the integer arguments as well as explanatory comments. At first glance it may seem that all these named constants simply complicate the code. However, they make writing and changing the code much easier.

Writing such constants helps you to plan and organize your drawing. The named constants enable you to clearly and explicitly specify constraints. For example, the statement

```
public static final int Y_LEFT_EYE = Y_RIGHT_EYE;
```

ensures that the two eyes appear at the same level.

A graphics program like this one often needs to be tuned by adjusting the various integer values. Finding the right value to change when you need to adjust, say, the mouth width is much easier when you use named constants.

LISTING 2.9 Revision of Listing 1.2 Using Comments and Named Constants (part 1 of 2)

```
import javafx.application.Application;
                                                  These can go after the big comment
import javafx.scene.canvas.Canvas;
                                                  if you prefer.
import javafx.scene.Scene;
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.shape.ArcType;
JavaFX Application that displays a happy face.
Author: Jane Q. Programmer
Revision of Listing 1.2.
* /
public class HappyFace extends Application
{
  public static final int WINDOW_WIDTH = 400;
  public static final int WINDOW_HEIGHT = 300;
   public static final int FACE_DIAMETER = 200;
  public static final int X_FACE = 100;
   public static final int Y_FACE = 50;
```

# LISTING 2.9 Revision of Listing 1.2 Using Comments and Named Constants $(part\ 2\ of\ 2)$

```
public static final int EYE WIDTH = 10;
   public static final int EYE HEIGHT = 20;
   public static final int X_RIGHT_EYE = 155;
   public static final int Y_RIGHT_EYE = 100;
   public static final int X LEFT EYE = 230;
   public static final int Y_LEFT_EYE = Y_RIGHT_EYE;
   public static final int MOUTH_WIDTH = 100;
   public static final int MOUTH HEIGHT = 50;
   public static final int X_MOUTH = 150;
   public static final int Y MOUTH = 160;
   public static final int MOUTH_START_ANGLE = 180;
   public static final int MOUTH_DEGREES_SHOWN = 180;
   public static void main(String[] args)
   {
      launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
   {
        Group root = new Group();
        Scene scene = new Scene(root);
        Canvas canvas = new Canvas(WINDOW WIDTH, WINDOW HEIGHT);
        GraphicsContext gc = canvas.getGraphicsContext2D();
        // Draw face outline
        gc.strokeOval(X_FACE, Y_FACE, FACE_DIAMETER, FACE_DIAMETER);
        // Draw eyes
        gc.fillOval(X_RIGHT_EYE, Y_RIGHT_EYE, EYE_WIDTH, EYE_HEIGHT);
        gc.fillOval(X_LEFT_EYE, Y_LEFT_EYE, EYE_WIDTH, EYE_HEIGHT);
        // Draw mouth
        gc.strokeArc(X_MOUTH, Y_MOUTH, MOUTH_WIDTH, MOUTH_HEIGHT,
                     MOUTH_START_ANGLE, MOUTH_DEGREES_SHOWN, ArcType.OPEN);
        root.getChildren().add(canvas);
        primaryStage.setTitle("HappyFace in JavaFX");
        primaryStage.setScene(scene);
        primaryStage.show();
   }
}
                         The JavaFX application drawing is the
```

The JavaFX application drawing is the same as the one shown in Listing 1.2.

# PROGRAMMING TIP Use Named Constants in a Graphics Application

When designing a drawing, identify the components and their dimensions. Give names to these dimensions and define them as named constants. As much as possible and reasonable, make these constants interdependent. That is, since it is likely that certain dimensions are related to others, define one named constant in terms of another one. Fine-tuning the values of these constants is easier if you can describe the relationships among the various dimensions symbolically by using named constants.

# Introducing the Class JOptionPane

Any application program can use windows for I/O

Listing 2.10 contains a very simple Java application program that has a windowing interface. The program produces three windows, one at a time. The first window to appear is labeled Dialog 1 in Listing 2.10. The user enters a number in the text field of this window and then clicks the OK button with the mouse. The first window then goes away and the second window appears. The user handles the second window in a similar way. When the user clicks the OK button in the second window, the second window goes away and the third window appears. Let's look at the details.

# LISTING 2.10 Program Using JOptionPane for I/O (part 1 of 2)

```
import javax.swing.JOptionPane;
public class JOptionPaneDemo
    public static void main(String[] args)
    {
        String appleString =
          JOptionPane.showInputDialog("Enter number of apples:");
          int appleCount = Integer.parseInt(appleString);
        String orangeString =
           JOptionPane.showInputDialog("Enter number of oranges:");
        int orangeCount = Integer.parseInt(orangeString);
        int totalFruitCount = appleCount + orangeCount;
        JOptionPane.showMessageDialog(null,
               "The total number of fruits = " + totalFruitCount);
        System.exit(0);
    }
}
```

# LISTING 2.10 Program Using JOptionPane for I/O (part 2 of 2)

# Dialog 1



When the user clicks OK, the window goes away and the next window (if any) is displayed.

# Dialog 2



# Dialog 3



# REMEMBER Running a JOptionPane Program

You run a program that uses J0ptionPane, such as the one in Listing 2.10, in the same way you run any application program. You do not run it as if it were an applet.

Import JOptionPane from the Swing package This program uses the class JOptionPane to construct the windows that interact with the user. JOptionPane is a standard, predefined class that comes with every installation of Java. To make it available to your program, you write

```
import javax.swing.JOptionPane;
```

This statement tells the computer where to find the definition of the JOptionPane class. You may recall that we mentioned a library called Swing, which is a library of classes that we can use for windowing interfaces. These libraries are called packages, and in a Java program the Swing package is denoted javax.swing, with a lowercase s. The class JOptionPane is in this package. The previous import statement indicates this fact. You put this statement at the start of any program file that uses the class JOptionPane.

In Chapter 1 we indicated that JavaFX is replacing Swing. However, at this time there is not an equivalent version of JOptionPane in JavaFX with the same simplicity as the version discussed here. For this reason we continue to use JOptionPane until a better alternative is made available in JavaFX.

The first program instruction for the computer is

```
String appleString =
   JOptionPane.showInputDialog("Enter number of apples:");
```

It declares appleString to be a variable of type String and then starts the windowing action. The two lines are a single statement, or instruction, and would normally be written on one line, except that doing so would make the line inconveniently long.

JOptionPane is a class used for producing special windows—called dialog windows, dialog boxes, or simply dialogs—that either obtain input or display output from your program. The method showInputDialog produces a dialog for obtaining input. The string argument, in this case "Enter number of apples:", is written in the window to tell the user what to enter. You the programmer choose this string, depending on what sort of input you want. This invocation of the method showInputDialog will produce the first dialog shown in Listing 2.10. The user clicks the mouse in the text field and then types in some input. The user can use the backspace key to back up and change the input if necessary. Once the user is happy with the input, the user clicks the OK button and the window goes away. As an alternative, the user can press the Enter (Return) key instead of clicking the OK button. That takes care of the responsibility of the user, but how does this input get to your program? Read on.

The method invocation

```
Defining a dialog for input
```

```
JOptionPane.showInputDialog("Enter number of apples:");
```

returns—that is, produces—the input that the user typed into the text field. This invocation is within an assignment statement that stores this input. Specifically, the string input is stored in the variable appleString. When you use JOptionPane to read user input, only string values are read. If you want numbers, your program must convert the input string to a number.

The next statement begins by declaring the variable appleCount as an int. The int says that the data stored in the variable appleCount must be an *integer*. The programmer who wrote this program wants the user to enter an integer into that first input window and wants the program to store this integer in the variable appleCount. Because JOptionPane reads only strings, this means converting the string to a value of type int. To see why this conversion is necessary, let's say that the user types 10 into the dialog box, indicating that there are 10 apples. What he or she has actually typed is the character '1' followed by

# **ASIDE** All Input and Output Are Strings

All program input from the user and all output to the user consist of strings of characters. When using the class JOptionPane to read numeric input, you must convert the string that is read to the desired numeric value, as you will see next. Even the class Scanner reads user input as a string. However, when you call a method like nextInt or nextDouble, for example, the conversion from string input to numeric input is done for you.

the character '0' to produce the string "10". When using these input windows, you must be aware of the fact that all program input from the user—and all output to the user for that matter—consists of strings of characters. If you want your program to think of the input from an input window as a number, your program must convert the string, such as "10", into the corresponding number, in this case 10. To computers, "10" and 10 are very different things. (In real life they are also different, but we usually ignore that difference.) "10" is a string consisting of two characters, while 10 is a number that can, for example, be added to or subtracted from another number.

In Listing 2.10, the string typed in by the user is stored in the variable appleString. Since we expect the user to type the digits of an integer, our program needs to convert this string to an int. We store the resulting int value in the variable appleCount, as follows:

int appleCount = Integer.parseInt(appleString);

Integer is a class provided by Java, and parseInt is a method of the class Integer. The method invocation Integer.parseInt(appleString) converts the string stored in the variable appleString into the corresponding integer number. For example, if the string stored in appleString is "10", this method invocation will return the integer 10.

parseInt is a method of the class Integer

# FAQ Why do you invoke some methods using a class name instead of an object name?

Normally, a method invocation uses an object name. For example, if greeting is a variable of type String, we write greeting.length() to invoke the method length. However, when we call the methods of the class JOptionPane, we use the class name JOptionPane in place of an object name. The same is true of the method parseInt in the

(continued)

class Integer. What is the story? Some special methods do not require an object to be invoked and, instead, are called using the class name. These methods are called static methods and are discussed in Chapter 6. Although static methods are only a very small fraction of all methods, they are used for certain fundamental tasks, such as I/O, and so we have encountered them early. You can tell whether a standard method in the Java Class Library is static by looking at the documentation for its class on the Oracle Web site.

# **GOTCHA** Inappropriate Input

A program is said to crash when it ends abnormally, usually because something went wrong. When a program uses the method JOptionPane.showInputDialog to get input—as in Listing 2.10—the user must enter the input in the correct format, or else the program is likely to crash. If your program expects an integer to be entered, and the user enters 2,000 instead of 2000, your program will crash, because integers in Java cannot contain a comma. Later you will learn how to write more robust windowing programs that do not require that the user be so knowledgeable and careful. Until then, you will have to simply tell the user to be very careful.

A crash is an abnormal end to a program's execution

The next few statements in Listing 2.10 are only a slight variation on what we have just discussed. A dialog box—the second one in Listing 2.10—is produced and gets an input string from the user. The string is converted to the corresponding integer and stored in the variable orangeCount.

The next line of the program contains nothing new to you:

```
int totalFruitCount = appleCount + orangeCount;
```

It declares totalFruitCount as a variable of type int and sets its value to the sum of the int values in the two variables appleCount and orangeCount.

The program now should display the number stored in the variable totalFruitCount. This output is accomplished by the following statement:

This statement calls the method showMessageDialog, which is another method in the class JOptionPane. This method displays a dialog window that shows some output. The method has two arguments, which are separated by a comma. For now the first argument will always be written as null. You will have to wait for an explanation of what this null is. Until then, you will not go

Defining a dialog for output

too far wrong in thinking of null as a place holder that is being used because we do not need any "real" first argument. The second argument is easy to explain; it is the string that is written in the output dialog. So the previous method invocation produces the third dialog shown in Listing 2.10. This dialog stays on the screen until the user clicks the OK button with the mouse or presses the Enter (Return) key, at which time the window disappears.

Note that you can give the method showMessageDialog its string argument using the plus symbol in the same way you do when you give a string as an argument to System.out.println. That is, you can append the integer value stored in totalFruitCount to a string literal. Moreover, Java will automatically convert the integer value stored in totalFruitCount to the corresponding string.

# **GOTCHA** Displaying Only a Number

In Listing 2.10 the final program output is sent to an output window by the following statement:

It is good style to always label any output. So displaying the string

```
"The total number of fruits = "
```

is very important to the style and understandability of the program. Moreover, the invocation of the method showMessageDialog will not even compile unless you include a string in the output. For example, the following will not compile

```
JOptionPane.showMessageDialog(null, totalFruitCount);
//Illegal
```

The method showMessageDialog will not accept an int value—or a value of any other primitive type—as its second argument. But if you connect the variable or number to a string by using the plus symbol, the number is converted to a string, and the argument will then be accepted.

The last program statement in Listing 2.10,

```
System.exit(0);
```

simply says that the program should end. System is a predefined Java class that is automatically provided by Java, and exit is a method in the class System. The method exit ends the program as soon as it is invoked. In the programs that we will write, the integer argument 0 can be any integer, but by tradition we use 0 because it is used to indicate the normal ending of a program. The next chapter formally presents this method.

System.exit(0) must end a program that uses dialogs

# **GOTCHA** Forgetting System.exit(0);

If you omit the last line

```
System.exit(0);
```

from the program in Listing 2.10, everything will work as we described. The user will enter input using the input windows, and the output window will show the output. However, when the user clicks the OK button in the output window, the output window will go away, but the program will not end. The "invisible" program will still be there, using up computer resources and possibly keeping you from doing other things. With windowing programs, it ain't over till it's over. System.exit(0) is what really ends the program, not running out of statements to execute. So do not forget to invoke System.exit(0) in all of your windowing programs.

What do you do if you forget to call System.exit(0) and the program does not end by itself? You can end a program that does not end by itself, but the way to do so depends on your particular operating system. On many systems (but not all), you can stop a program by typing control-C, which you type by holding down the control (Ctrl) key while pressing the C key.

When you write an application program that has a windowing interface you always need to end the program with the statement

```
System.exit(0);
```

If the program does not use a windowing interface, such as the programs in Sections 2.1 through 2.4, you do not need to invoke System.exit(0).

# FAQ Why do some programs need System.exit and some do not?

An application program that uses a windowing interface, such as the one in Listing 2.10, must end with the following method invocation:

```
System.exit(0);
```

A program that uses simple text input and output—like the ones in previous sections of this chapter—does not require this call. What is the reason for this difference?

If a program uses simple text input and output, Java can easily tell when it should end; the program should end when all the statements have executed.

(continued)

The situation is not so simple for application programs that have windowing interfaces. Java cannot easily tell when a windowing program should end. Many windowing programs end only when the user clicks a certain button or takes certain other actions. Those details are determined by the programmer, not by the Java language. The simple program in this section does happen to end when all its statements have executed. But for more complicated windowing programs, the end is not so easy to find, so you must tell Java when to end a program's execution by invoking System.exit.

## RECAP JOptionPane for Windowing Input/Output

You can use the methods showInputDialog and showMessageDialog to produce input and output windows—called dialogs—for your Java programs. When using these methods, you include the following at the start of the file that contains your program:

```
import javax.swing.JOptionPane;
```

The syntax for input and output statements using these methods is given below:

#### SYNTAX FOR INPUT

The *String\_Expression* is displayed in a dialog window that has both a text field in which the user can enter input and a button labeled OK. When the user types in a string and clicks the OK button in the window, the method returns the string. That string is stored in the *String\_Variable*. As an alternative, pressing the Enter (Return) key is equivalent to clicking the OK button. Note that when input is done in this way, it is read as a string. If you want the user to enter, for example, integers, your program must convert the input string to the equivalent number.

#### **EXAMPLE**

```
String orangeString =
   JOptionPane.showInputDialog(
    "Enter number of oranges:");
```

(continued)

#### SYNTAX FOR OUTPUT

```
JOptionPane.showMessageDialog(null, String_Expression);
```

The String\_Expression is displayed in a dialog window that has a button labeled OK. When the user clicks the OK button with the mouse or presses the Enter (Return) key, the window disappears.

#### **EXAMPLE**

# **SELF-TEST QUESTIONS**

35. In the following two lines, one identifier names a class, one identifier names a method, and something is an argument. What is the class name? What is the method name? What is the argument?

```
appleString =
    JOptionPane.showInputDialog("Enter number of apples:");
```

36. Give a Java statement that will display a dialog window on the screen with the message

I Love You.

- 37. Give a Java statement that, when executed, will end the program.
- 38. What would happen if you omitted System.exit(0) from the program in Listing 2.10? Would the program compile? Would it run without problems?
- 39. Write a complete Java program that produces a dialog window containing the message HelloWorld!. Your program does nothing else.
- 40. Write a complete Java program that behaves as follows. The program displays an input dialog window asking the user to enter a whole number. When the user enters a whole number and clicks the OK button, the window goes away and an output dialog window appears. This window simply tells the user what number was entered. When the user clicks the

OK button in the window, the program ends. (Hey, this is only Chapter 2. The programs will get complicated soon enough.)

# **Reading Input as Other Numeric Types**

Since the method JOptionPane.showInputDialog reads a string from the user, we had to convert it to an int in our previous program by using the method parseIntfrom the class Integer. You can convert a number represented as a string to any of the other numeric types by using other methods. For example, the following code asks the user to enter a value of type double and stores it in the variable decimalNumber of type double:

Figure 2.9 lists the correct conversion method for each numeric primitive type. To convert a value of type String to a value of the type given in the first column of the figure, you use the method given in the second column. Each of the methods in this second column returns a value of the type given in the first column. The *String\_To\_Convert* must be a correct string representation of a value of the type given in the first column. For example, to convert to an int, *String\_To\_Convert* must be a whole number written in the usual way without any decimal point and in the range of the type int. Chapter 6 will discuss these classes and methods in more detail.

FIGURE 2.9 Methods for Converting Strings to Numbers

Result Type	Method for Converting
byte	Byte.parseByte(String_To_Convert)
short	Short.parseShort(String_To_Convert)
int	<pre>Integer.parseInt(String_To_Convert)</pre>
long	Long.parseLong(String_To_Convert)
float	Float.parseFloat(String_To_Convert)
double	Double.parseDouble(String_To_Convert)

# PROGRAMMING TIP Multiline Output in a Dialog Window

If you want to display multiple lines by using JOptionPane's method showMessageDialog, you can insert the new-line character '\n'into the string used as the second argument. If the string becomes too long, which almost always happens with multiline output, you can write each line as a separate string ending with '\n' and connect them with plus symbols. If the lines are long or numerous, the window will expand as needed to hold all the output.

For example, consider

```
JOptionPane.showMessageDialog(null,

"The number of apples\n"

+ "plus the number of oranges\n"

+ "is equal to " + totalFruit);
```

This invocation will produce the dialog shown in Figure 2.10, provided totalFruit is a variable of type int whose value is 12.

FIGURE 2.10 A Dialog Window Containing Multiline Output



# PROGRAMMING EXAMPLE

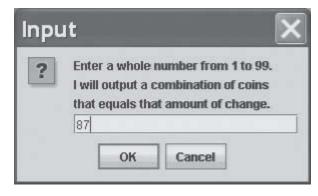
Change-Making Program with Windowing I/O

The program in Listing 2.11 is the same as the one in Listing 2.3, but it has a windowing interface. Notice that both the input dialog and the output dialog display multiple lines of text. If any of the details about calculating the numbers of coins is unclear, look back at the explanation of Listing 2.3.

# LISTING 2.11 A Change-Making Program with Windows for I/O (part 1 of 2)

```
import javax.swing.JOptionPane;
public class ChangeMakerWindow
{
    public static void main(String[] args)
    {
        String amountString = JOptionPane.showInputDialog(
                     "Enter a whole number from 1 to 99.\n" +
                     "I will output a combination of coins\n" +
                     "that equals that amount of change.");
        int amount, originalAmount,
        quarters, dimes, nickels, pennies;
        amount = Integer.parseInt(amountString);
        originalAmount = amount;
        quarters = amount / 25;
        amount = amount % 25;
        dimes = amount / 10;
        amount = amount % 10:
        nickels = amount / 5;
        amount = amount % 5;
        pennies = amount;
        JOptionPane.showMessageDialog(null, originalAmount +
                        " cents in coins can be given as:\n" +
                        quarters + " quarters\n" +
                        dimes + " dimes\n" +
                        nickels + " nickels and \n" +
                        pennies + " pennies");
        System.exit(0); \leftarrow
                                   Do not forget that you need
    }
                                   System.exit in a program with
}
                                   input or output windows.
```

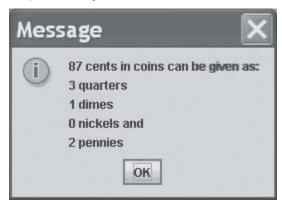
Input Dialog



(continued)

# LISTING 2.11 A Change-Making Program with Windows for I/O (part 2 of 2)

Output Dialog



Note that we did not forget the import statement

import javax.swing.JOptionPane;

nor did we forget that an application program using JOptionPane must invoke the method System.exit to terminate execution. If you forget the import statement, the compiler will complain. However, if you omit the invocation of the method System.exit, the compiler will not complain, but your program will not end, even after all the statements are executed and all the windows have disappeared.

#### **CHAPTER SUMMARY**

- A variable can hold values, such as numbers. The type of the variable must match the type of the value stored in the variable.
- Variables and all other items in a program should be given names that indicate how they are used. These names are called identifiers in Java.
- All variables should be given an initial value before you use them in the program. You can do this using an assignment statement, optionally combined with the variable declaration.
- Parentheses in arithmetic expressions indicate the order in which the operations are performed.
- When you give a value to a variable by using an assignment statement, the data type of the variable must be compatible with the type of the value. Otherwise, a type cast is necessary.

- The methods in the class Scanner can be used to read keyboard input.
- Your program should display a message to prompt the user to enter data at the keyboard.
- The method println advances to a new line after it displays its output, whereas the method print does not.
- The method printf may be used for formatted output.
- You can have variables and constants of type String. String is a class type that behaves very much like a primitive type.
- You can use the plus symbol to indicate the concatenation of two strings.
- The class String has methods that you can use for string processing.
- You should define names for number constants in a program and use these names rather than writing out the numbers within your program.
- Programs should be self-documenting to the extent possible. However, you should also insert comments to explain any unclear points. Use // to begin a one-line comment, or use either of the pairs /\*\* and \*/ or /\* and \*/ to enclose multiline comments.
- You can use the class JOptionPane to create a windowing interface for input and output.

## **Exercises**

- 1. Write a program that demonstrates the approximate nature of double values by performing the following tasks:
  - Use Scanner to read a double value x.
  - Compute 5.0 \* x and store the result in y.
  - Display x, y, and the sum of x and y.
  - Divide 5.0 from *x* and store the result in *z*. Display the value of *z*.

Try your program with values of x that range from 2e-11 to 2e11.

- 2. Write a program that demonstrates type casting of double values by performing the following tasks:
  - Use Scanner to read a floating-point value x.
  - Type cast x to an int value and store the result in y.
  - Display x and y clearly labeled.
  - Type cast *x* to a byte value and store the result in *z*.
  - Display *x* and *z* clearly labeled.

Try your program with positive and negative values of x that range in magnitude from 2e-11 to 2e11. What can you conclude?

- 3. Write a program that demonstrates the operator ++ by performing the following tasks:
  - Use Scanner to read an integer value x.
  - Compute *x*++ and store the result in *y*.
  - Display *x* and *y* clearly labeled.
  - Compute ++x and store the result in z.
  - Display x and z clearly labeled.

Try your program with positive and negative values of x. What can you conclude about pre- and post-increment?

- 4. If u = 2, v = 3, w = 5, x = 7, and y = 11, what is the value of each of the following expressions, assuming int variables?
  - u + v \* w + × • u + y % v \* w + × • u++ / v + u++ \* w
- 5. What changes to the ChangeMaker program in Listing 2.3 are necessary if it also accepts coins for one dollar and half a dollar?
- 6. If the int variable × contains 10, what will the following Java statements display?

```
System.out.println("Test 1" + \times * 3 * 2.0);
System.out.println("Test 2" + \times * 3 + 2.0);
```

Given these results, explain why the following Java statement will not compile:

```
System.out.println("Test 3" + * * 3 - 2.0);
```

7. Write some Java statements that use the String methods lastIndexOf and substring to find the last word in a string. We define *word* to be a string of characters that does not include whitespace. For example, the last word of the string

```
"Hello, my good friend!" is the string "friend!".
```

- 8. Repeat the previous exercise, but find the second last word in the string.
- 9. What does the following Java statement display?

```
System.out.println("\"\\Release\"\\\tYour\n\\\'Stress\'\\"\
robot\"");
```

What is the significance of \R and \r here?

10. Write a single Java statement that will display the words *Alice, In,* and *WonderLand,* adding tab between the words and the third word within double quotes.

11. What does the Java code

```
Scanner keyboard = new Scanner(System.in);
System.out.println("Enter a value");
double val = keyboard.nextDouble();
System.out.println("Value entered is " + val);
display when the keyboard input is 4pi?

12. What does the Java code
Scanner keyboard = new Scanner(System.in);
keyboard.useDelimiter("m");
System.out.println("Enter a string.");
String string1 = keyboard.next();
```

System.out.println("String1 is " + string1);
System.out.println("String2 is " + string2);

display when the keyboard input is

String string2 = keyboard.next();

Dream Think Imagine

- 13. Repeat the previous exercise, but remove the statement keyboard .useDelimiter("m"). Enter 'Dream' as the first string and 'Think Imagine' as the second string.
- 14. Many sports have constants embedded in their rules. For example, baseball has 9 innings, 3 outs per inning, 3 strikes in an out, and 4 balls per walk. We might encode the constants for a program involving baseball as follows:

```
public static final int INNINGS = 9;
public static final int OUTS_PER_INNING = 3;
public static final int STRIKES_PER_OUT = 3;
public static final int BALLS_PER_WALK = 4;
```

For each of the following popular sports, give Java named constants that could be used in a program involving that sport:

- Basketball
- American football
- Soccer
- Cricket
- Bowling
- 15. Repeat Exercise 18 in Chapter 1, but define and use named constants.

**Graphics** 

16. Define named constants that you could use in Programming Project 6 in Chapter 1.

#### PRACTICE PROGRAMS

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

- 1. Write a program that reads Principal, Rate and Time from the user. The program then calculates and displays the Simple Interest and the Amount.
- 2. Write a program that uses Scanner to read two strings from the keyboard. Display each string, along with its length, on two separate lines. Then create a new string by joining the two strings, separated by a blank. Display the new string and its length on a third line.
- 3. Write a program that reads the amount of a monthly mortgage payment and the amount still owed—the outstanding balance—and then displays the amount of the payment that goes to interest and the amount that goes to principal (i.e., the amount that goes to reducing the debt). Assume that the annual interest rate is 7.49 percent. Use a named constant for the interest rate. Note that payments are made monthly, so the interest is only one twelfth of the annual interest of 7.49 percent.
- 4. Write a program that reads a four-digit integer, such as 2014, and then displays it, one digit per line in reverse order, like so:

Your prompt should tell the user to enter a four-digit integer. You can then assume that the user follows directions. (*Hint*: Use the division and remainder operators.)

- 5. Repeat the previous project, but read the input in string and display the alternate characters from last.
- 6. The following program has some compile time errors. Find and fix the errors.

```
import java.util.Scanner;
public class CompErrors
{
  public static void main(String[] args)
  {
    Scanner keyboard = new Scanner(System.in);
    string mbBrand;
    double price;
    System.out.println("Enter the Mobile Brand name");
    MbBrand = keyboard.nextLine();
    System.out.println("Enter the price ");
    price = keyboard.nextInt();
    MbBrand.toLowercase()
```

```
System.out.printn("The Mobile Brand is " +
   MbBrand + " and its price is " + Price);
}
```

#### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.



1. Write a program that converts degrees from Fahrenheit to Celsius, using the formula

```
DegreesC = 5(DegreesF - 32)/9
```

Prompt the user to enter a temperature in degrees Fahrenheit as a whole number without a fractional part. Then have the program display the equivalent Celsius temperature, including the fractional part to at least one decimal point. A possible dialogue with the user might be

```
Enter a temperature in degrees Fahrenheit: 72 72 degrees Fahrenheit is 22.2 degrees Celsius.
```

2. Write a program that reads a line of text and then displays the line, but with the first occurrence of *hate* changed to *love*. For example, a possible sample dialogue might be

```
Enter a line of text.
I hate you.
I have rephrased that line to read:
I love you.
```

You can assume that the word *hate* occurs in the input. If the word *hate* occurs more than once in the line, your program will replace only its first occurrence.

3. Write a program that will read a line of text as input and then display the line with the first word moved to the end of the line. For example, a possible sample interaction with the user might be

```
Enter a line of text. No punctuation please. Java is the language
I have rephrased that line to read:
Is the language Java
```

Assume that there is no space before the first word and that the end of the first word is indicated by a blank, not by a comma or other punctuation. Note that the new first word must begin with a capital letter.

4. Write a program that asks the user to enter a favorite color, a favorite food, a favorite animal, and the first name of a friend or relative. The program should then print the following two lines, with the user's input replacing the items in italics:

I had a dream that Name ate a Color Animal and said it tasted like Food!

For example, if the user entered blue for the color, hamburger for the food, dog for the animal, and Jake for the person's name, the output would be

I had a dream that Jake ate a blue dog and said it tasted like hamburger!

Don't forget to put the exclamation mark at the end.

5. Write a program that determines the change to be dispensed from a vending machine. An item in the machine can cost between 25 cents and a dollar, in 5-cent increments (25, 30, 35, ..., 90, 95, or 100), and the machine accepts only a single dollar bill to pay for the item. For example, a possible dialogue with the user might be

```
Enter price of item (from 25 cents to a dollar, in 5-cent increments): 45 You bought an item for 45 cents and gave me a dollar, so your change is 2 quarters, 0 dimes, and 1 nickel.
```

- 6. Write a program that reads a 4-bit binary number from the keyboard as a string and then converts it into decimal. For example, if the input is 1100, the output should be 12. (*Hint:* Break the string into substrings and then convert each substring to a value for a single bit. If the bits are  $b_0$ ,  $b_1$ ,  $b_2$ , and  $b_3$ , the decimal equivalent is  $8b_0 + 4b_1 + 2b_2 + b_3$ .)
- 7. Many private water wells produce only 1 or 2 gallons of water per minute. One way to avoid running out of water with these low-yield wells is to use a holding tank. A family of 4 will use about 250 gallons of water per day. However, there is a "natural" water holding tank in the casing (i.e., the hole) of the well itself. The deeper the well, the more water that will be stored that can be pumped out for household use. But how much water will be available?

Write a program that allows the user to input the radius of the well casing in inches (a typical well will have a 3-inch radius) and the depth of the well in feet (assume water will fill this entire depth, although in practice that will not be true since the static water level will generally be 50 feet or more below the ground surface). The program should output the number of gallons stored in the well casing. For your reference:

The volume of a cylinder is  $\pi r^2 h$ , where r is the radius and h is the height. 1 cubic foot = 7.48 gallons of water.

For example, a 300-foot well full of water with a radius of 3 inches for the casing holds about 441 gallons of water—plenty for a family of 4 and no need to install a separate holding tank.

8. The Harris-Benedict equation estimates the number of calories your body needs to maintain your weight if you do no exercise. This is called your basal metabolic rate, or BMR.



The calories needed for a woman to maintain her weight is:

BMR = 
$$655 + (4.3 \times \text{weight in pounds}) + (4.7 \times \text{height in inches}) - (4.7 \times \text{age in years})$$

The calories needed for a man to maintain his weight is:

BMR = 
$$66 + (6.3 \times \text{weight in pounds}) + (12.9 \times \text{height in inches}) - (6.8 \times \text{age in years})$$

A typical chocolate bar will contain around 230 calories. Write a program that allows the user to input his or her weight in pounds, height in inches, and age in years. The program should then output the number of chocolate bars that should be consumed to maintain one's weight for both a woman and a man of the input weight, height, and age.

9. Repeat any of the previous programming projects using J0ptionPane, which is described in the graphics supplement.

Graphics

10. Write a program that reads a string for a date in the format *month* / *day* / *year* and displays it in the format *day* . *month* . *year*, which is a typical format used in Europe. For example, if the input is 06 /17/11, the output should be 17.06.11. Your program should use JOptionPane for input and output.

Graphics

11. It is important to consider the effect of thermal expansion when building a structure that must withstand changes in temperature. For example, a metal beam will expand in hot temperatures. The additional stress could cause the structure to fail. Similarly, a material will contract in cold temperatures. The linear change in length of a material if it is allowed to freely expand is described by the following equation:

$$L_{\Lambda} = \alpha L_0 T_{\Lambda}$$

Here,  $L_0$  is the initial length of the material in meters,  $L_\Delta$  is the displacement in meters,  $T_\Delta$  is the change in temperature in Celsius, and  $\alpha$  is a coefficient for linear expansion.

Write a program that inputs  $\alpha$ ,  $L_{\Delta}$ ,  $T_{\Delta}$ , and the name of the material, then calculates and outputs the material's name and the amount of linear displacement. Here are some values for  $\alpha$  for different materials.

Aluminum  $2.31 \times 10^{-5}$ Copper  $1.70 \times 10^{-5}$ Glass  $8.50 \times 10^{-6}$ Steel  $1.20 \times 10^{-5}$ 

# **Answers to Self-Test Questions**

1. The following are all legal variable names:

```
rate1, TimeLimit, numberOfWindows
```

TimeLimit is a poor choice, however, since it violates the normal convention that variables should start with a lowercase letter. A better choice would be timeLimit. 1stPlayer is illegal because it starts with a digit. myprogram. java is illegal because it contains an illegal character, the dot. Finally, long is illegal as a variable because it is a keyword.

- 2. Yes, a Java program can have two different variables with the names aVariable and avariable, since they use different capitalization and so are different identifiers in Java. However, it is not a good idea to use identifiers that differ only in the way they are capitalized.
- 3. int count = 0;

С

4. double rate = 0.0, time = 0.0;

You could write this declaration as two statements, as follows:

```
double rate = 0.0;
double time = 0.0;
```

It is also correct to replace 0.0 with 0, because Java will automatically convert the int value 0 to the double value 0.0:

```
5. int miles = 0;
  double flowRate = 50.56;
```

6. The normal practice of programmers is to spell named constants with all uppercase letters, using the underscore symbol to separate words.

```
7. public static final int HOURS_PER_DAY = 24;
8. interest = 0.05 * balance;
  The following is also correct:
  interest = balance * 0.05;
9. interest = balance * rate;
10. count = count + 3;
11. b
```

The last output is c, because the last assignment (a = b) has no quotes. This last assignment sets the variable a equal to the value of the variable b, which is 'c'.

12. (int) symbol - (int) '0'

To see that this works, note that it works for '0', and then see that it works for '1', and then '2', and so forth. You can use an actual number in place of (int)'0', but (int)'0' is a bit easier to understand.

- 13. quotient = 2 remainder = 1
- 14. (1 / 2) \* 2 is equal to 0.0

Because 1/2 is integer division, the part after the decimal point is discarded, producing 0 instead of 0.5.

15. result is -10

```
The expression -3 * 7 \% 3 - 4 - 6 is equivalent to (((-3 * 7) \% 3) - 4) - 6
```

- 16. result is 5
- 17. The output would change to the following:

Enter a whole number from 1 to 99 I will find a combination of coins that equals that amount of change. 87

2 cents in coins can be given as:

3 quarters

1 dimes

0 nickels and

2 pennies

- 18. n is 3 n is 2
- 19. How do you doSeven of Nine. Note that there is no space in doSeven.
- 20. 7 b
- 21. defg
- 22. abc def
- 23. abc\ndef
- 24. HELLO JOHN
- 25. False, because the strings are not equal.
- 26. True, because the strings are equal.

- 27. System.out.println("Once upon a time,");
   System.out.println("there were three little programmers.");
  - Since we did not specify where the next output goes, the second of these statements could use print instead of println.
- 28. The method System.out.println displays its output and then advances to the next line. Subsequent output would begin on this next line. In contrast, System.out.println displays its output but does not advance to the next line. Thus, subsequent output would begin on the same line.

```
29. import java.util.Scanner;
   public class Question29
   {
       public static void main(String[] args)
           Scanner keyboard = new Scanner(System.in);
           System.out.println("Enter two whole numbers:");
           int n1 = keyboard.nextInt( );
           int n2 = keyboard.nextInt();
           System.out.println("You entered: " + n1 + " " + n2);
       }
   }
30. import java.util.Scanner;
   public class Question30
       public static void main(String[] args)
           Scanner keyboard = new Scanner(System.in);
           String word1, word2, word3;
           System.out.println("Type three words on one line:");
           word1 = keyboard.next( );
           word2 = keyboard.next( );
           word3 = keyboard.next( );
           System.out.println("You typed the words");
           System.out.println(word1 + " " + word2 +" " + word3);
       }
   }
```

- 31. Since the empty string is the second of the three strings, the output is HelloJoe
- 32. There are // comments, /\* \*/ comments, and /\*\* \*/ comments. Everything following a / / on the same line is a comment. Everything between a /\* and a matching \*/ is a comment. Everything between a /\*\* and a matching \*/ is a comment that is recognized by the program javadoc.
- 33. One
  And hit it

34. Change the line

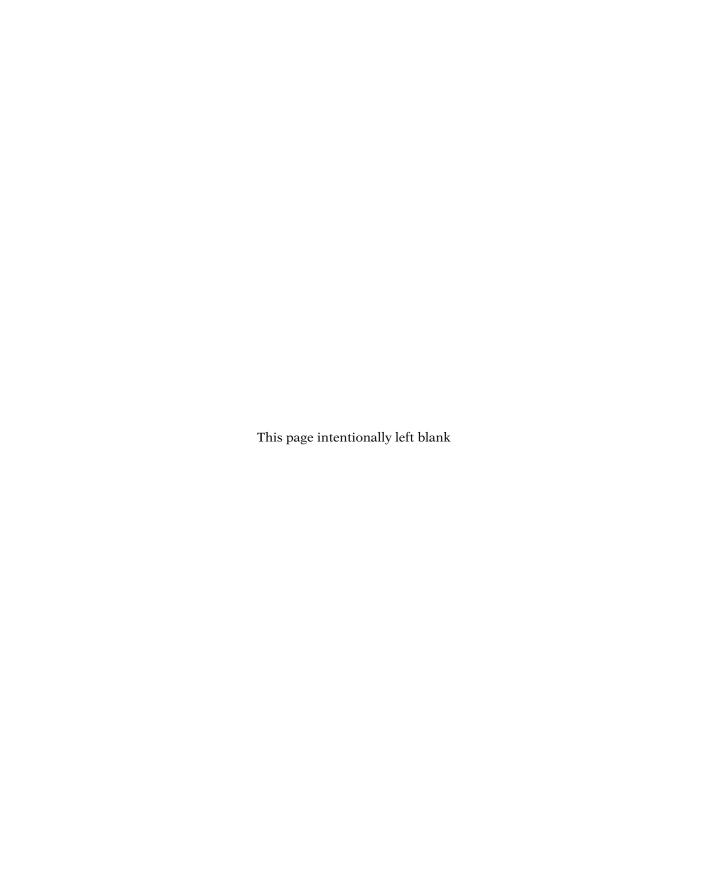
```
public static final double PI = 3.14159;
to
public static final double PI = 3.14;
```

Since values of type double are stored with only a limited amount of accuracy, you could argue that this is not "exactly" 3.14, but any legislator who is stupid enough to legislate the value of pi is unlikely to be aware of this subtlety.

- 35. JOptionPane is a class, showInputDialog is a method, and "Enter number of apples:" is an argument.
- 36. JOptionPane.showMessageDialog(null, "I Love You.");
- 37. System.exit(0);
- 38. It would compile. It would run. It would even appear to run with no problems. However, even after all the windows have disappeared, the program would still be running. It would continue to run and consume resources, and nothing in the Java code would ever end the program. You would have to use the operating system to end the program.

```
39. import javax.swing.JOptionPane;
   public class Question39
   {
      public static void main(String[] args)
      {
            JOptionPane.showMessageDialog(null, "Hello World!");
            System.exit(0);
      }
   }
}
```

40. You might want to convert numberString to an int, but that will not affect anything the user sees when the program is run.



# Flow of Control: Branching

#### 3.1 THE if-else STATEMENT 176

The Basic if-else Statement 177
Boolean Expressions 184
Comparing Strings 189
Nested if-else Statements 194
Multibranch if-else Statements 196
Programming Example: Assigning Letter
Grades 198
Case Study: Body Mass Index 201
The Conditional Operator (Optional) 204
The exit Method 204

#### 3.2 THE TYPE boolean 205

Boolean Variables 206 Precedence Rules 207 Input and Output of Boolean Values 210

# 3.3 THE switch STATEMENT 212

Enumerations 218

#### **3.4 GRAPHICS SUPPLEMENT** 219

Specifying a Drawing Color 220 A Dialog Box for a Yes-or-No Question 224

"Would you tell me, please, which way I ought to go from here?"

"That depends a good deal on where you want to get to," said the Cat.

-LEWIS CARROLL, Alice's Adventures in Wonderland

Flow of control is the order in which a program performs actions. Until this chapter, that order has been simple. Actions were taken in the order in which they were written down. In this chapter, we begin to show you how to write programs having a more complicated flow of control. Java and most other programming languages use two kinds of statements to regulate flow of control. A branching statement chooses one action from a list of two or more possible actions. A loop statement repeats an action again and again until some stopping condition is met. Both kinds of statements form **control structures** within a program. Because branching statements choose, or decide, among possible actions, they are also called decision structures. We talk about branching in this chapter and discuss loops in the next.

#### **OBJECTIVES**

After studying this chapter, you should be able to

- Use the Java branching statements—if-else and switch—in a program
- Compare values of a primitive type
- Compare objects such as strings
- Use the primitive data type boolean
- Use simple enumerations in a program
- Use color in a graphics program
- Use the class JOptionPane to create a dialog box for a yes-or-no question

# **PREREQUISITES**

Before reading this chapter, you need to be familiar with all the material in Chapter 2.

# 3.1 THE if-else STATEMENT

When you have eliminated the impossible, that which remains, however improbable, must be the truth.

—SIR ARTHUR CONAN DOYLE

When you come to a fork in the road, take it.

—ATTRIBUTED TO YOGI BERRA

We begin our discussion of branching with a kind of Java statement that chooses between two alternative actions.

# The Basic if-else Statement

In programs, as in everyday life, things can sometimes go in one of two different ways. If you have money in your checking account, some banks will pay you a little interest. On the other hand, if you have overdrawn your checking account, your account balance is negative, and you will be charged a penalty that will make your balance even more negative. This policy might be reflected in the bank's accounting program by the following Java statement, known as an if-else statement:

```
if (balance >= 0)
  balance = balance + (INTEREST_RATE * balance) / 12;
else
  balance = balance - OVERDRAWN_PENALTY;
```

if-else offers a choice of two actions

The pair of symbols >= is used to mean *greater than or equal to* in Java, because the symbol  $\geq$  is not on the keyboard.

The meaning of an if-else statement is really just the meaning it would have if read as an English sentence. When your program executes an if-else statement, it first checks the expression in parentheses after the keyword if. This expression must be something that is either true or false. If it is true, the statement before the else is executed. If the expression is false, the statement after the else is executed. In the preceding example, if balance is positive or zero, the following action is taken:

```
balance = balance + (INTEREST_RATE * balance) / 12;
```

(Since we are adding interest for only one month, we have to divide the annual interest rate by 12.) On the other hand, if the value of balance is negative, the following is done instead:

```
balance = balance - OVERDRAWN_PENALTY;
```

Figure 3.1 illustrates the action of this if-else statement, and Listing 3.1 shows it in a complete program.

The expression balance >= 0 is an example of a **boolean expression**. It is simply an expression that is either true or false. The name *boolean* is derived from George Boole, a 19th-century English logician and mathematician whose work was related to these kinds of expressions. We will investigate boolean expressions in the next section.

Notice that an if-else statement contains two smaller statements within it. For example, the if-else statement in Listing 3.1 contains within it the following two smaller statements:

```
balance = balance + (INTEREST_RATE * balance) / 12;
balance = balance - OVERDRAWN_PENALTY;
```

# FIGURE 3.1 The Action of the if-else Statement in Listing 3.1

```
if (balance >= 0)
    balance = balance + (INTEREST_RATE * balance) / 12;
else
    balance = balance - OVERDRAWN_PENALTY;

Start

Evaluate
balance >= 0

True

False

balance = balance +
    (INTEREST_RATE * balance) / 12;

Execute
balance = balance -
    OVERDRAWN_PENALTY;
```

Note that these smaller statements are indented one more level than the if and the else.

## PROGRAMMING TIP Indentation

Indentation in a program aids readability

We talked about indentation in the previous chapter. It is a stylistic convention that you really should follow. Although the compiler ignores indentation, inconsistent use of this convention will confuse the people who read your program and likely will cause you to make mistakes.

If you want to include more than one statement in each branch, simply enclose the statements in braces { }. Several statements enclosed within braces are considered to be one larger statement. So the following is one large statement that has two smaller statements inside it:

```
{
   System.out.println("Good for you. You earned interest.");
   balance = balance + (INTEREST_RATE * balance) / 12;
}
```

These statements formed by enclosing a list of statements within braces are called **compound statements**. They are seldom used by themselves but are

## LISTING 3.1 A Program Using if-else

```
import java.util.Scanner;
public class BankBalance
    public static final double OVERDRAWN_PENALTY = 8.00;
    public static final double INTEREST_RATE = 0.02; //2% annually
    public static void main(String[] args)
    {
        double balance;
        System.out.print("Enter your checking account balance: $");
        Scanner keyboard = new Scanner(System.in);
        balance = keyboard.nextDouble();
        System.out.println("Original balance $" + balance);
        if (balance >= 0)
            balance = balance + (INTEREST_RATE * balance)
            / 12;
        else
            balance = balance - OVERDRAWN_PENALTY;
        System.out.print("After adjusting for one month ");
        System.out.println("of interest and penalties,");
        System.out.println("your new balance is $" + balance);
    }
}
```

## Sample Screen Output 1

```
Enter your checking account balance: $505.67
Original balance $505.67
After adjusting for one month of interest and penalties,
your new balance is $506.51278
```

#### Sample Screen Output 2

```
Enter your checking account balance: \$-15.53 Original balance \$-15.53 After adjusting for one month of interest and penalties, your new balance is \$-23.53
```

often used as substatements of larger statements, such as if-else statements. The preceding compound statement might occur in an if-else statement such as the following:

Braces group multiline actions to form a compound statement

```
if (balance >= 0)
{
    System.out.println("Good for you. You earned interest.");
    balance = balance + (INTEREST_RATE * balance) / 12;
}
else
{
    System.out.println("You will be charged a penalty.");
    balance = balance - OVERDRAWN_PENALTY;
}
```

Notice that compound statements can simplify our description of an if-else statement. Once we know about compound statements, we can say that every if-else statement is of the form

```
if(Boolean_Expression)
    Statement_1
else
    Statement 2
```

else is optional

If you want one or both branches to contain several statements instead of just one, use a compound statement for *Statement\_1* and/or *Statement\_2*. Figure 3.2 summarizes the **semantics**, or meaning, of an if-else statement.

#### FIGURE 3.2 The Semantics of the if-else Statement

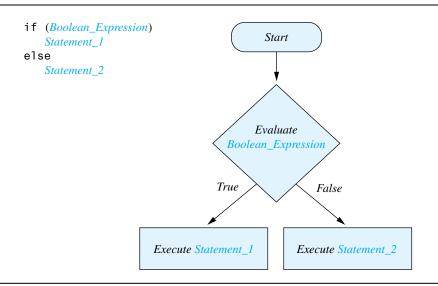
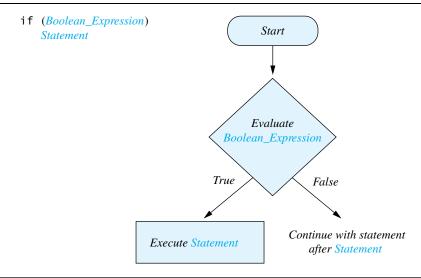


FIGURE 3.3 The Semantics of an if Statement Without an else



If you omit the else part, the program simply skips *Statement* when the if statement's expression is false, as Figure 3.3 illustrates. For example, if your bank does not charge an overdraft penalty, the statement shown previously would be shortened to the following:

```
if (balance >= 0)
{
    System.out.println("Good for you. You earned interest.");
    balance = balance + (INTEREST_RATE * balance) / 12;
}
```

To see how this statement works, let's give it a little more context by adding some additional statements, as follows, where keyboard is a Scanner object of the usual sort:

```
System.out.print("Enter your balance $");
balance = keyboard.nextDouble();
if (balance >= 0)
{
    System.out.println("Good for you. You earned interest.");
    balance = balance + (INTEREST_RATE * balance) / 12;
    either performs
    an action or does
System.out.println("Your new balance is $" + balance);
```

Executing these statements when your checking account balance is \$100 would produce the following interaction:

```
Enter your balance $100.00
Good for you. You earned interest.
Your new balance is $100.16
```

Since the expression balance >= 0 is true, you earn some interest. Exactly how much is irrelevant to this example. (However, we used an interest rate of 2 percent per year, as in Listing 3.1.)

Now suppose that your account is overdrawn and has a balance of minus \$50. The output would then be as follows:

```
Enter your balance $-50.00
Your new balance is $-50.00
```

In this case, the expression balance >= 0 is false, but since there is no else part, nothing happens—the balance is not changed, and the program simply goes on to the next statement, which is an output statement.



## **GOTCHA** Secure Programming: Input Validation and Overflow

You should check your input to ensure that it is within a valid or reasonable range. For example, consider a program that converts feet to inches. You might write the following:

```
int feet = keyboard.nextInt();
int inches = feet * 12;
```

This looks perfectly harmless, but what if the user types in unexpected values, either intentionally or by mistake? The result could crash the program or cause unexpected behavior. Some scenarios include:

- 1. If the user types a negative number for feet then your program might not work correctly with a negative value for inches.
- 2. If the program is expecting feet to represent the height of a person then there is nothing to stop the user from entering an unreasonable value, like 100 feet
- 3. An integer in Java is only able to hold a positive number up to 2,147,483,647. If we try to store a larger number then we get **overflow** which results in an incorrect value. If the user types a number such as 2,000,000,000 then we multiply it by 12 and get a value that is too large to fit into an integer. When Java encounters an integer value that is too large to fit then it begins to cycle around to the minimum value and continues from there. In this case it results in a negative number for inches, -1,769,803,776.

We can address these problems with validation to determine that input is in the proper range:

```
int feet = keyboard.nextInt();
if ((feet >= 0) && (feet < 10))
{
   int inches = feet * 12;
   . . .
}</pre>
```

#### RECAP if-else Statements

#### SYNTAX (BASIC FORM)

```
if (Boolean_Expression)
    Statement_1
else
    Statement_2
```

If the expression Boolean\_Expression is true, Statement\_1 is executed; otherwise, Statement\_2 is executed.

#### **EXAMPLE**

```
if (time < limit)
    System.out.println("You made it.");
else
    System.out.println("You missed the deadline.");</pre>
```

## SYNTAX (NO else PART)

```
if (Boolean_Expression)
   Statement
```

If the expression <code>Boolean\_Expression</code> is true, <code>Statement</code> is executed; otherwise, <code>Statement</code> is ignored and the program goes on to the next statement.

#### **EXAMPLE**

```
if (weight > ideal)
  calorieAllotment = calorieAllotment - 500;
```

#### **COMPOUND STATEMENT ALTERNATIVES**

Each of Statement, Statement\_1, and Statement\_2 can be a compound statement. If you want to include several statements to be executed for a given branch of the expression, group them between braces, as in the following example:

```
if (balance >= 0)
{
    System.out.println("Good for you. You earned interest.");
    balance = balance + (INTEREST_RATE * balance) / 12;
}
else
{
    System.out.println("You will be charged a penalty.");
    balance = balance - OVERDRAWN_PENALTY;
}
```

FIGURE 3.4	Java	Comparison	<b>Operators</b>
------------	------	------------	------------------

Math Notation	Name	Java Notation	Java Examples
=	Equal to	==	balance == 0 answer == 'y'
<b>≠</b>	Not equal to	!=	income != tax answer != 'y'
>	Greater than	>	expenses > income
≥	Greater than or equal to	>=	points >= 60
<	Less than	<	pressure < max
<u> </u>	Less than or equal to	<=	expenses <= income

## **Boolean Expressions**

We have already been using simple boolean expressions in if-else statements. The simplest boolean expressions compare two smaller expressions, as in these examples:

```
balance >= 0
and
time < limit</pre>
```

Figure 3.4 shows the various Java **comparison operators** you can use to compare two expressions.

Note that a boolean expression need not begin and end with parentheses. However, a boolean expression does need to be enclosed in parentheses when it is used in an if-else statement.

## **GOTCHA** Using = Instead of = = to Test for Equality

The operator = is the assignment operator. Although this symbol means equality in mathematics, it does not have this meaning in Java. If you write if (x = y) instead of if (x == y) to test whether x and y are equal, you will get a syntax error message.

## **GOTCHA** Using = = or != to Compare Floating-Point Values

The previous chapter warned that floating-point numbers must be thought of as approximations. Numbers that have a fractional part can have an

infinite number of digits. Since the computer can store only a limited number of digits in a fraction, floating-point numbers often are not exact. These approximations can get even less accurate after every operation in a calculation.

Thus, if you compute two floating-point values, they likely will not be exactly equal. Two values that are almost equal might be all you can hope for. Therefore, you should not use == to compare floating-point numbers. Using the != operator can cause the same problem.

Instead, to test two floating-point numbers for "equality," you see whether they differ by so little that it could only be due to their approximate nature. If so, you can conclude that they are "close enough" to be considered equal.

You can form more complicated boolean expressions from simpler ones by joining them with the **logical operator** &&, which is the Java version of *and*. For example, consider the following:

```
if ((pressure > min) && (pressure < max))
    System.out.println("Pressure is OK.");
else
    System.out.println("Warning: Pressure is out of range.");</pre>
```

If the value of pressure is greater than min *and* the value of pressure is less than max, the output will be

```
Pressure is OK.
```

Otherwise, the output will be

```
Warning: Pressure is out of range.
```

Note that you cannot write

```
min < pressure < max - Incorrect!
```

Instead, you must express each inequality separately and connect them with &&, as follows:

```
(pressure > min) && (pressure < max)
```

When you form a larger boolean expression by connecting two smaller expressions with &&, the entire larger expression is true only if both of the smaller expressions are true. If at least one of the smaller expressions is false, the larger expression is false. For example,

```
(pressure > min) && (pressure < max)
```

is true provided that both (pressure > min) and (pressure < max) are true; otherwise, the expression is false.

#### **RECAP** Use && for and

The symbol pair && means and in Java. You can use && to form a larger boolean expression out of two smaller boolean expressions.

#### **SYNTAX**

```
(Sub_Expression_1) && (Sub_Expression_2)
```

This expression is true if and only if both Sub\_Expression\_1 and Sub\_Expression\_2 are true.

#### **EXAMPLE**

Instead of joining boolean expressions with *and*, you can join them with or. The Java way of expressing or is  $|\cdot|$ , which you create by typing two vertical lines. (The symbol  $|\cdot|$  appears on some systems with a gap in the line.) The meaning of the operator  $|\cdot|$  is essentially the same as the English word or. For example, consider

```
if ((salary > expenses) || (savings > expenses))
   System.out.println("Solvent");
else
   System.out.println("Bankrupt");
```

If the value of salary is greater than the value of expenses or the value of savings is greater than the value of expenses or both are true, then the output will be Solvent; otherwise, the output will be Bankrupt.

```
|| means or
```

#### **RECAP** Use || for or

The symbol pair || means or in Java. You can use || to form a larger boolean expression out of two smaller boolean expressions.

## **SYNTAX**

```
(Sub_Expression_1) || (Sub_Expression_2)
```

(continued)

This expression is true if either Sub\_Expression\_1 or Sub\_Expression\_2 is true or both are true.

#### **EXAMPLE**

```
if ((salary > expenses) || (savings > expenses))
   System.out.println("Solvent");
else
   System.out.println("Bankrupt");
```

As we noted earlier, the boolean expression in an if-else statement must be enclosed in parentheses. An if-else statement that uses the && operator is normally parenthesized as follows:

```
if ((pressure > min) && (pressure < max))</pre>
```

The parentheses in (pressure > min) and in (pressure < max) are not required, but we will normally include them to aid readability. Parentheses are used in expressions containing the operator || in the same way that they are used with &&.

Parentheses clarify the meaning of a boolean expression

In Java, you can negate a boolean expression by preceding it with !. For example,

```
if (!(number >= min))
    System.out.println("Too small");
else
    System.out.println("OK");
```

! means negate

If number is *not* greater than or equal to min, the output will be Too small; otherwise, the output will be OK.

You often can avoid using !, and you should do so when possible. For example, the previous if-else statement is equivalent to

FIGURE 3.5 Avoiding the Negation Operator

! (A Op B) Is Equivalent to (A Op B)		
<	>=	
<=	>	
>	<=	
>=	<	
==	!=	
!=	==	

```
if (number < min)
    System.out.println("Too small");
else
    System.out.println("OK");</pre>
```

Figure 3.5 shows how to transform an expression of the form

```
!(A Comparison_Operator B)
```

to one without the negation operator.

If you can avoid using !, your programs should be easier to understand. However, we will encounter situations that use this operator naturally and clearly. In particular, we can use ! in the context of a loop—which we cover in the next chapter—to negate the value of a boolean variable, which we discuss later in this chapter.

#### **RECAP Use! for not**

The symbol! means *not* in Java. You can use! to negate the value of a boolean expression. Doing so is more common when the expression is a boolean variable. Otherwise, you often can rewrite a boolean expression to avoid negating it.

#### **SYNTAX**

```
!Boolean_Expression
```

The value of this expression is the opposite of the value of the boolean expression: It is true if *Boolean\_Expression* is false and false if *Boolean\_Expression* is true.

#### **EXAMPLE**

```
if (!(number < 0))
    System.out.println("OK");
else
    System.out.println("Negative!");</pre>
```



Figure 3.6 summarizes the three logical operators. Java combines the values of true and false according to the rules given in the chart in Figure 3.7. For example, if boolean expression A is true, and boolean expression B is false, A && B evaluates to false.

FIGURE 3.6 Java Logical Operators

Name	Java Notation	Java Examples
Logical <i>and</i>	&&	(sum > min) && (sum < max)
Logical or	11	(answer == 'y')    (answer == 'Y')
Logical <i>not</i>	!	!(number < 0)

## **Comparing Strings**

To test whether two values of a primitive type—such as two numbers—are equal, you use the **equality operator** ==. But == has a different meaning when applied to objects. Recall that a string is an object of the class String, so == applied to two strings does not test whether the strings are equal. To see whether two strings have equal values, you must use the method equals rather than ==.

For example, the boolean expression s1.equals(s2) returns true if the strings s1 and s2 have equal values, and returns false otherwise. The program in Listing 3.2 illustrates the use of the method equals. Notice that the two expressions

Use the equals method, not ==, to see whether two strings are equal

```
s1.equals(s2)
s2.equals(s1)
```

are equivalent.

Listing 3.2 also demonstrates the String method equalsIgnoreCase. This method behaves like equals, except that equalsIgnoreCase considers the uppercase and lowercase versions of the same letter to be the same. For example, "Hello" and "hello" are not equal because their first characters, 'H' and 'h', are different characters. But the method equalsIgnoreCase would consider them equal. For example, the following will display Equal:

```
if ("Hello".equalsIgnoreCase("hello"))
     System.out.println("Equal");
```

FIGURE 3.7 The Effect of the Boolean Operators && (and), || (or), and ! (not) on Boolean Values

Value of A	Value of <b>B</b>	Value of <i>A</i> && <i>B</i>	Value of A     B	Value of! (A)
true	true	true	true	false
true	false	false	true	false
false	true	false	true	true
false	false	false	false	true

Notice that it is perfectly valid to use the quoted string "Hello" in the invocation of equals IgnoreCase. A quoted string is an object of type String and has all the methods that any other object of type String has.

## **LISTING 3.2** Testing Strings for Equality

```
import java.util.Scanner;
public class StringEqualityDemo
{
    public static void main(String[] args)
        String s1, s2;
        System.out.println("Enter two lines of text:");
        Scanner keyboard = new Scanner(System.in);
        s1 = keyboard.nextLine();
                                               These two invocations of
        s2 = keyboard.nextLine();
                                               the method equals are
                                               equivalent.
        if (s1.equals(s2))
           System.out.println("The two lines are equal.");
        else
           System.out.println("The two lines are not equal.");
        if (s2.equals(s1))
           System.out.println("The two lines are equal.");
        else
           System.out.println("The two lines are not equal.");
        if (s1.equalsIgnoreCase(s2))
           System.out.println(
                        "But the lines are equal, ignoring case.");
        else
           System.out.println(
                        "Lines are not equal, even ignoring case.");
    }
}
```

## Sample Screen Output

```
Enter two lines of text:

Java is not coffee.

Java is NOT COFFEE.

The two lines are not equal.

The two lines are not equal.

But the lines are equal, ignoring case.
```

## **GOTCHA** Using == with Strings

When applied to two strings (or any two objects), the operator == tests whether they are stored in the same memory location. We will discuss that concept in Chapter 5, but for now, we need only realize that == does not test whether two strings have the same values.

For the kinds of applications we consider in this chapter, using == to test for equality of strings can appear to give you the correct answer. However, doing so is a dangerous habit to acquire. You should always use the method equals rather than == to test strings. Analogous comments apply to the other comparison operators, such as <, and the method compareTo, as you will soon see.

#### **RECAP The Methods** equals and equalsIgnoreCase

When testing strings for equality, use either of the methods equals or equals IgnoreCase.

#### **SYNTAX**

```
String.equals(Other_String)
String.equalsIgnoreCase(Other_String)
```

#### **EXAMPLE**

```
String s1 = keyboard.next(); //keyboard is a Scanner object
if (s1.equals("Hello"))
    System.out.println("The string is Hello.");
else
    System.out.println("The string is not Hello.");
```

Programs frequently need to compare two strings to see which is alphabetically before the other. Just as you should not use the == operator to test for equality of strings, you should not use operators such as < and > to test for alphabetic order. Instead you should use the String method compareTo, which we described in Figure 2.5 of Chapter 2.

The method compareTo tests two strings to determine their **lexicographic order**. Lexicographic order is similar to alphabetic order and is sometimes, but not always, the same as alphabetic order. In lexicographic ordering, the letters and other characters are ordered according to their Unicode sequence, which is shown in the appendix of this book.

Use the compareTo method to compare strings

If s1 and s2 are two variables of type String that have been given String values, the method call

```
s1.compareTo(s2)
```

compares the lexicographic ordering of the two strings and returns

- A negative number if s1 comes before s2
- Zero if the two strings are equal
- A positive number if \$1 comes after \$2

Thus, the boolean expression

```
s1.compareTo(s2) < 0
```

is true if s1 comes before s2 in lexicographic order and false otherwise. For example, the following will produce correct output:

But suppose that we want to check for alphabetic ordering, not lexicographic ordering. If you look at a Unicode chart, you will see that *all* uppercase letters come before *all* lowercase letters in lexicographic order. For example, 'Z' comes before 'a' lexicographically. So when comparing two strings consisting of a mix of lowercase and uppercase letters, lexicographic order and alphabetic order are not the same. However, in Unicode, all the lowercase letters are in alphabetic order and all the uppercase letters are in alphabetic order. So for any two strings of all lowercase letters, lexicographic order is the same as ordinary alphabetic order. Similarly, for any two strings of all uppercase letters, lexicographic order. Thus, to compare two strings of letters for ordinary alphabetic order, you need only convert the two strings to either all uppercase letters or all lowercase letters and then compare them for lexicographic ordering. Let's look at the Java details.

Suppose we arbitrarily convert our two strings of letters, s1 and s2, to all uppercase. We then use compareTo to test the uppercase versions of s1 and s2 for lexicographic ordering. The following will produce correct output:

## PROGRAMMING TIP Alphabetic Order

To see whether two strings of letters are in alphabetic order, you must ensure that all the letters have the same case before using the method compareTo to compare the strings. You can use either of the String methods toUpperCase or toLowerCase to accomplish this. If you were to omit this step, using compareTo would compare lexicographic order instead of alphabetic order.

## **SELF-TEST QUESTIONS**

- 1. Suppose goals is a variable of type int. Write an if-else statement that displays the word Wow if the value of the variable goals is greater than 10 and displays the words 0h Well if the value of goals is at most 10.
- 2. Suppose goals and errors are variables of type int. Write an if-else statement that displays the word Wow if the value of the variable goals is greater than 10 and the value of errors is 0. Otherwise, the if-else statement should display the words 0h Well.
- 3. Suppose salary and deductions are variables of type double that have been given values. Write an if-else statement that displays OK and sets the variable net equal to salary minus deductions, provided that salary is at least as large as deductions. If, however, salary is less than deductions, the if-else statement should simply display the words No Way but not change the value of any variables.
- 4. Suppose speed and visibility are variables of type int. Write an if statement that sets the variable speed equal to 25 and displays the word Caution, provided the value of speed is greater than 25 and the value of visibility is under 20. There is no else part.
- 5. Suppose salary and bonus are variables of type double. Write an if-else statement that displays the word OK provided that either salary is greater than or equal to MIN\_SALARY or bonus is greater than or equal to MIN\_BONUS. Otherwise, it should display Toolow. MIN\_SALARY and MIN\_BONUS are named constants.

- 6. Assume that nextWord is a String variable that has been given a value consisting entirely of letters. Write some Java code that displays the message First half of the alphabet, provided that nextWord precedes the letter N in alphabetic ordering. If nextWord does not precede N in alphabetic ordering, your code should display Second half of the alphabet. Be careful when you represent the letter N. You will need a String value, as opposed to a char value.
- 7. Suppose x1 and x2 are two variables that have been given values. How do you test whether the values are equal when the variables are of type int? How about when the variables are of type String?

### Nested if-else Statements

An if-else statement can contain any sort of statements within it. In particular, you can **nest** one if-else statement within another if-else statement, as illustrated by the following:

Any action within an if-else statement can be nested in another if-else statement

```
if (balance >= 0)
if (INTEREST_RATE >= 0)
   balance = balance + (INTEREST_RATE * balance) / 12;
else
   System.out.println("Cannot have a negative interest.");
else
   balance = balance - OVERDRAWN_PENALTY;
```

If the value of balance is greater than or equal to zero, the entire following if-else statement is executed:

```
if (INTEREST_RATE >= 0)
   balance = balance + (INTEREST_RATE * balance) / 12;
else
   System.out.println("Cannot have a negative interest.");
```

The nested statements can be made clearer by adding braces, as follows:

```
if (balance >= 0)
{
   if (INTEREST_RATE >= 0)
      balance = balance + (INTEREST_RATE * balance)/12;
   else
      System.out.println("Cannot have a negative interest.");
}
else
   balance = balance - OVERDRAWN_PENALTY;
```

In this case, the braces are an aid to clarity but are not, strictly speaking, needed.

In other cases, braces are needed. If we omit an else, for example, things get a bit trickier. The following two statements differ in appearance only in that one has a pair of braces, but they do *not* have the same meaning:

```
//First Version - Braces
if (balance >= 0)
{
    if (INTEREST_RATE >= 0)
        balance = balance + (INTEREST_RATE * balance)/12;
}
else
    balance = balance - OVERDRAWN_PENALTY;
//Second Version - No Braces
if (balance >= 0)
    if (INTEREST_RATE >= 0)
        balance = balance + (INTEREST_RATE * balance)/12;
else
    balance = balance - OVERDRAWN_PENALTY;
```

In an if-else statement, each else is paired with the nearest preceding unmatched if. The second version—without braces—pairs the else with the second if, despite the misleading indentation. Thus, the meaning is

To clarify the difference a bit more, consider what happens when balance is greater than or equal to zero. In the first version, the following action occurs:

```
if (INTEREST_RATE >= 0)
balance = balance + (INTEREST_RATE * balance)/12;
```

If balance is not greater than or equal to zero in the first version, the following action is taken instead:

```
balance = balance - OVERDRAWN PENALTY;
```

In the second version, if balance is greater than or equal to zero, the following entire if-else statement is executed:

```
if (INTEREST_RATE >= 0)
   balance = balance + (INTEREST_RATE * balance)/12;
else
   balance = balance - OVERDRAWN_PENALTY;
```

If balance is not greater than or equal to zero in the second version, no action is taken.

## PROGRAMMING TIP Matching else and if

In an if-else statement, each else is paired with the nearest preceding unmatched if. Use indentation that is consistent with the meaning of the statement to clarify your intent. But remember that the compiler ignores indentation. When in doubt, use braces to make the statement's meaning explicit.

## Multibranch if-else Statements

If you have the ability to branch two ways, you have the ability to branch four ways. Just branch two ways and have each of those two outcomes branch two ways. Using this trick, you can nest if-else statements to produce multiway branches that result in any number of possibilities. Programmers have a standard way of doing this. In fact, it has become so standard that it is treated as if it were a new kind of branching statement rather than just several nested if-else statements. Let's start with an example.

Suppose balance is a variable that holds your checking account balance, and you want to know whether your balance is positive, negative (overdrawn), or zero. To avoid any questions about accuracy, let's say balance is the number of dollars in your account, with the cents ignored. That is, let's assume that balance is of type int. To find out if your balance is positive, negative, or zero, you could use the following nested if-else statement:

```
if (balance > 0)
    System.out.println("Positive balance");
else
    if (balance < 0)
        System.out.println("Negative balance");
    else
        if (balance == 0)
            System.out.println("Zero balance");</pre>
```

An equivalent, clearer, and preferred way to write this statement is as follows:

```
if (balance > 0)
   System.out.println("Positive balance");
else if (balance < 0)
   System.out.println("Negative balance");
else if (balance == 0)
   System.out.println("Zero balance");</pre>
```

We call this form a **multibranch** if-else statement. This statement is really an ordinary nested if-else statement, but the way we have indented it reflects the way we think about multibranch if-else statements.

A multibranch if-else statement offers a choice among several actions

When a multibranch if-else statement is executed, the computer tests the boolean expressions one after the other, starting from the top. When the first true boolean expression is found, the statement following that true boolean expression is executed. For example, if balance is greater than zero, the preceding code will display Positive balance. If balance is less than zero, then Negative balance is displayed. Finally, if balance is equal to zero, the code displays Zero balance. Exactly one of the three possible outputs will be produced, depending on the value of the variable balance.

In this first example, we had three possibilities, but you can have any number of possibilities; just add more else-if parts. Also, the possibilities in this example were **mutually exclusive**. That is, only one possibility is true at a given time. However, you can use any boolean expressions, even if they are not mutually exclusive. If more than one boolean expression is true, only the action associated with the first true boolean expression is executed. A multibranch if-else statement never performs more than one action.

Only one action occurs

If none of the boolean expressions is true, nothing happens. However, it is a good practice to add an else clause—without any if—at the end that will be executed in case none of the boolean expressions is true. In fact, we can rewrite our original checking-account example in this way. We know that, if balance is neither positive nor negative, it must be zero. So we do not need the last test:

```
if (balance == 0)
```

Thus, our previous multibranch if-else statement is equivalent to the following one:

```
if (balance > 0)
    System.out.println("Positive balance");
else if (balance < 0)
    System.out.println("Negative balance");
else
    System.out.println("Zero balance");</pre>
```

Write a final else clause

## **RECAP Multibranch** if-else Statement

#### **SYNTAX**

```
if (Boolean_Expression_1)
   Action_1
else if (Boolean_Expression_2)
   Action_2 .
.
.
else if (Boolean_Expression_n)
   Action_n
else
   Default Action
```

VideoNote
Using multibranch if-else

(continued)

The actions are Java statements. The boolean expressions are tested one after the other, starting from the top one. As soon as a boolean expression is found to be true, the action following that true boolean expression is executed, and subsequent tests and actions are ignored. The *Default\_Action* is executed if none of the boolean expressions is true. Figure 3.8 illustrates the semantics of this form of if-else statement.

#### **EXAMPLE**

```
if (number < 10)
    System.out.println("number < 10");
else if (number < 50)
    System.out.println("number >= 10 and number < 50");
else if (number < 100)
    System.out.println("number >= 50 and number < 100");
else
    System.out.println("number >= 100.");
```

## PROGRAMMING EXAMPLE

**Assigning Letter Grades** 

Listing 3.3 contains a program that assigns letter grades according to the traditional rule that a score of 90 or above is an A, a score in the 80s is a B, and so forth.

Note that, as with any multibranch if-else statement, the boolean expressions are evaluated in order, and so the second boolean expression is not checked unless the first boolean expression is found to be false. Thus, when and if the second boolean expression is checked, we know that the first boolean expression is false, and therefore we know that score is less than 90.

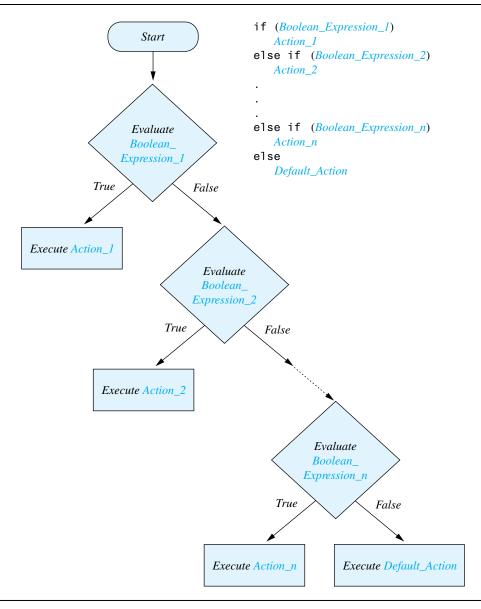
Thus, the multibranch if-else statement would have the same meaning if we replaced

```
(score >= 80)
with
((score >= 80) && (score < 90))
```

Using the same sort of reasoning on each boolean expression, we see that the multibranch if-else statement in Listing 3.3 is equivalent to the following:

```
if (score >= 90)
  grade = 'A';
else if ((score >= 80) && (score < 90))
  grade = 'B';</pre>
```

FIGURE 3.8 The Semantics of a Multibranch if-else Statement



```
else if ((score >= 70) && (score < 80))
   grade = 'C';
else if ((score >= 60) && (score < 70))
   grade = 'D';
else
   grade = 'F';</pre>
```

Most programmers would use the version in Listing 3.3, because it is a bit more efficient and is more elegant, but either version is acceptable.

## LISTING 3.3 Assigning Letter Grades Using a Multibranch if-else Statement

```
import java.util.Scanner;
public class Grader
    public static void main(String[] args)
    {
        int score;
        char grade;
        System.out.println("Enter your score: ");
        Scanner keyboard = new Scanner(System.in);
        score = keyboard.nextInt();
        if (score >= 90)
            grade = 'A';
        else if (score >= 80)
            grade = 'B';
        else if (score >= 70)
            grade = 'C';
        else if (score >= 60)
            grade = 'D';
        else
            grade = 'F';
        System.out.println("Score = " + score);
        System.out.println("Grade = " + grade);
    }
}
```

## Sample Screen Output

```
Enter your score:
85
Score = 85
Grade = B
```

## **CASE STUDY** Body Mass Index

The body mass index (BMI) is used to estimate the risk of weight-related problems based on a subject's height and mass. It was designed by the mathematician Adolphe Quetelet in the 1800s and is sometimes referred to as the Quetelet index. The BMI is computed as

$$BMI = \frac{mass}{height^2}$$

In this formula, mass is in kilograms and height is in meters. The health risk associated with a BMI value is

- Underweight < 18.5
- Normal weight ≥ 18.5 and < 25</li>
- Overweight ≥ 25 and < 30
- Obese ≥ 30

In this case study the users input their weight in pounds and height in feet and inches. The program then outputs the BMI and associated health risk. To do this we must first make our program convert from pounds to kilograms. One kilogram is 2.2 pounds. Additionally, the program must convert a height in feet and inches to meters. If we convert the height to all inches, then we can multiply by 0.0254 to convert inches into meters.

## Algorithm to compute BMI

- 1. Read the weight in pounds into the variable pounds.
- 2. Read the height in feet into the variable feet.
- 3. Read the additional height in inches into the variable inches.
- 4. Set the variable heightMeters to the value ((feet \* 12) + inches) \* 0.0254.
- 5. Set the variable mass to the value pounds / 2.2.
- 6. Set the variable BMI to the value mass / (heightMeters \* heightMeters).
- 7. Output BMI.
- 8. If BMI < 18.5 then output "Underweight."
- 9. Else if BMI ≥ 18.5 and BMI < 25 then output "Normal weight."
- 10. Else if BMI ≥ 25 and BMI < 30 then output "Overweight."
- 11. Otherwise, output "Obese."

This algorithm will work but it can be simplified a bit. If the BMI is less than 18.5, then the condition on line 8 will be true and the program will output "Underweight." Line 9 is only evaluated if line 8 is false. This means that if

the program reaches line 9 we know that the BMI is not less than 18.5. In other words, the BMI is greater than or equal to 18.5. This makes the check on line 9 for the BMI greater than or equal to 18.5 redundant. The same condition applies to line 10. Consequently, we can change lines 9 and 10 of the algorithm to

- 9. Else if BMI < 25 then output "Normal weight."
- 10. Else if BMI < 30 then output "Overweight."

The algorithm translated to code is shown in Listing 3.4. The variables heightMeters, mass, and BMI are declared as double for additional precision after multiplying by the conversion factors.

# LISTING 3.4 A Body Mass Index Calculation Program (part 1 of 2)

```
import java.util.Scanner;
public class BMI
{
    public static void main(String[] args)
        Scanner keyboard = new Scanner(System.in);
        int pounds, feet, inches;
        double heightMeters, mass, BMI;
        System.out.println("Enter your weight in pounds.");
        pounds = keyboard.nextInt();
        System.out.println("Enter your height in feet" +
           "followed by a space" +
           "then additional inches.");
        feet = keyboard.nextInt();
        inches = keyboard.nextInt();
        heightMeters = ((feet * 12) + inches) * 0.0254;
        mass = (pounds / 2.2);
        BMI = mass / (heightMeters * heightMeters);
        System.out.println("Your BMI is " + BMI);
        System.out.print("Your risk category is ");
        if (BMI < 18.5)
           System.out.println("Underweight.");
        else if (BMI < 25)
           System.out.println("Normal weight.");
        else if (BMI < 30)
           System.out.println("Overweight.");
        else System.out.println("Obese.");
}
```

(continued)

## LISTING 3.4 A Body Mass Index Calculation Program (part 2 of 2)

## Sample Screen Output

```
Enter your weight in pounds.

150
Enter your height in feet followed
by a space then additional inches.
5 5
Your BMI is 25.013498117367398
Your risk category is Overweight.
```

## **SELF-TEST QUESTIONS**

8. What output is produced by the following code?

```
int time = 2, tide = 3;
if (time + tide > 6)
    System.out.println("Time and tide wait for no one.");
else
    System.out.println("Time and tide wait for me.");
```

9. Suppose you change the code in the previous question so that the first line is the following:

```
int time = 4, tide = 3;
```

What output would be produced?

10. What output is produced by the following code?

```
int time = 2, tide = 3;
if (time + tide > 6)
    System.out.println("Time and tide wait for no one.");
else if (time + tide > 5)
    System.out.println("Time and tide wait for someone.");
else if (time + tide > 4)
    System.out.println("Time and tide wait for everyone.");
else
    System.out.println("Time and tide wait for me.");
```

11. Suppose number is a variable of type int that has been given a value. Write a multibranch if-else statement that displays the word High if number is greater than 10, Low if number is less than 5, and So-so if number is anything else.

## The Conditional Operator (Optional)

To allow compatibility with older programming styles, Java includes an operator that is a notational variant on certain forms of the if-else statement. For example, the statement

```
if (n1 > n2)
   max = n1;
else
   max = n2:
```

can be expressed as follows:

```
max = (n1 > n2) ? n1 : n2;
```

Together, the ? and : on the right side of this assignment statement are known as the conditional operator, or ternary operator. The conditional operator expression

```
(n1 > n2) ? n1 : n2;
```

starts with a boolean expression followed by a ? and then two expressions separated by a colon. If the boolean expression is true, the first of the two expressions is returned; otherwise, the second of the two expressions is returned.

As illustrated here, the most common use of the conditional operator is to set a variable to one of two different values, depending on a boolean condition. Be sure to note that a conditional expression always returns a value and so is equivalent to only certain special kinds of if-else statements.

Another example may help to illustrate the conditional operator. Suppose that an employee's weekly pay is the number of hours worked multiplied by the hourly wage. However, if the employee works more than 40 hours, the overtime is paid at 1.5 times the usual hourly rate. The following if-else statement performs this computation:

```
if (hoursWork <= 40)
   pay = hoursWorked * payRate;
else
   pay = 40 * payRate + 1.5 * payRate * (hoursWorked - 40);</pre>
```

This statement can be expressed by using the conditional operator, as follows:

```
pay = (hoursWorked <= 40) ? (hoursWorked * payRate) :
(40 * payRate + 1.5 * payRate * (hoursWorked - 40));</pre>
```

## The exit Method

Sometimes your program can encounter a situation that makes continuing execution pointless. In such cases, you can end your program by calling the exit method, as follows:

```
System.exit(0);
```

The preceding statement will end a Java program as soon as it is executed. For example, consider the following code:

```
if (numberOfWinners == 0)
{
    System.out.println("Error: Dividing by zero.");
    System.exit(0);
}
else
{
    oneShare = payoff / numberOfWinners;
    System.out.println("Each winner will receive $" + oneShare);
}
```

This code will normally display the share that each winner should receive. However, if the number of winners is zero, a division by zero would be an invalid operation. To avoid this division by zero, the program checks the number of winners and, if it is zero, calls the exit method to end execution.

System is a class in the Java Class Library that is automatically available to your programs without requiring an import statement; exit is a method in the class System. The number 0 given as the argument to System.exit is returned to the operating system. Most operating systems use 0 to indicate a normal termination of the program and 1 to indicate an abnormal termination of the program (just the opposite of what most people would guess). Thus, if your System.exit statement ends the program normally, the argument should be 0. In this case, *normal* means that the program did not violate any system or other important constraints. It does not mean that the program did what you wanted it to do. So you would almost always use 0 as the argument.

#### **RECAP The exit Method**

An invocation of the exit method ends the program. The normal form for an invocation to exit is

```
System.exit(0);
```

As mentioned in the previous chapter, any program that uses J0ptionPane to create dialog boxes must call this method to end its execution. Other programs typically do not call exit, doing so only in unusual situations.

## 3.2 THE TYPE boolean

He who would distinguish the true from the false must have an adequate idea of what is true and false.

```
-BENEDICT SPINOZA, Ethics
```

Truth is truth

To the end of reckoning.

-WILLIAM SHAKESPEARE, Measure for Measure

The type boolean is a primitive type, just like the types int, double, and char. As with these other types, you can have values of type boolean, constants of type boolean, variables of type boolean, and expressions of type boolean. However, the type boolean specifies only two values: true and false. You can use the two values true and false in a program, just as you use numeric constants, such as 2 and 3.45, and character constants, such as 'A'.

## **Boolean Variables**

Boolean variables can be used, among other things, to make your program easier to read. For example, a program might contain the following statement, where systemsAreOK is a boolean variable that is true if, in fact, the launch systems are ready to go:

```
if (systemsAreOK)
    System.out.println("Initiate launch sequence.");
else
    System.out.println("Abort launch sequence.");
```

If you do not use a boolean variable, the preceding code is likely to read something like the following:

```
if ((temperature <= 100) && (thrust >= 12000) &&
    (cabinPressure > 30))
    System.out.println("Initiate launch sequence.");
else
    System.out.println("Abort launch sequence.");
```

Clearly, the boolean variable systemsAreOK makes the first version easier for a human being to understand. Of course, your program needs to set the value of this variable in some way. As you will see, that is easy to do.

A boolean expression such as number > 0 evaluates to one of the two values true or false. For example, if number > 0 is true, the following statement displays The number is positive:

```
if (number > 0)
    System.out.println("The number is positive");
else
    System.out.println("The number is negative or zero");
```

If, on the other hand, number > 0 is false, the output is The number is negative or zero. The meaning of a boolean expression like number > 0 is a bit easier to understand within a context, such as an if-else statement. However, when programming with boolean variables, you need to think about a boolean expression more or less without a context. A boolean expression can

be evaluated and can produce a value of true or false without reference to any context such as an if-else statement.

A boolean variable can be given the value of a boolean expression by using an assignment statement, in the same way that you use an assignment statement to set the value of any other type of variable. For example, the following sets the value of the boolean variable isPositive to false:

You can use boolean variables in assignments

```
int number = -5;
boolean isPositive = (number > 0);
```

The parentheses are not needed, but they make the statement a bit easier to read. Once a boolean variable has a value, you can use the variable just as you would use any other boolean expression. For example,

```
boolean isPositive = (number > 0);
if (isPositive)
   System.out.println("The number is positive");
else
   System.out.println("The number is negative or zero");
```

is equivalent to our previous if-else statement.

Of course, this is just a toy example, but you might use something like it if the value of number, and therefore the value of the boolean expression, might change. Such is more likely to be the case in the context of a loop, which we will study in the next chapter.

More complicated boolean expressions can be used in the same way. For example, our opening example that checks whether we are ready for a launch would be preceded by a statement such as

```
boolean systemsAreOK = (temperature <= 100) &&
(thrust >= 12000) && (cabinPressure > 30)
```

```
FAQ Why can I write if (b)...instead of if (b == true)... when b is a boolean variable?
```

The boolean variable b is a boolean expression. So is the expression b == true. If b is true, both of these expressions are true. If b is false, both expressions are false. Thus, you can use these two expressions interchangeably.

## **Precedence Rules**

Java evaluates boolean expressions using the same strategy that it uses to evaluate arithmetic expressions. For example, if the integer variable score is 95 in the expression

```
(score >= 80) && (score < 90)
```

the first subexpression (score >= 80) is true, but the second subexpression (score < 90) is false. So the entire expression is equivalent to

```
true && false
```

As you saw earlier in this chapter, Java combines the values of true and false according to the rules given in Figure 3.7. So the preceding expression evaluates to false.

Just as when writing arithmetic expressions, it is usually best to use parentheses to indicate the order of operations within boolean expressions. However, if you omit parentheses, Java performs the operations in the order specified by the precedence rules shown in Figure 3.9. This figure is an augmented version of Figure 2.2 and shows all the operators you are likely to use for some time. As we mentioned in Chapter 2, operators listed higher on the list have a higher precedence. When the order of two operations is not dictated by parentheses, Java considers their precedence and performs the operation with the higher precedence before performing the other one. Some operators have equal precedence, in which case they are performed in order of appearance: Binary operators of equal precedence are performed in left-to-right order. Unary operators of equal precedence are performed in right-to-left order. Recall that a unary operator has only one operand—one thing that it applies to. A binary operator has two operands.

Let's consider an example. The following is written in rather poor style because it lacks parentheses, but the computer has no problem with it:

```
score < min / 2 - 10 || score > 90
```

## FIGURE 3.9 Operator Precedence

```
Highest Precedence

First: the unary operators +, -, ++, --, and!

Second: the binary arithmetic operators *, /, %

Third: the binary arithmetic operators +, -

Fourth: the boolean operators <, >, <=, >=

Fifth: the boolean operators ==, !=

Sixth: the boolean operator &

Seventh: the boolean operator |

Eighth: the boolean operator ||

Lowest Precedence
```

Of all the operators in the expression, the division operator has the highest precedence, and so the division is performed first. We indicate that fact by adding parentheses, as follows:

```
score <(min / 2) - 10 || score > 90
```

Of the remaining operators in the expression, the subtraction operator has the highest precedence, and so the subtraction is performed next:

```
score < (min / 2) - 10) | | score > 90
```

Of the remaining operators in the expression, the comparison operators > and < have the highest precedence and so are performed next. Because > and < have equal precedence, they are performed in left-to-right order:

```
(score < ((min / 2) - 10)) | | (score > 90)
```

Finally, the results of the two comparisons are combined with the operator ||, since it has the lowest precedence.

We have produced a parenthesized version of the expression by using the precedence rules. To the computer, this version and the original unparenthesized version are equivalent. You should include most parentheses in order to make your arithmetic and boolean expressions easier to understand. However, you can safely omit parentheses when the expression contains a simple sequence of &&s or of ||s. For example, the following is good style even though a few parentheses are omitted:

```
(temperature > 95) || (rainFall > 20) || (humidity >= 60)
```

You might conclude that the three comparisons in the previous expression occur first and then are combined with the operator ||. But the rules are a bit more complicated than what you have seen so far. Suppose that the value of temperature is 99. In this case we know that the entire boolean expression is true no matter what the values of rainFall and humidity are. We know this because true || true is true and so is true || false. So regardless of whether rainFall > 20 is true, the value of

```
(temperature > 95) \mid \mid (rainFall > 20)
```

is bound to be true. By a similar reasoning, we conclude that

```
true || (humidity >= 60)
```

is true regardless of whether humidity >= 60 is true.

Java evaluates the first subexpression, and if that is enough information to learn the value of the whole expression, it does not evaluate subsequent subexpressions. So in this example, Java never bothers to evaluate the subexpressions involving rainFall and humidity. This way of evaluating an expression is called **short-circuit evaluation**, or sometimes **lazy evaluation**, and is what Java does with expressions involving | | or &&.

Parentheses clarify operator precedence in a boolean expression

Java uses shortcircuit evaluation Now let's look at an expression containing &&. We'll give the boolean expression some context by placing it in an if-else statement:

```
if ( (assignmentsDone > 0) &&
    ((totalScore / assignmentsDone) > 60) )
    System.out.println("Good work.");
else
    System.out.println("Work harder.");
```

Suppose assignmentsDone has a value of zero. Then the first subexpression is false. Since both false && true and false && false are false, the entire boolean expression is false, regardless of whether the second expression is true or false. Therefore, Java does not bother to evaluate the second subexpression:

```
(totalScore / assignmentsDone) > 60
```

In this case, not evaluating the second subexpression makes a big difference, because the second subexpression includes a division by zero. If Java had tried to evaluate the second subexpression, it would have produced a run-time error. By using short-circuit evaluation, Java has prevented this error.

Java also allows you to ask for **complete evaluation**. In complete evaluation, when two expressions are joined by an *and* or an *or* operator, both subexpressions are *always evaluated*, and then the truth tables are used to obtain the value of the final expression. To obtain a complete evaluation in Java, you use & rather than && for *and* and use | in place of | | for *or*.

In most situations, short-circuit evaluation and complete evaluation give the same result, but as you have just seen, there are times when short-circuit evaluation can avoid a run-time error. There are also some situations in which complete evaluation is preferred, but we will not use those techniques in this book. We will always use && and | | and so will obtain short-circuit evaluation.

#### **REMEMBER Short-Circuit Evaluation**

For a boolean expression of the form  $Expr\_A \parallel Expr\_B$ , if  $Expr\_A$  is true, Java concludes that the entire expression is true without evaluating  $Expr\_B$ . Likewise, for an expression of the form  $Expr\_A \& Expr\_B$ , if  $Expr\_A$  is false, Java concludes that the entire expression is false without evaluating  $Expr\_B$ .

## Input and Output of Boolean Values

The values true and false of the type boolean can be read as input or written as output in the same way as values of the other primitive types, such as int and double. For example, consider the following fragment from a Java program:

Java also offers complete evaluation

```
boolean booleanVar = false;
System.out.println(booleanVar);
System.out.println("Enter a boolean value:");
Scanner keyboard = new Scanner(System.in);
booleanVar = keyboard.nextBoolean();
System.out.println("You entered " + booleanVar);
```

This code could produce the following interaction with the user:

```
false
Enter a boolean value:
true
You entered true
```

As you can see from this example, the class Scanner has a method named next Boolean that will read a single boolean value. For this input method, you may spell true and false using either uppercase or lowercase letters or a combination of both. In a Java program, the constants true or false must be spelled with all lowercase letters, but the input method nextBoolean is more forgiving.

## **SELF-TEST QUESTIONS**

12. What output is produced by the following statements?

```
int number = 7;
boolean isPositive = (number > 0);
if (number > 0);
   number = -100;
if (isPositive)
   System.out.println("Positive.");
else
   System.out.println("Not positive.");
   System.out.println(number);
```

13. What output is produced by the following statements?

```
System.out.println(false);
System.out.println(7 < 0);
System.out.println(7 > 0);
int n = 7;
System.out.println(n > 0);
```

14. What output is produced by the following statements?

```
System.out.println(true &&false);
System.out.println(true || false);
System.out.println(false && (x > 0));
System.out.println(true || (x > 0));
```

## 3.3 THE switch STATEMENT

Determine on some course, more than a wild exposure to each chance that starts i' the way before thee.

```
-WILLIAM SHAKESPEARE, Coriolanus (1609)
```

When a multiway if-else statement has many possible outcomes, it can be hard to read. If the choice is based on the value of an integer or character expression, the **switch statement** can make your code easier to understand.

The switch statement begins with the keyword switch followed by a **controlling expression** in parentheses:

```
switch (Controlling_Expression)
{
    . . .
}
```

The body of the statement is always enclosed in a pair of braces. Listing 3.5 shows a sample switch statement, whose controlling expression is the variable numberOfBabies. Within the braces is a list of cases, each case consisting of the keyword case followed by a constant—called a case label—then a colon, and then a list of statements, which are the actions for that case:

```
case Case_Label:
    List_of_Statements
```

When the switch statement is executed, the controlling expression—numberOfBabies in this example—is evaluated. The list of alternatives is then searched until a case label that matches the value of the controlling expression is found, and the action associated with that label is executed. You cannot have duplicate case labels, since that would produce an ambiguous situation.

Notice that the action for each case in Listing 3.5 ends with a **break statement**, which consists of the word break followed by a semicolon. When execution reaches a break statement, the switch statement's execution ends. If no break statement is found within the statements for a particular case, execution continues on with the next case until either a break statement is encountered or the end of the switch statement is reached.

Sometimes you want a case without a break statement. You cannot have multiple labels in one case, but you can list cases one after the other so they all produce the same action. For example, in Listing 3.5, both case 4 and case 5 produce the same case action, because case 4 has no break statement; in fact, case 4 has no action statements at all.

If no case matches the value of the controlling expression, the **default case**—which begins with the keyword default and a colon—is executed. However, the default case is optional. If you omit the default case and no match is found to any of the cases, no action is taken. Although the default case is optional, you are encouraged to always use it. If you think your cases cover all the possibilities without a default case, you can insert an error message as the default case. You never know when you might have missed some obscure case.

The switch statement offers a choice of actions according to the value of a controlling expression

A default case is optional but useful

## LISTING 3.5 A switch Statement (part 1 of 2)

```
import java.util.Scanner;
public class MultipleBirths
    public static void main(String[] args)
    {
        int numberOfBabies;
        System.out.print("Enter number of babies: ");
        Scanner keyboard = new Scanner(System.in);
        numberOfBabies = keyboard.nextInt();
        switch (numberOfBabies) 
Controlling expression
        {
                                           Case label
           case 1:
               System.out.println("Congratulations.");
               break;
           case 2:
               System.out.println("Wow. Twins.");
                                           break statement
           case 3:
               System.out.println("Wow. Triplets.");
           case 4:
                                           Case with no break
           case 5:
               System.out.print("Unbelievable; ");
               System.out.println(numberOfBabies +
                                  " babies.");
               break;
           default:
               System.out.println("I don't believe you.");
               break;
        }
    }
}
```

## Sample Screen Output 1

```
Enter number of babies: 1
Congratulations.
```

### Sample Screen Output 2

```
Enter number of babies: 3
Wow. Triplets.
```

(continued)

## LISTING 3.5 A switch Statement (part 2 of 2)

# Sample Screen Output 3 Enter number of babies: 4 Unbelievable; 4 babies.

# Sample Screen Output 4 Enter number of babies: 6 I don't believe you.

Here is another example of a switch statement, one that has a char variable as its controlling expression:

```
switch (eggGrade)
{
    case 'A':
    case 'a':
        System.out.println("Grade A");
        break;
    case 'C':
    case 'c':
        System.out.println("Grade C");
        break;
    default:
        System.out.println("We only buy grade A and grade C.");
        break;
}
```

In this example, grade A and grade C eggs can be indicated by either uppercase or lowercase letters. Other values of eggGrade are handled by the default case.

Note that the case labels need not be consecutive or even ordered. You can have 'A' and 'C' and no 'B', as in the preceding example. Similarly, in a switch statement with integer case labels, you could have integers 1 and 3, but no 2. Case labels must be discrete values; one label cannot indicate a range. If, for example, you wanted to take the same action for the values 1 through 4, you would need to write a case for each value. For a large range, an if-else statement would be more practical than a switch statement.

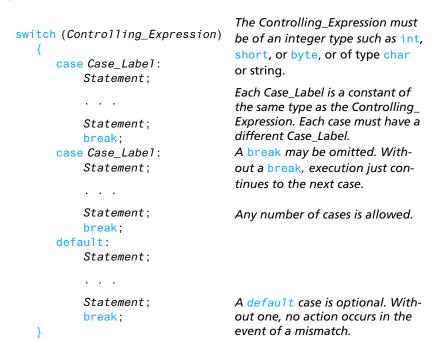
The controlling expression in a switch statement can be more complicated than a single variable; for example, it can involve arithmetic operators. Prior to Java Development Kit (JDK) version 7, the controlling expression had to evaluate to a value of an integer type, such as the type int, or to a value of

(continued)

type char. Starting with JDK version 7, a controlling expression of type String is allowed. The following example will run on JDK version 7 or higher but will cause a compilation error on previous versions. Note that we invoke a method that returns the variable answer in lowercase as the controlling expression.

# **RECAP** The switch Statement

#### **SYNTAX**





# **EXAMPLE**

```
int seatLocationCode;
switch (seatLocationCode)
   case 1:
      System.out.println("Orchestra.");
      price = 40.00;
      break;
   case 2:
      System.out.println("Mezzanine.");
      price = 30.00;
      break;
   case 3:
      System.out.println("Balcony.");
      price = 15.00;
      break:
   default:
      System.out.println("Unknown ticket code.");
      break:
}
```

# GOTCHA Omitting a break Statement

If you test a program that contains a switch statement and it executes two cases when you expect it to execute only one case, you probably have forgotten to include a break statement where one is needed.

# **GOTCHA** Omitting the Default Case

If the cases of a switch statement assign values to a variable, omitting a default case can cause a syntax error. The compiler might think that the variable has an undefined value after the switch executes. To avoid this error, either provide a default case or initialize the variable before the switch statement executes.

# **SELF-TEST QUESTIONS**

15. What output is produced by the following code?

```
int code = 2;
switch (code)
```

```
{
       case 1:
          System.out.println("Hello.");
       case 3:
          System.out.println("Good-bye.");
       default:
          System.out.println("Till we meet again.");
   }
16. Suppose you change the code in the previous question so that the first line
   is the following:
   int code = 1;
   What output would be produced?
17. What output is produced by the following code?
   char letter = 'B';
   switch (letter)
       case'A':
       case'a':
          System.out.println("Some kind of A.");
       case'B':
       case'b':
          System.out.println("Some kind of B.");
          break:
       default:
          System.out.println("Something else.");
          break:
   }
18. What output is produced by the following code?
   int key = 1;
   switch (key + 1)
   {
       case 1:
          System.out.println("Cake");
          break:
       case 2:
          System.out.println("Pie");
          break:
       case 3:
          System.out.println("Ice cream");
```

System.out.println("Cookies");

break:

}

```
default:
    System.out.println("Diet time");
```

19. Suppose you change the first line of the code in the previous question to

```
int key = 3;
```

What output would be produced?

20. Suppose you change the first line of the code in Self-Test Question 18 to

```
int key = 5;
```

What output would be produced?

# **Enumerations**

Imagine a reviewer who rates movies as either excellent, average, or bad. If you wrote a Java program to organize these reviews, you could represent the ratings as, for example, the integers 3, 2, and 1 or the characters E, A, and B. If you define a variable whose data type is either int or char to contain the rating, it might end up with a value other than one of the three valid ratings. Instead, to restrict the contents of the variable to certain values, you could declare it as an **enumerated data type**, or **enumeration**. An enumeration lists the values that a variable can have.

For example, the following statement defines MovieRating as an enumeration:

```
enum MovieRating {E, A, B}
```

Notice that no semicolon follows an enumeration's definition. Including one, however, will not cause a syntax error; the semicolon will simply be ignored. Also, notice that the values E, A, and B are not enclosed in single quotes, since they are not char values.

An enumeration acts as a class type, so we can use it to declare a variable rating, as follows:

```
MovieRating rating;
```

In the definition of MovieRating, the items listed between the braces are objects that we can assign to rating as values. For example, we could write

```
rating = MovieRating.A;
```

to assign A to rating. Note that we must preface the value A with the name of the enumeration and a dot. Assigning a value other than E, A, or B to rating will cause a syntax error.

Once we have assigned a value to a variable whose data type is an enumeration, we can use it within a switch statement to choose a course of

An enumeration provides a way to restrict the values of a variable

action. For example, the following statement displays a message based upon the value of rating:

```
switch (rating)
{
case E: //Excellent
    System.out.println("You must see this movie!");
    break;
case A: //Average
    System.out.println("This movie is OK, but not great.");
    break;
case B: //Bad
    System.out.println("Skip it!");
    break;
default:
    System.out.println("Something is wrong.");
}
```

Since the data type of the expression in the switch statement is an enumeration, the case labels are assumed to belong to that enumeration without writing its name. In fact, writing case MovieRating.E, for example, is a syntax error. However, if you need to reference one of the enumerated values elsewhere within the switch statement, you must precede it with the enumeration's name. Although we wrote a default case, it is unnecessary here, because we know that rating cannot have values other than those in the enumeration.

The values of an enumeration behave much like named constants. For this reason, we will use the same naming convention for them as we do for named constants, that is, all letters will be uppercase. The names need not be single letters. We could, for example, define our previous enumeration as

```
enum MovieRating {EXCELLENT, AVERAGE, BAD}
and then write an assignment like
  rating = MovieRating.AVERAGE;
or a case statement like
  case EXCELLENT:
```

An enumeration is actually a class. You typically define it within another class, but always outside of method definitions. We will talk more about enumerations as classes in Chapter 6.

# **3.4** GRAPHICS SUPPLEMENT

```
One picture in color is worth a thousand black-and-white pictures.
```

```
-VARIATION ON A CHINESE PROVERB
```

The oldest, shortest words—'yes' and 'no'—are those which require the most thought.

```
—PYTHAGORAS
```

In this section, we continue our discussion of drawing that we began in Chapter 1 and our discussion of JOptionPane that we began in Chapter 2. First, we tell you how to add color to your JavaFX drawings. In particular, we add color to our happy face application. Next, we show you how to use one more kind of dialog window, namely one for asking yes-or-no questions. We did not present this window in Chapter 2, because you need the branching mechanisms introduced in this chapter to use this kind of window effectively. If you skipped the previous material about JOptionPane, you can skip the description of this dialog window. None of the JOptionPane material in this chapter or in Chapter 2 is used in future chapters.

# **Specifying a Drawing Color**

The setColor method sets the color of the pen

When drawing shapes with methods such as strokeOval inside the definition of an applet's paint method, you can think of your drawing as being done with a pen that can change colors. The method setFill, which is in the class GraphicsContext, will change the color of your pen.

For example, the happy face that is drawn in Listing 3.6 is a yellow face with blue eyes and red lips. Aside from the color, the face is basically the same as the one shown in Listing 1.2, except that we have now added a nose. The code in Listing 3.6 is based on the code in Listing 2.9, which is simply a more stylistic version of the code in Listing 1.2.



# LISTING 3.6 Adding Color (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import iavafx.scene.Scene:
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.shape.ArcType;
import javafx.scene.paint.Color;
public class YellowFace extends Application
{
   public static final int WINDOW WIDTH = 400;
   public static final int WINDOW_HEIGHT = 300;
   public static final int FACE DIAMETER = 200;
   public static final int X_FACE = 100;
   public static final int Y_FACE = 50;
   public static final int EYE_WIDTH = 10;
   public static final int EYE HEIGHT = 20;
   public static final int X_RIGHT_EYE = 155;
```

(continued)

# LISTING 3.6 Adding Color (part 2 of 2)

```
public static final int Y_RIGHT_EYE = 100;
public static final int X_LEFT_EYE = 230;
public static final int Y_LEFT_EYE = Y_RIGHT_EYE;
public static final int NOSE_DIAMETER = 10;
public static final int X_NOSE = 195; // Center of nose at 200
public static final int Y_NOSE = 135;
public static final int MOUTH WIDTH = 100;
public static final int MOUTH_HEIGHT = 50;
public static final int X_MOUTH = 150;
public static final int Y_MOUTH = 160;
public static final int MOUTH_START_ANGLE = 180;
public static final int MOUTH_DEGREES_SHOWN = 180;
public static void main(String[] args)
  launch(args);
@Override
public void start(Stage primaryStage) throws Exception
  Group root = new Group();
  Scene scene = new Scene(root);
  Canvas canvas = new Canvas(WINDOW_WIDTH, WINDOW_HEIGHT);
  GraphicsContext gc = canvas.getGraphicsContext2D();
   // Draw face interior in yellow and outline in black
  gc.setFill(Color.YELLOW);
  gc.fillOval(X_FACE, Y_FACE, FACE_DIAMETER, FACE_DIAMETER);
  gc.setFill(Color.BLACK);
  gc.strokeOval(X_FACE, Y_FACE, FACE_DIAMETER, FACE_DIAMETER);
   // Draw eyes
  gc.setFill(Color.BLUE);
  gc.fillOval(X_RIGHT_EYE, Y_RIGHT_EYE, EYE_WIDTH, EYE_HEIGHT);
  gc.fillOval(X_LEFT_EYE, Y_LEFT_EYE, EYE_WIDTH, EYE_HEIGHT);
   // Draw nose
   gc.setFill(Color.BLACK);
  gc.filloval(X_NOSE, Y_NOSE, NOSE_DIAMETER, NOSE_DIAMETER);
   // Draw mouth
   gc.setFill(Color.RED);
   gc.strokeArc(X_MOUTH, Y_MOUTH, MOUTH_WIDTH, MOUTH_HEIGHT,
                MOUTH START ANGLE, MOUTH DEGREES SHOWN,
                ArcType.OPEN);
   root.getChildren().add(canvas);
   primaryStage.setTitle("HappyFace in JavaFX");
  primaryStage.setScene(scene);
  primaryStage.show();
}
```

Use of the method setFill in Listing 3.6 is routine. For example, the statement

```
gc.setFill(Color.YELLOW);
```

sets the color of the pen to yellow. So now the statement

```
gc.fillOval(X_FACE, Y_FACE, FACE_DIAMETER, FACE_DIAMETER);
```

draws a circle for the face that is filled in with yellow.

We need to emphasize one point. The order in which you draw the components of the face affects the final outcome. Note that the solid yellow circle is drawn first, so that the other drawings, such as the eyes, will be on top of the yellow. As when using an actual pen or brush, the drawings are done one on top of the other in the order of the code in the paint method. If we had instead drawn the yellow circle last, it would be on top of the eyes, nose, and mouth, and only the yellow circle would be visible. Unlike drawing with an actual pen, however, placing one color over another does not blend the two colors. The newest drawing hides—actually, replaces—any earlier drawing made in the same spot. You are simply setting the state and color of pixels, replacing their earlier values.

Certain colors are already defined for you as public named constants in the class Color which you import from javafx.scene.paint.Color; these are given in Figure 3.10. You can define other colors as well, but we will not go into that here.

FIGURE 3.10 Some Predefined Colors for the setFill Method

```
Color.BLACK
Color.BLUE
Color.CYAN
Color.DARKGRAY
Color.GRAY
Color.GREEN
Color.LIGHTGRAY

Color.YELLOW
```

# **RECAP The setFill Method**

When you draw using an object of the class GraphicsContext, you can set the color of the drawing by invoking the method setFill. You can later change the color by invoking setFill again, so a single drawing can have multiple colors.

# **EXAMPLE**

```
gc.setFill(Color.RED);
```

The order in which you draw affects the outcome

# SELF-TEST QUESTIONS

21. Suppose you change the order of the drawing commands in Listing 3.6 to the following. Will the gc.setFill picture change? If so, how will it change?

```
//Draw mouth:
gc.setFill(Color.RED);
gc.strokeArc(X_MOUTH, Y_MOUTH, MOUTH_WIDTH,
    MOUTH_HEIGHT, MOUTH_START_ANGLE,
    MOUTH_EXTENT_ANGLE), ArcType.OPEN;
//Draw face interior and outline:
gc.setFill(Color.YELLOW);
gc.fillOval(X_FACE, Y_FACE,
    FACE_DIAMETER, FACE_DIAMETER);
gc.setFill(Color.BLACK);
gc.stroke0val(X_FACE, Y_FACE,
    FACE_DIAMETER, FACE_DIAMETER);
//Draw eyes:
gc.setFill(Color.BLUE);
gc.fillOval(X_RIGHT_EYE, Y_RIGHT_EYE,
    EYE_WIDTH, EYE_HEIGHT);
gc.fill0val(X_LEFT_EYE, Y_LEFT_EYE,
    EYE_WIDTH, EYE_HEIGHT);
//Draw nose:
gc.setFill(Color.BLACK);
gc.fillOval(X_NOSE, Y_NOSE,
    NOSE_DIAMETER, NOSE_DIAMETER);
```

22. Repeat the previous question, but use the following changes instead:

```
//Draw face interior:
gc.setFill(Color.YELLOW);
gc.fillOval(X_FACE, Y_FACE,
    FACE_DIAMETER, FACE_DIAMETER);
//Draw mouth:
gc.setFill(Color.RED);
gc.strokeArc(X_MOUTH, Y_MOUTH, MOUTH_WIDTH,
   MOUTH_HEIGHT, MOUTH_START_ANGLE,
   MOUTH_EXTENT_ANGLE, ArcType.OPEN);
//Draw face outline:
gc.setFill(Color.BLACK);
gc.stroke0val(X_FACE, Y_FACE,
    FACE_DIAMETER, FACE_DIAMETER);
//Draw nose:
gc.setFill(Color.BLACK);
gc.fillOval(X_NOSE, Y_NOSE,
   NOSE_DIAMETER, NOSE_DIAMETER);
```

# A Dialog Box for a Yes-or-No Question

Chapter 2 showed how to use the class JOptionPane to produce two kinds of windows called dialogs. One kind asked the user to enter input data that the program could read. The other kind of dialog displayed a message to the user. JOptionPane provides yet another dialog box for asking yes-or-no questions of the user. The dialog has a title and contains the question you specify along with two buttons labeled Yes and No. For example, the code

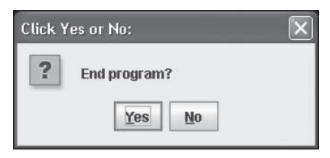
produces the dialog box shown in Figure 3.11.

Let's describe the list of arguments for the method showConfirmDialog by considering the argument list in our example:

```
(null, "End program?", "Click Yes or No:",
JOptionPane.YES_NO_OPTION)
```

The first argument has to do with where the dialog is placed on the screen, but we have not developed enough material to allow us to consider the possible options. So we will simply write null as the first argument, which gives us the default placement. We will explain the actual meaning of null in Chapter 6.

FIGURE 3.11 A Yes-or-No Dialog Box



The second argument is a string that appears in the dialog containing the Yes and No buttons. Of course, the string should normally be a yes-or-no question. In our example, this argument is "End program?".

The third argument is a string displayed as the title of the dialog. In our example, this argument is "Click Yes or No:".

The last argument, JOptionPane.YES\_NO\_OPTION, indicates that we want a dialog containing Yes and No buttons. Other options are possible, but we will not discuss them here.

If the user clicks the Yes button, the method showConfirmDialog will return the int value JOptionPane.YES\_OPTION and the window will disappear. In our example, the multibranch if-else statement will then invoke System.exit(0) to end the program. If the user clicks the No button, the method showConfirmDialog will return the intvalue JOptionPane.NO\_OPTION, and then the multibranch if-else statement will invoke System.out.println to display One more time.

The class JOptionPane defines several named constants, including the int constants YES\_NO\_OPTION, YES\_OPTION, and NO\_OPTION that we have used here. Note that to use these constants, you must precede each of their names with the name of the class and a dot. What int values are actually named by these constants? It does not matter. Think of the value that showConfirmDialog returns as the answer to a yes-or-no question.

The code that we used in our example appears in the file JOptionPaneYesNo-Demo.java, which is available on the Web along with the other source code for this book.

Java code on the book's Web site

# **RECAP** Dialog Boxes for Yes-or-No Questions

The class JOptionPane in the package javax.swing defines the method show-ConfirmDialog. You can use this method to create a dialog box to ask a yes-or-no question and get the user's response.

#### **SYNTAX**

```
Integer_Response = JOptionPane.showConfirmDialog(null,
Question_String, Title_String, Option);
```

The displayed dialog box is titled *Title\_String* and contains the text *Question\_String* and buttons as indicated by *Option*. When *Option* is JOptionPane.YES\_NO\_OPTION, two buttons labeled Yes and No are displayed. The method returns the int constant YES\_OPTION if the user clicks the Yes button, or NO\_OPTION if the user clicks the No button.

#### **EXAMPLE**

```
int answer = JOptionPane.showConfirmDialog(null, "Done?",
    "Click a Button:", JOptionPane.YES_NO_OPTION);
```



# **SELF-TEST QUESTION**

23. Write code for a JOptionPane dialog that will ask whether the user is at least 18 years of age. Then set the boolean variable adult equal to either true, if the user is at least 18, or false otherwise. Include the declaration of the variable adult.

# **CHAPTER SUMMARY**

- A branching statement chooses and then performs one of a number of actions. The if-else statement and switch statement are branching statements.
- A boolean expression combines variables and comparison operators such as < to produce a value that is either true or false.
- An if-else statement tests the value of a boolean expression and takes one of two actions according to whether the value is true or false.
- You can omit the else part to get an if statement that takes an action if a boolean expression is true but takes no action if the expression is false.
- A compound statement is a sequence of Java statements, all enclosed in a pair of braces.
- You can nest if-else statements. Either or both of the if part and the else part can have another if-else statement as its action. Using braces to form compound statements can clarify your intent. Without braces, remember that each else is paired with the nearest preceding and unpaired if.
- A special form of nested if-else statements forms a multibranch structure. In this form, you typically write the next if part immediately after an else. Thus, you write if, else if, else if,..., else. Although a final else is not mandatory, it usually is a good idea to include it.
- Boolean expressions can be combined with the logical operators &&, ||, and!to form a larger expression. Java uses short-circuit evaluation in these cases.
- Calling the exit method ends a program's execution. Although you must call exit to end a program that uses JOptionPane, you typically do not call it under ordinary circumstances.
- The value of a boolean expression can be stored in a variable of type boolean. This variable is itself a boolean expression, and so it can then be used to control an if-else statement. That is, a boolean variable can be used anyplace that a boolean expression is allowed.
- The switch statement provides another multibranch decision structure. It tests the value of an integer, character, or string expression and executes a case according to that value. Providing a default case is usually a good idea.

- You can define an enumeration to provide a data type whose values are like named constants.
- You can add color to a JavaFX drawing by using the application method setFill and the colors defined as named constants within the class Color.
- JOptionPane enables you to use a dialog box for yes-or-no questions.

# **Exercises**

- 1. Write a fragment of code that will test whether a double variable rate contains a valid rate of interest. Valid rates of interest are in the range 5.25% to 7.50%.
- 2. Write a fragment of code that will check whether the year entered is a leap year or not. If it is not, then display the number of years until the next leap year.
- 3. Suppose you are writing a program that asks the user to give a yes-or-no response. Assume that the program reads the user's response into the String variable response.
  - a. If response is yes or y, set the boolean variable accept to true; otherwise, set it to false.
  - b. How would you change the code so that it will also accept Yes and Y?
- 4. Consider the following fragment of code:

```
if (n >= 0.4)
    System.out.println("Large");
else if (n < 0.5)
    System.out.println("Small");
else
    System.out.println("What");</pre>
```

What is displayed if n is

- ,

b. 0.4?

a. 0.7?

- c. 0.5?
- d. 1.3?
- e. 0.2? f. 0.11?
- 5. Consider the following fragment of code:

```
if (n >= 0.4)
{
    System.out.println("Large");
    if (n < 0.5)
     System.out.println("Small");
}
else
    System.out.println("What");</pre>
```

What is displayed if n is

- a. 0.7? b. 0.4?
- c. 0.5?
- d. 1.3?
  - e. 0.2?
- f. 0.11?

- 6. We would like to assess a service charge for car parking. The service charge depends on the duration for which a car is parked. If the parking time is less than or equal to 1 hour, we will charge \$2. If the parking time is greater than 1 hour but less than 2 hours, we will charge twice the amount. If the parking time is greater than 2 hours but less than 6 hours, we will charge \$2 times the number of hours. If the parking time is more than 6 hours but less than 24 hours, we will charge \$20. Use a multibranch if-else statement in a fragment of code to compute the service charge.
- 7. What is the value of each of the following boolean expressions if a is 12, b is 7, and c is 28?

```
a. (a > (c - b) / 3)
b. (2 * b < a + 2 && 2 * a < c - 2)
c. !(a % 2 < 1) || !(c - a < 2 * b)
d. (c / b < (a + 2) / b || c != a + 2 * b && 3 * b == c)
```

8. The following code fragment will not compile. Why?

```
if {b+c > !a}
    c = b / a;
else
    c = b % 2;
```

- 9. Consider the boolean expression ((10 > 7) && (z >= 50)). Why is this expression probably not what the programmer intended?
- 10. Consider the boolean expression  $((z > 5) \mid | (z < 6))$ . Why is this expression probably not what the programmer intended?
- 11. Write a switch statement to convert a letter grade into an equivalent numeric value on a four-point scale. Set the value of the variable gradeValue to 4.0 for an A, 3.0 for a B, 2.0 for a C, 1.0 for a D, and 0.0 for an F. For any other letter, set the value to 0.0 and display an error message.
- 12. Consider the previous question, but include + or letter grades. A+ is 4.25, A– is 3.75, B+ is 3.25, B– is 2.75, and so on.
  - a. Why can't we use one switch statement with no other conditionals to convert these additional letter grades?
  - b. Write a fragment of code that will do the conversion using a multibranch if-else statement.
  - c. Write a fragment of code that will do the conversion using nested switch statements.
- 13. Imagine a program that displays a menu of five possible choices, lettered *a* through *e*. Suppose the user's selection is read into the character variable choice. Write a switch statement that reacts to this choice by displaying a message that indicates the choice. Display an error message if the user makes an invalid choice.

- 14. Repeat the previous exercise, but define an enumeration and use it within the switch statement.
- 15. Repeat Exercise 13, but use a multibranch if-else statement instead of a switch statement.
- 16. Given that the int variable temp contains a temperature that is not negative, write a Java statement that uses the conditional operator to set the String variable label to either "degree" or "degrees". We want to use label to produce grammatically correct output, such as 0 degrees, 1 degree, 2 degrees, and so on. If you have not studied the conditional operator, use an if-else statement instead.
- 17. Write Java statements that create an "OK" dialog box in response to the message, "The error is found and corrected!"

# PRACTICE PROGRAMS

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

- 1. If a number *x* is multiplied by the number 0, the result is zero. Write a program that tests whether the result is zero if one number is multiplied by 0. Read the number from the keyboard.
- 2. Write a program to read in three nonnegative integers from the keyboard. Display the integers in increasing order.
- 3. Write a program that reads three strings from the keyboard. Although the strings are in no particular order, display the string that would be second if they were arranged lexicographically.
- 4. Write a program that reads a one-line sentence as input and then displays the following response: If the sentence ends with a question mark (?) and the input contains an even number of characters, display the word Yes. If the sentence ends with a question mark and the input contains an odd number of characters, display the word No. If the sentence ends with an exclamation point (!), display the word Wow. In all other cases, display the words You always say followed by the input string enclosed in quotes. Your output should all be on one line. Be sure to note that in the last case, your output must include quotation marks around the echoed input string. In all other cases, there are no quotes in the output. Your program does not have to check the input to see that the user has entered a legitimate sentence.
- 5. Write a program that allows the user to convert a temperature given in degrees from either Celsius to Fahrenheit or Fahrenheit to Celsius. Use the following formulas:

```
Degrees\_C = 5(Degrees\_F - 32)/9

Degrees\_F = (9(Degrees\_C)/5) + 32)
```





Prompt the user to enter a temperature and either a C or c for Celsius or an F or f for Fahrenheit. Convert the temperature to Fahrenheit if Celsius is entered, or to Celsius if Fahrenheit is entered. Display the result in a readable format. If anything other than C, c, F, or f is entered, print an error message and stop.

6. Write a program that inputs a double value. If the double value is greater than 150.45 or between 60.30 and 70.25 (inclusive), then output YES. Otherwise, output NO. Your program should use an if-else statement along with && (and) and || (or) relational operators.

Examples of numbers that would result in an output of YES: 151, 60.5, 65.35, 65, 69, 68, 250

Examples of numbers that would result in an output of NO: 49, 76, 100, 80, 10, 135, 0

7. The following formula gives a rough estimate of your blood alcohol content (BAC) and is derived from formulas posted by the National Highway Traffic Safety Administration:

```
BAC = (4.136 x numDrinks x ouncesAlcohol) / (weight)
numDrinks is the number of drinks ingested.
ouncesAlcohol is the number of ounces of alcohol per drink
weight is the weight of the drinker in pounds
```

Note that this formula gives only a rough estimate and doesn't include your metabolism, time spent drinking, gender differences, etc. Write a program that calculates the blood alcohol content of someone drinking Jagerbombs. Assume that there are 0.55 ounces of alcohol in one Jagerbomb. Pick values of your own choosing for the number of drinks and the weight. Also output whether or not the person would be legally intoxicated in your state.

# **PROGRAMMING PROJECTS**

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

- 1. Repeat Programming Project 5 of Chapter 2, but include input checking. Display the change only if a valid price is entered (no less than 25 cents, no more than 100 cents, and an integer multiple of 5 cents). Otherwise, display separate error messages for any of the following invalid inputs: a cost under 25 cents, a cost that is not an integer multiple of 5, and a cost that is more than a dollar.
- 2. Repeat any of the previous Practice Programs using JOptionPane, which is described in the graphics supplement at the end of Chapter 2.

**Graphics** 

- 3. Suppose that we are working for an online service that provides a bulletin board for its users. We would like to give our users the option of filtering out profanity. Suppose that we consider the words *cat*, *dog*, and *llama* to be profane. Write a program that reads a string from the keyboard and tests whether the string contains one of our profane words. Your program should find words like *cAt* that differ only in case. *Option*: As an extra challenge, have your program reject only lines that contain a profane word exactly. For example, *Dogmatic concatenation is a small category* should not be considered profane.
- 4. Write a program that reads a string from the keyboard and tests whether it contains a valid date. Display the date and a message that indicates whether it is valid. If it is not valid, also display a message explaining why it is not valid.

The input date will have the format  $mm/dd/\gamma\gamma\gamma\gamma$ . A valid month value mm must be from 1 to 12 (January is 1). The day value dd must be from 1 to a value that is appropriate for the given month. September, April, June, and November each have 30 days. February has 28 days except for leap years when it has 29. The remaining months all have 31 days each. A leap year is any year that is divisible by 4 but not divisible by 100 unless it is also divisible by 400.

- 5. Repeat the calorie-counting program described in Programming Project 8 from Chapter 2. This time ask the user to input the string "M" if the user is a man and "W" if the user is a woman. Use only the male formula to calculate calories if "M" is entered and use only the female formula to calculate calories if "W" is entered. Output the number of chocolate bars to consume as before.
- 6. Repeat Programming Project 5 but in addition ask the user if he or she is
  - a. Sedentary
  - b. Somewhat active (exercise occasionally)
  - c. Active (exercise 3-4 days per week)
  - d. Highly active (exercise every day)

If the user answers "Sedentary," then increase the calculated BMR by 20 percent. If the user answers "Somewhat active," then increase the calculated BMR by 30 percent. If the user answers "Active," then increase the calculated BMR by 40 percent. Finally, if the user answers "Highly active," then increase the calculated BMR by 50 percent. Output the number of chocolate bars based on the new BMR value.

7. Repeat Programming Project 11 in Chapter 2, but if the displacement is positive then output that "The (material name) will expand by" the displacement in meters. If the displacement is negative then output that "The (material name) will contract by" the displacement in meters. You shouldn't output the displacement as a negative number.

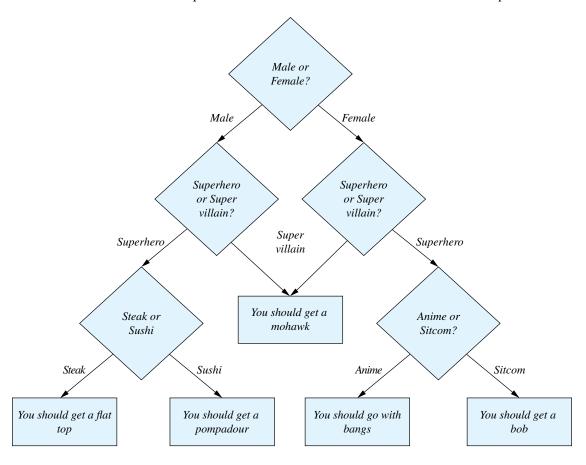
8. Write a program to play the rock-paper-scissor game. Each of two users types in either P, R, or S. The program then announces the winner as well as the basis for determining the winner: paper covers rock, rock breaks scissors, scissors cuts paper, or nobody wins. Your program should allow the users to use lowercase as well as uppercase letters.

Graphics

9. Write a JavaFX application to draw the five interlocking rings that are the symbol of the Olympics. The color of the rings, from left to right, is blue, yellow, black, green, and red.

Graphics

- 10. Repeat Programming Project 8 in Chapter 1, but add yes-or-no dialogs to allow the user to make the following color changes:
  - Change the color of the solid center circle from black to red.
  - Change the color of the outer circle from black to blue.
  - Change the color of the spines from black to green.
- 11. The following flowchart contains a series of questions to determine what kind of haircut to get. Write a program that asks the questions to the user and outputs the recommended haircut based on the user's input.



12. Write a program that inputs two strings that represents a time of day using the format HH:MM:SS AM or PM and then outputs the time elapsed from the first to the second time in minutes and seconds.

For example, given the strings:

```
11:58:10 PM
12:02:15 AM
```

The program should output that the time elapsed is 4 minutes and 5 seconds.

# **Answers to Self-Test Questions**

```
1. if (goals > 10)
     System.out.println("Wow");
  else
     System.out.println("Oh Well");
2. if ((goals > 10) \&\& (errors == 0))
         System.out.println("Wow");
  else
         System.out.println("Oh Well");
3. if (salary >= deductions)
  {
     System.out.println("OK");
     net = salary - deductions;
  }
  else
  {
     System.out.println("No Way");
  It is also acceptable to omit the braces in the else part.
4. if ((speed > 25) && (visibility < 20))
  {
      speed = 25;
     System.out.println("Caution");
5. if ((salary >= MIN_SALARY) || (bonus >= MIN_BONUS))
     System.out.println("OK");
  else
     System.out.println("Too low");
6. String upperWord = nextWord.toUpperCase();
  if(upperWord.compareTo("N") < 0)</pre>
     System.out.println("First half of the alphabet");
  else
     System.out.println("Second half of the alphabet");
```

- 7. If they are of type int, you use x1 == x2. If they are of type String, you use x1.equals(x2).
- 8. Time and tide wait for me.
- 9. Time and tide wait for no one.
- 10. Time and tide wait for everyone.

12. Positive –100

13. The output produced is

false false true true

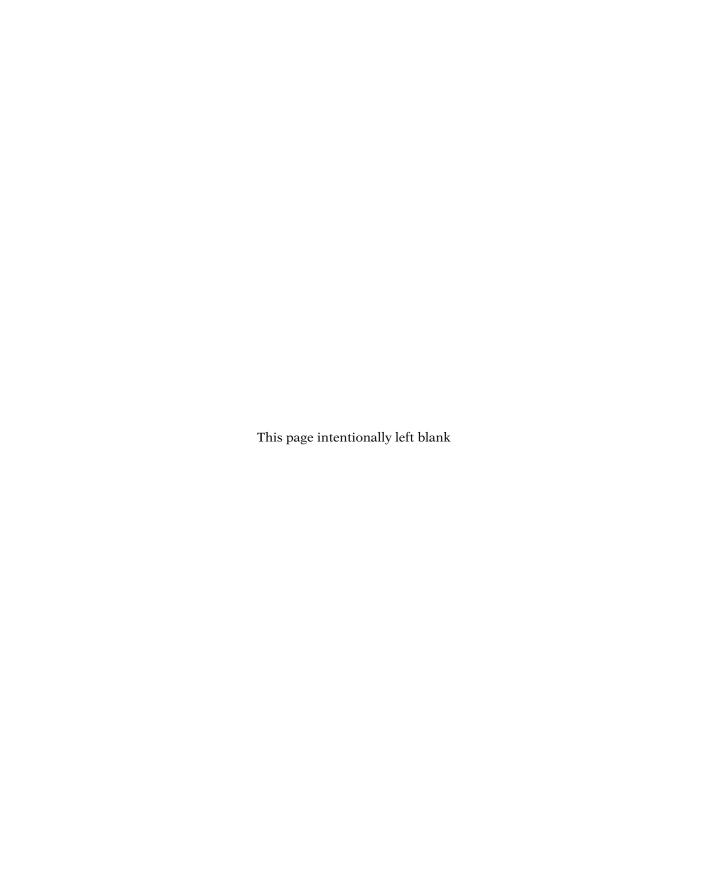
14. The output produced is

false true false true

Because of short-circuit evaluation, you do not need to know the value of  $\boldsymbol{x}$ .

- 15. Till we meet again.
- 16. Hello Good-bye
- 17. Some kind of B.
- 18. Pie
- 19. Cookies
- 20. Diet time
- 21. The mouth will not be visible because it will be covered by the filled yellow circle. The rest of the face will be the same as that drawn by Listing 3.6.
- 22. The face drawn will be exactly the same as that drawn by Listing 3.6.
- 23. You are not required to give a complete program, but we have embedded the answer in a complete program.

```
import javax.swing.JOptionPane;
public class Question23
  public static void main(String[] args)
      boolean adult = false;
      //Initialized to keep the compiler happy.
      int answer = JOptionPane.showConfirmDialog(null,
         "Are you at least 18 years old?",
         "Age Check", JOptionPane.YES_NO_OPTION);
      if (answer == JOptionPane.YES_OPTION)
         adult = true;
      else if (answer == JOptionPane.NO_OPTION)
         adult = false;
      else
         System.out.println("Error");
      if (adult)
         {\sf JOptionPane.showMessageDialog}
                     (null, "You are old enough.");
      else
         JOptionPane.showMessageDialog(null,
                     "Sorry. you must be 18.");
         System.exit(0);
   }
}
```



# Flow of Control: Loops 4

#### 4.1 JAVA LOOP STATEMENTS 238

The while Statement 239
The do-while Statement 242
Programming Example: Bug Infestation 247
Programming Example: Nested Loops 253
The for Statement 255
Declaring Variables Within a for Statement 261
Using a Comma in a for Statement (Optional) 262
The for-each Statement 264

# 4.2 PROGRAMMING WITH LOOPS 264

The Loop Body 265 Initializing Statements 266 Controlling the Number of Loop Iterations 267

Case Study: Using a Boolean Variable to End a
Loop 269

Programming Example: Spending Spree 271

The break Statement and continue Statement in
Loops (Optional) 274

Loop Bugs 277

Tracing Variables 279

Assertion Checks 281

#### 4.3 GRAPHICS SUPPLEMENT 283

Programming Example: A Multiface JavaFX
Application 283
Drawing Text 288



#### One more time

—COUNT BASIE, recording of "April in Paris"

# Play it again, Sam

—Reputed, incorrectly, to be in the movie Casablanca, which does contain similar phrases, such as "Play it, Sam."

We now continue our discussion of flow of control that we began in the previous chapter. Although Java statements that choose among two or more paths through the logic of a program are extremely important, the real power of a computer is its ability to repeat a group of instructions numerous times. Java provides statements that enable us to make use of this ability.

# **OBJECTIVES**

After studying this chapter, you should be able to

- Design a loop
- Use the Java statements while, do, and for in a program
- Use the for-each statement with enumerations
- Use assertion checks in a program
- Use repetition in a graphics program
- Use the method drawString to display text in a graphics program

# **PREREQUISITES**

The examples in this chapter use the if-else statement, the switch statement, and enumerations, all of which were presented in Chapter 3.

# **4.1** JAVA LOOP STATEMENTS

Each thing is of like form from everlasting and comes round again in its cycle.

—MARCUS AURELIUS, BARTLETT'S FAMILIAR QUOTATIONS (1919)

Programs often need to repeat some action. For example, a grading program would contain branching statements that assign a letter grade to a student on the basis of the student's scores on assignments and exams. To assign grades to the entire class, the program would repeat this action for each student in the class. A portion of a program that repeats a statement or group of statements is called a **loop**. The statement or group of statements to be repeated in a loop is called the **body** of the loop. Each repetition of the loop body is called an **iteration** of the loop.

A loop repeats a group of statements

When you design a loop, you need to determine what action the body of the loop will take. In addition, you need a mechanism for deciding when the repetition of the loop body should stop. Java has several loop statements that provide this mechanism. We examine these statements in this chapter. Java has several statements for controlling loops

# The while Statement

One way to construct a loop in Java is by using a while statement, also known as a while loop. A while statement repeats its action again and again as long as a controlling boolean expression is true. That is why it is called a while loop; the loop is repeated while the controlling boolean expression is true. When the expression is false, the repetition ends. For example, Listing 4.1 contains a toy example of a while statement. The statement starts with the keyword while followed by a boolean expression in parentheses. That is the controlling boolean expression. The loop's body is repeated while that controlling boolean expression is true. Often, the body is a compound statement enclosed in braces {}. The loop's body normally contains an action that can change the value of the controlling boolean expression from true to false and so end the loop. Let's step through the execution of the while loop in Listing 4.1.

step through the execution of the while loop in Listing 4.1.

Consider the first sample run for the while statement in Listing 4.1.

The user enters a 2, and so 2 becomes the value of the variable number. The controlling boolean expression is

```
count <= number
```

Since count is 1 and number is 2, this boolean expression is true, so the loop body, shown here, is executed:

```
{
    System.out.print(count + ", ");
    count++;
}
```

The loop body displays the value of count, which is 1, on the screen and then increases the value of count by 1 so it becomes 2.

After one iteration of the loop body, the controlling boolean expression is checked again. Since count is 2 and number is 2, the boolean expression is still true. So the loop body executes one more time. It again displays the value of count, which is 2, on the screen and again increases the value of count by 1 so it becomes 3.

After the second iteration of the loop body, the controlling boolean expression is checked again. The value of count is now 3 and the value of number is still 2, and so the controlling boolean expression count <= number is now false. As a result, when this expression is checked again, the while loop ends and the program goes on to execute the two System.out.println statements that follow the while loop. The first of these two statements ends the line of numbers displayed by the while loop, and the second one displays Buckle my shoe. Figure 4.1 summarizes the action of this loop.

A while loop repeats its body while a boolean expression is true

# LISTING 4.1 A while Loop

```
import java.util.Scanner;
public class WhileDemo
    public static void main(String[] args)
        int count, number;
        System.out.println("Enter a number");
        Scanner keyboard = new Scanner(System.in);
        number = keyboard.nextInt();
        count = 1;
        while (count <= number)</pre>
        {
            System.out.print(count + ", ");
            count++;
        }
        System.out.println();
        System.out.println("Buckle my shoe.");
    }
}
```

# Sample Screen Output 1

```
Enter a number:
2
1, 2,
Buckle my shoe.
```

# Sample Screen Output 2

```
Enter a number:

3
1, 2, 3,
Buckle my shoe.
```

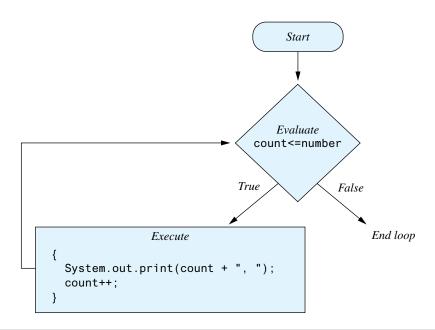
# Sample Screen Output 3

```
Enter a number:

The loop body is iterated zero times.
```

# FIGURE 4.1 The Action of the while Loop in Listing 4.1

```
while (count <= number)
{
    System.out.print(count + ", ");
    count++;
}</pre>
```



# **RECAP The while Statement**

#### **SYNTAX**

```
while (Boolean_Expression)
    Body
```

The *Body* may be either a simple statement or, more likely, a compound statement consisting of a list of statements enclosed in braces {}.

# **EXAMPLE**

# //Sum positive integers read until one is not positive int total = 0; int next = keyboard.nextInt(); while (next > 0) { total = total + next; next = keyboard.nextInt(); }

The body of a while loop often is a compound statement

All while statements are formed in a way similar to the sample shown in Listing 4.1. The body can be a simple statement, but it is more likely to be a compound statement, as in Listing 4.1. So the most common form of a while loop is

```
while (Boolean_Expression)
{
    First_Statement
    Second_Statement
    . . .
    Last_Statement
}
```

The semantics, or meaning, of a while loop is summarized in Figure 4.2. This semantics assumes that no break statement is in the body of the loop. We discuss the possible use of the break statement within loops later in this chapter.

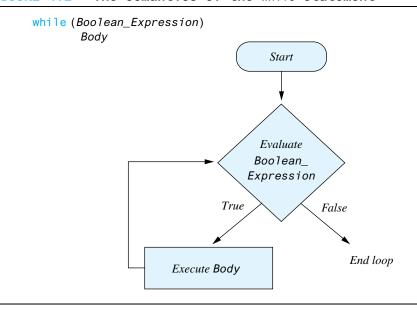
# PROGRAMMING TIP A while Loop Can Perform Zero Iterations

The body of a while loop can be executed zero times. When a while loop executes, the controlling boolean expression is immediately checked. If that boolean expression is false, the loop body is not executed, not even one time. This may seem strange. After all, why write a loop if the body is never executed? The answer is that you may want a loop whose body is executed zero times or more than zero times, depending on input from the user. Perhaps the loop adds up the sum of all your bills for the day. If you have no bills, you do not want the loop body to be executed at all. Sample Screen Output 3 in Listing 4.1 shows a toy example of a while loop that iterates its loop body zero times.

#### The do-while Statement

The do-while **statement**, or do-while **loop**, is very similar to the while statement. The main difference is that the body of a do-while loop is always executed at least once. As you will recall, the body of a while loop might not be executed at all.

FIGURE 4.2 The Semantics of the while Statement



When a do-while loop is executed, the loop body executes first. After that, a do-while loop behaves in exactly the same way as a while loop. The boolean expression is checked. If the boolean expression is true, the loop body executes one more time. This is done again and again as long as the boolean expression is true. If the boolean expression is false, the loop ends.

A do-while loop also repeats its body while a boolean expression is true

The syntax for a do-while statement is as follows:

```
do
Body
while (Boolean_Expression); ← Note the semicolon!
```

The *Body* can be a simple statement, but it is more likely to be a compound statement. So the most common form of a do-while loop is

The body of a do-while loop often is a compound statement

```
do
{
    First_Statement
    Second_Statement
    . . .
    Last_Statement
} while (Boolean_Expression);
```

Notice the semicolon after the closing parenthesis that follows the *Boolean\_Expression*. Also note that although we place the ending brace } and the while on the same line, some programmers prefer to place them on different lines. Either form is fine, but be consistent.

A do-while loop repeats its body at least once

Listing 4.2 contains a sample do-while loop that is similar to the while loop in Listing 4.1 but produces different output. Note in Sample Screen Output 3 that the loop body is executed even though the boolean expression starts out false. Again, the body of a do-while loop always executes at least once. Figure 4.3 summarizes the action of this loop.

# LISTING 4.2 A do-while Loop

```
import java.util.Scanner;
public class DoWhileDemo
{
    public static void main(String[] args)
    {
        int count, number;
        System.out.println("Enter a number");
        Scanner keyboard = new Scanner(System.in);
        number = keyboard.nextInt();
        count = 1;
        do
           System.out.print(count + ", ");
           count++;
        } while (count <= number);</pre>
        System.out.println();
        System.out.println("Buckle my shoe.");
    }
}
```

# Sample Screen Output 1

```
Enter a number:

2
1, 2,
Buckle my shoe.
```

# Sample Screen Output 2

```
Enter a number:
3
1, 2, 3,
Buckle my shoe.
```

# Sample Screen Output 3

```
Enter a number:

O

1, 
Buckle my shoe.

The loop body always executes at least once.
```

# FIGURE 4.3 The Action of the do-while Loop in Listing 4.2

```
System.out.print(count + ", ");
count++;
} while (count <= number);

Execute
{
    System.out.print(count + ", ");
    count++;
}

Evaluate
count<=number

True
False

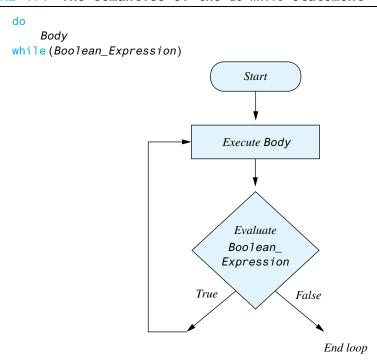
End loop</pre>
```

The do-while loop in Listing 4.2 can be rewritten as an equivalent while loop, as follows:

```
{
    System.out.print(count + ", ");
    count++;
}
while (count <= number)
{
    System.out.print(count + ", ");
    count++;
}</pre>
```

Although we do not recommend rewriting your do-while loops in this way, this example helps illustrate the difference between these two types of loop

FIGURE 4.4 The Semantics of the do-while Statement



statements. With a do-while loop, the loop body always executes at least once; with a while loop, the loop body may execute zero times.

The semantics of a do-while loop is shown in Figure 4.4. Like the semantics of the while loop shown in Figure 4.2, this semantics assumes that the body of the loop contains no break statement.

# **RECAP The** do-while **Statement**

# **SYNTAX**

do

Body
while (Boolean\_Expression);

The *Body* may be either a simple statement or, more likely, a compound statement consisting of a list of statements enclosed in braces {}. The *Body* is always executed at least once. Be sure to notice the semicolon at the end of the entire statement.

(continued)

#### **EXAMPLE**

```
//Get the next positive integer entered as input data
int next;
do
    next = keyboard.nextInt();//keyboard is a Scanner object
while (next <= 0);

EXAMPLE

//Sum the positive integers read until one is not positive
int total = 0;
int next = 0;
do
{
    total = total + next;
    next = keyboard.nextInt();
} while (next > 0);
```

# PROGRAMMING EXAMPLE

**Bug Infestation** 

This example involves real bugs, not programming bugs! Your hometown has been hit with an infestation of roaches. This is not the most pleasant topic, but fortunately a local company called Debugging Experts Inc. has a treatment that can eliminate roaches from a house. As the saying goes, "It's a dirty job, but somebody has to do it." The only problem is that the town's citizens are too complacent and might not exterminate the roaches before they get out of hand. So the company has installed a computer at the local shopping mall to let people know how bad the problem could be at their particular house. The program in this computer calculates the number of weeks that a population of roaches takes to completely fill a house from floor to ceiling.

The roach population grows relatively slowly—for roaches—but that is still pretty bad. Left unchecked, the population of roaches will almost double every week. If the population did double every week, the growth rate would be 100 percent per week, but fortunately it is only 95 percent per week. These roaches are also rather big. Expressed in terms of volume, their average size is 0.002 cubic foot, which is just a bit smaller than 0.3 cubic inch. The program does make some simplifying assumptions. It assumes that the house has no furniture and that the roaches fill the house with no space between them. The real situation would, of course, be far more complicated than the one portrayed by this program.

Let's think of the steps necessary to solve this problem. A first draft of an algorithm might look like this:

# Algorithm for roach population program (rough draft)

Basic steps of our algorithm

- 1. Get volume of house.
- 2. Get initial number of roaches in house.
- 3. Compute number of weeks until the house is full of roaches.
- 4. Display results.

Since we know the growth rate of the roach population and their average size, we won't read these values but rather will define them as constants in the program.

Our algorithm seems simple enough, but let's not rush to call in the programmers. What about step 3? It's the heart of the solution but gives no hint as to how to perform the calculation. Let's think some more. We need to compute a number of weeks, so let's use a counter that begins at zero to count them. Since we know the volume of the average roach and the initial number of roaches, we can compute their total volume simply by multiplying these two values. This gives the volume of the roach population at week 0. Are we done? We are if the roaches have already filled the house! If they haven't, we now must add in the volume of the new roaches hatched during the first week. Once again we ask whether we are done. If not, we add in the volume of the new roaches hatched during the second week, and so on. Ahh! We need a loop.

What kind of loop should we use? In some situations, we might not be able to decide just yet, and that would be all right. But for this problem we have already observed that the initial infestation might fill the house. If that were the case, we would not need to calculate anything. That is, we would not want the body of our proposed loop to execute. Thus, we should use a while loop, not a do-while loop. But let's see how we might proceed if we hadn't already reached this conclusion.

Regardless of whether we know what loop to use, let's choose some constants and variables, as follows:

Begin a list of constants and variables

GROWTH\_RATE—weekly growth rate of the roach population (a constant 0.95)

ONE\_BUG\_VOLUME—volume of an average roach (a constant 0.002)

houseVolume—volume of the house

startPopulation—initial number of roaches

countWeeks—week counter

population—current number of roaches

totalBugVolume—total volume of all the roaches

newBugs—number of roaches hatched this week

newBugVolume—volume of new roaches

You might not think of the variables you need all at once. As you refine your pseudocode, you can add other variables to the list as they come to mind. Maintaining a separate list of variables and their meanings can be an invaluable resource while designing and writing a program.

# PROGRAMMING TIP Take Notes

Before you write your first Java statement, take time to design your program. Write pseudocode, draw pictures, and make a list of proposed variables and their meanings. That is, organize your thoughts and commit them to paper. Your resulting Java program is likely to be better organized and more correct than one that you begin to code too soon.

We can now replace step 3 of our algorithm with the following steps:

```
3a. countWeeks = 0
3b. Repeat until house is full of bugs

{
         newBugs = population * GROWTH_RATE
         newBugVolume = newBugs * ONE_BUG_VOLUME
         population = population + newBugs
         totalBugVolume = totalBugVolume + newBugVolume
         countWeeks = countWeeks + 1
}
```

Step 3: Compute number of weeks until the house is full of roaches

Looking at step 3b, we note that Java does not have a *repeat until* construct. We can reword *Repeat until house* is full of bugs as *Repeat while house* is not full of bugs, or *Repeat while volume of bugs* is less than volume of house. Thus, we use the construct

```
while (totalBugVolume < houseVolume)</pre>
```

Assembling the pieces gives us the following algorithm:

# Algorithm for roach population program

```
1. Read houseVolume
2. Read startPopulation
3. population = startPopulation
4. totalBugVolume = population * ONE_BUG_VOLUME
5. countWeeks = 0
6. while (totalBugVolume < houseVolume)
{
    newBugs = population * GROWTH_RATE
    newBugVolume = newBugs * ONE_BUG_VOLUME
    population = population + newBugs
    totalBugVolume = totalBugVolume + newBugVolume
    countWeeks = countWeeks + 1
}</pre>
```

We use a while loop in case the house is already full of bugs

Display startPopulation, houseVolume, countWeeks, population, and totalBugVolume

Our loop simply updates the population of the roaches, the volume of roaches, and the week counter. Because the growth rate and the volume of one

bug are both positive numbers, we know that the value of population, and hence the value of totalBugVolume, will increase with each loop iteration. So eventually, the value of totalBugVolume will exceed the value of houseVolume, and the controlling boolean expression

```
totalBugVolume < houseVolume
```

will become false and end the while loop.

The variable countWeeks starts out as zero and is increased by 1 on each loop iteration. Thus, when the loop ends, the value of countWeeks is the total number of weeks it takes for the volume of roaches to exceed the volume of the house.

Listing 4.3 shows our Java program and sample output.

# LISTING 4.3 Roach Population Program (part 1 of 2)

```
import java.util.Scanner;
Program to calculate how long it will take a population of
roaches to completely fill a house from floor to ceiling.
public class BugTrouble
{
   public static final double GROWTH_RATE = 0.95;
                                                           //95% per week
   public static final double ONE BUG VOLUME = 0.002; //cubic feet
   public static void main(String[] args)
    {
        System.out.println("Enter the total volume of your house");
        System.out.print("in cubic feet: ");
        Scanner keyboard = new Scanner(System.in);
        double houseVolume = keyboard.nextDouble();
        System.out.println("Enter the estimated number of");
        System.out.print("roaches in your house: ");
        int startPopulation = keyboard.nextInt();
        int countWeeks = 0:
        double population = startPopulation;
        double totalBugVolume = population * ONE_BUG_VOLUME;
        double newBugs, newBugVolume;
        while (totalBugVolume < houseVolume)</pre>
        {
            newBugs = population * GROWTH_RATE;
            newBugVolume = newBugs * ONE_BUG_VOLUME;
            population = population + newBugs;
            totalBugVolume = totalBugVolume + newBugVolume;
            countWeeks++;
        }
```

(continued)

#### LISTING 4.3 Roach Population Program (part 2 of 2)

```
System.out.println("Starting with a roach population of " +
                                startPopulation);
            System.out.println("and a house with a volume of " + houseVolume +
                                " cubic feet,");
            System.out.println("after " + countWeeks + " weeks,");
            System.out.println("the house will be filled with " +
(int) is a
                                (int)population + " roaches.");
type cast as
            System.out.println("They will fill a volume of " +
discussed in
                                (int)totalBugVolume + " cubic feet.");
Chapter 2.
            System.out.println("Better call Debugging Experts Inc.");
    }
}
```

#### Sample Screen Output

```
Enter the total volume of your house in cubic feet: 20000
Enter the estimated number of roaches in your house: 100
Starting with a roach population of 100 and a house with a volume of 20000.0 cubic feet, after 18 weeks, the house will be filled with 16619693 roaches.
They will fill a volume of 33239 cubic feet.
Better call Debugging Experts Inc.
```

#### **GOTCHA** Infinite Loops

A common program bug is a loop that does not end, but simply repeats its loop body again and again forever. (Well, conceptually forever.) A loop that iterates its body repeatedly without ever ending is called an **infinite loop**. Normally, some statement in the body of a while loop or do-while loop will change one or more variables so that the controlling boolean expression becomes false. However, if the variable or variables do not change in the right way, you could get an infinite loop.

An infinite loop executes repeatedly due to an error in logic

For example, let's consider a slight variation of the program in Listing 4.3. Suppose your town is hit by an infestation of roach-eating frogs. These frogs eat roaches so quickly that the roach population actually decreases. As a result, the roaches have a negative growth rate. To reflect this fact, you could change the definition of one named constant to the following and recompile the program:

```
public static final double GROWTH_RATE = -0.05;
//-5% per week
```

If you make this change and run the program, the while loop will be an infinite loop, provided the house starts out with a relatively small number of roaches. Because the total number of roaches, and so the volume of roaches, continually *decreases*, the controlling boolean expression, totalBugVolume < houseVolume, is always true. Therefore, the loop never ends.

Some infinite loops will not really run forever but will instead end your program when some system resource is exhausted. However, some infinite loops will run forever if left alone. To be able to end a program containing an infinite loop, you should learn how to force a program to stop running. The way to do this depends on your operating system. On many systems—but not all—you can stop program execution by typing control-C, which you do by holding down the control (Ctrl) key while pressing the C key.

Sometimes a programmer might intentionally write an infinite loop. For example, an ATM machine would typically be controlled by a program's infinite loop that handles deposits and withdrawals indefinitely. However, at this point in your programming, an infinite loop is likely to be an error.

Learn how to force a program to stop running

#### **SELF-TEST QUESTIONS**

1. What output is produced by the following code?

```
int count = 0;
while (count < 5)
{
    System.out.println(count);
    count++;
}
System.out.println("count after loop = " + count);</pre>
```

- 2. Can the body of a while loop execute zero times? Can the body of a do-while loop execute zero times?
- 3. What output is produced by the following code?

```
int count = 0;
do
{
    System.out.println(count);
    count++;
}
while (count < 0);
System.out.println("count after loop = " + count);</pre>
```

4. Revise the following code so that it uses a while loop instead of a do-while loop:

```
Scanner keyboard = new Scanner(System.in);
int number;
do
{
    System.out.println("Enter a whole number:");
    number = keyboard.nextInt();
    System.out.println("You entered " + number);
} while (number > 0);
System.out.println("number after loop = " + number);
```

5. What output is produced by the following code?

```
int count = 0;
while (count < 5)
{
    System.out.println(count);
    count--;
}
System.out.println("count after loop = " + count);</pre>
```

6. Imagine a program that reads the population of a city using the following statements:

```
System.out.print("Enter the population of the city: ");
int population = keyboard.nextInt( );
```

Write a while loop after these statements that ensures that population is positive. If the user enters a population that is either negative or zero, ask the user to enter a nonnegative value.

#### PROGRAMMING EXAMPLE

**Nested Loops** 

The body of a loop can contain any sort of statements. In particular, you can have a loop statement within the body of a larger loop statement. For example, the program in Listing 4.4 uses a while loop to compute the average of a list of nonnegative scores. The program asks the user to enter all the scores followed by a negative sentinel value to mark the end of the data. This while loop is placed inside a do-while loop so that the user can repeat the entire process for another exam, and another, until the user wishes to end the program.

The body of one loop can contain another loop

#### LISTING 4.4 Nested Loops (part 1 of 2)

```
import java.util.Scanner;
/ * *
Computes the average of a list of (nonnegative) exam scores.
Repeats computation for more exams until the user says to stop.
*/
public class ExamAverager
   public static void main(String[] args)
    {
        System.out.println("This program computes the average of");
        System.out.println("a list of (nonnegative) exam scores.");
        double sum:
        int numberOfStudents;
        double next:
        String answer;
        Scanner keyboard = new Scanner(System.in);
        do
        {
            System.out.println();
            System.out.println("Enter all the scores to be averaged.");
            System.out.println("Enter a negative number after");
            System.out.println("you have entered all the scores.");
            sum = 0:
            numberOfStudents = 0;
            next = keyboard.nextDouble();
            while (next >= 0)
            {
               sum = sum + next;
               numberOfStudents++;
               next = keyboard.nextDouble();
            }
            if (numberOfStudents > 0)
                System.out.println("The average is " +
                                    (sum / numberOfStudents));
            else
                System.out.println("No scores to average.");
            System.out.println("Want to average another exam?");
            System.out.println("Enter yes or no.");
            answer = keyboard.next();
        } while (answer.equalsIgnoreCase("yes"));
   }
}
```

#### Sample Screen Output

```
This program computes the average of
a list of (nonnegative) exam scores.
Enter all the scores to be averaged.
Enter a negative number after
you have entered all the scores.
100
90
100
90
-1
The average is 95.0
Want to average another exam?
Enter yes or no.
yes
Enter all the scores to be averaged.
Enter a negative number after
you have entered all the scores. 90
70
80
-1
The average is 80.0
Want to average another exam?
Enter yes or no.
```



#### The for Statement

The **for statement**, or **for loop**, enables you to easily write a loop that is controlled by some sort of counter. For example, the following pseudocode defines a loop that iterates three times and is controlled by the counter count:

Do the following for each value of count from 1 to 3: Display count

This particular pseudocode can be expressed in Java as the following for statement:

```
for (count = 1; count <= 3; count++)
   System.out.println(count);</pre>
```

This for statement causes the output

1

2

After the for statement ends, any statement after the loop body executes. In this first example of a for statement, the loop body is

```
System.out.println(count);
```

The iteration of the loop body is controlled by the line

```
for (count = 1; count <= 3; count++)</pre>
```

The first of the three expressions in parentheses, count = 1, tells what happens before the loop body is executed for the first time. The third expression, count++, is executed after each iteration of the loop body. The middle expression, count <= 3, is a boolean expression that determines when the loop will end, and it does so in the same way as the controlling boolean expression in a while loop. Thus, the loop body is executed while the value of count is less than or equal to 3. To rephrase what we just said, the for statement

```
for (count = 1; count <= 3; count++)
    Body

is equivalent to
    count = 1;
    while (count <= 3)
    {
        Body
        count++;
    }</pre>
```

The syntax of a for statement is as follows:

A for statement groups the major aspects of a loop

```
for (Initializing_Action; Boolean_Expression; Update_Action)
    Body
```

The *Body* can be a simple statement, as in our first example, but it more likely is a compound statement. Thus, the more common form of a for loop can be described as follows:

When it is executed, a for statement is equivalent to code involving a while loop. So a for statement of the preceding form is equivalent to the following:

A for loop is logically equivalent to a while loop

```
Initializing_Action;
while (Boolean_Expression)
{
    Statements
    . . .
    Update_Action;
}
```

Since a for statement is basically another notation for a kind of while loop, a for statement—just like a while statement—might not repeat its loop body at all.

Listing 4.5 provides an example of a for statement. Its action is summarized in Figure 4.5. Figure 4.6 describes the semantics of a for loop in general.

#### LISTING 4.5 An Example of a for Statement

#### Screen Output

```
and counting.

and counting.

and counting.

and counting.

and counting.

Blast off!
```

FIGURE 4.5 The Action of the for Loop in Listing 4.5

```
for (countDown = 3; countDown >= 0; countDown-)
    System.out.println(countDown);
    System.out.println("and counting.");
}
                                                Start
                                               Execute
                                          countDown = 3;
                                               Evaluate
                                             count >= 0
                                         True
                                                        False
                                                            End loop
                         Execute
         System.out.println(countDown);
         System.out.println("and counting.");
                          Execute
                      countDown--;
```

# RECAP The for Statement SYNTAX for (Initializing\_Action; Boolean\_Expression; Update\_Action) Body (continued)

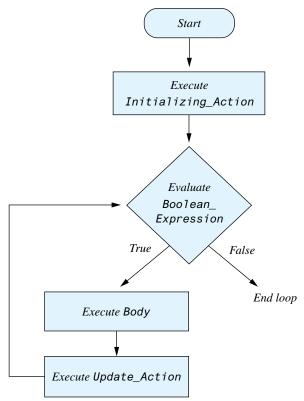
The *Body* may be either a simple statement or, more likely, a compound statement consisting of a list of statements enclosed in braces {}. Notice that the three items in parentheses are separated by two, not three, semicolons.

#### **EXAMPLE**

```
for (next = 0; next <= 10; next = next + 2)
{
    sum = sum + next;
    System.out.println("sum now is " + sum);
}</pre>
```

#### FIGURE 4.6 The Semantics of the for Statement

for(Initializing\_Action; Boolean\_Expression; Update\_Action)
 Body



#### **GOTCHA** Extra Semicolon in a Loop Statement

The following code looks quite ordinary. Moreover, it will compile and run with no error messages. It does, however, contain a mistake. See if you can find the mistake before reading on.

If you include this code in a program and run the program, the output will be

```
Product of the numbers 1 through 10 is 11
```

Now can you see what is wrong? Try to explain the problem before reading on. If you were testing the program that produced this puzzling output, it could leave you bewildered. Clearly, something is wrong with the for loop, but what? The for loop is supposed to set the value of product equal to

```
1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9 \times 10
```

but instead, it sets the value of product equal to 11. How could that happen? The problem is typographically very small. The for statement has an extra semicolon at the end of the first line:

Do not write a semicolon after the beginning of a for statement

```
for (number = 1; number <= 10; number++) (;
{
    product = product * number;
}</pre>
```

What does this for statement do? The semicolon at the end means that the body of the for statement is empty. A semicolon by itself is considered a statement that does nothing. It is called the **empty statement** or the **null statement**. This for statement with the extra semicolon is equivalent to

```
for (number = 1; number <= 10; number++)
{
     //Do nothing.
}
{
    product = product * number;
}</pre>
```

Thus, the body of the for statement is in fact executed ten times; however, each time it executes, the loop does nothing but increment the variable number by 1. That leaves number equal to 11 when the program reaches the statement

```
product = product * number;
```

(Remember, number starts out equal to 1 and is increased by 1 ten times, so the value becomes 11.) With product still 1 and number equal to 11, the assignment statement sets the value of product to 1 times 11, or 11, as the output says. To fix the problem, simply remove the extra semicolon at the end of the line that begins with for.

The same sort of problem can occur with a while loop. The following while loop has the same problem as our troublesome for loop, but the results are even worse:

Do not write a semicolon after the beginning of a while statement

The extra semicolon ends the while loop, and so the body of the while loop is the empty statement. Because the body of the loop is the empty statement, nothing happens on each loop iteration. Therefore, the value of number never changes, and the condition

```
number <= 10
```

is always true. So the loop is an infinite loop that does nothing and does it forever!

### **Declaring Variables Within a for Statement**

You can declare a variable within the initialization part of a for statement, as in the following example:

```
int sum = 0;
for (int n = 1; n <= 10; n++)
    sum = sum + n * n;</pre>
```

In this case, the variable n is **local** to the for loop, meaning that it cannot be used outside of the loop. For example, you would not be able to display n in a println statement after the loop completes:

```
for (int n = 1; n <= 10; n++)
    sum = sum + n * n;
System.out.println(n); //Invalid</pre>
```

The portion of a program in which a variable has meaning is known as the variable's **scope**. In the previous example, the scope of the variable n is the for statement, including its body. Thus, n has no meaning beyond the for statement.

A variable's scope is where it has meaning in a program When a variable exists solely to control a for loop, you should declare it within the initialization portion instead of before the loop. If we had taken this advice in the example given in the previous Gotcha, we would have written the code as follows:

```
int product = 1;
for (int number = 1; number <= 10; number++);
    product = product * number; //Invalid</pre>
```

Since number is now local to the for loop, and because the stray semicolon ends the loop, number is not defined after the loop. We would get a syntax error.

We will talk more about variable declarations and scope in the next chapter.

#### Using a Comma in a for Statement (Optional)

A for loop can perform more than one initialization. To use a list of initialization actions, simply separate the actions with commas, as in the following example:

```
for (n = 1, product = 1; n <= 10; n++)
    product = product * n;</pre>
```

This for loop initializes n to 1 and also initializes product to 1. Note that we use a comma, not a semicolon, to separate the initialization actions. Such a comma is called the **comma operator**.

Likewise, you can have multiple update actions by separating them with commas. This practice can sometimes result in a for statement that has an empty body but still does something useful. For example, the previous for statement can be rewritten as follows:

```
for (n = 1, product = 1; n \le 10; product = product * n, n++);
```

In effect, we have made the loop body part of the update action. However, your code will be more readable if you use the update action only for the variables that control the loop, as in the previous version of this for loop. We do not advocate using for loops with no body, but many programmers consider them "clever." As indicated in the previous Gotcha section, often a for loop without a body is the result of a programmer error.

You cannot have multiple boolean expressions to test for ending a for loop. However, you can string together multiple tests using the && or || operators to form one larger boolean expression.

Note that the comma operator can be used only in for statements. Be careful if you have programmed in other programming languages that allow a comma operator to be used elsewhere.

A comma can separate multiple initializations in a for statement

## **SELF-TEST QUESTIONS**

7. What output is produced by the following code?

```
for (int n = 1; n <= 4; n++)
    System.out.println(n);</pre>
```

8. What output is produced by the following code?

9. What output is produced by the following code?

```
for (int n = 4; n > 0; n--)
    System.out.println(n);
```

10. What output is produced by the following code?

```
for (int n = 4; n > 0; n--);
    System.out.println(n);
```

(This is not the same as the previous question. Look carefully.)

11. What output is produced by the following code?

```
for (double test = 0; test < 3; test = test + 0.5)
    System.out.println(test);</pre>
```

- 12. Write a for statement that displays the even numbers 2, 4, 6, 8, and 10. Each number should appear on a separate line. Declare all the variables you use.
- 13. What output is produced by the following code?

```
for (int count = 0; count <= 3; count++)
  for (int count2 = 0; count2 < count; count2++)
      System.out.println(count2);</pre>
```

#### ■ PROGRAMMING TIP Choosing a Loop Statement

Suppose that your program needs a loop. How do you decide whether to use a while statement, a do-while statement, or a for statement? We can give you some general guidelines. You *cannot* use a do-while statement unless you are certain that, for all possible inputs to your program, the loop should be iterated at least one time. If you know that your loop should always be iterated at least one time, a do-while statement is likely to be a good choice. However,



more often than you might think, a loop requires the possibility of iterating the body zero times. In those cases, you must use either a while statement or a for statement. If your computation changes some numeric quantity—such as a counter—by an equal amount on each iteration, consider a for statement. If the for statement does not seem clear, use a while statement. The while statement is always a safe choice, because you can use it to realize any sort of loop. This is not to say that you should use while loops exclusively; sometimes one of the other alternatives is clearer or easier to write. Many programmers use for statements to clarify the logic of their code.

#### The for-each Statement

A for-each statement iterates for each item in a data collection When you want to restrict the value of a variable to a handful of values, you can define an enumeration, as you saw in the previous chapter. If you need to repeat some action for each item in an enumeration, you can use any of the loop statements that we have presented. But Java also provides another form of the for statement for use when you have a collection of data such as an enumeration. This form is called the **for-each statement**.

For example, in a program that plays a card game, you could define an enumeration for the four suits—clubs, diamonds, hearts, and spades—as follows:

```
enum Suit {CLUBS, DIAMONDS, HEARTS, SPADES}
```

To display these suits, you can write the following for-each loop:

```
for (Suit nextSuit : Suit.values())
    System.out.print(nextSuit + " ");
System.out.println();
```

The expression Suit.values() represents all the values in the enumeration. The variable nextSuit takes on each of these values one at a time as the iteration progresses. Thus, the output from this loop is

```
CLUBS DIAMONDS HEARTS SPADES
```

Chapters 7 and 12 will show you how to use the for-each statement for data collections other than enumerations.

#### **4.2** PROGRAMMING WITH LOOPS

The cautious seldom err.

```
—CONFUCIUS
```

A loop typically involves three elements: the initializing statements that must precede any repetition, the loop body, and the mechanism for ending the loop. In this section we give you techniques for designing each of these loop components. Although the initializing statements come before the loop body, the loop body is naturally designed first, and so we will start our discussion there.

#### The Loop Body

One way to design a loop body is to write out the sequence of actions that you want your code to accomplish. For example, you might write the following actions:

Write down a sequence of actions when designing a loop

- 1. Display instructions to the user.
- 2. Initialize variables.
- 3. Read a number into the variable next.
- 4. sum = sum + next
- 5. Display the number and the sum so far.
- 6. Read another number into the variable next.
- 7. sum = sum + next
- 8. Display the number and the sum so far.
- 9. Read another number into the variable next.
- 10. sum = sum + next
- 11. Display the number and the sum so far.
- 12. Read another number into the variable next.
- 13. and so forth.

Now look for a repeated pattern in the list of actions. In this case, the repeated pattern is

```
Read another number into the variable next.

sum = sum + next

Display the number and the sum so far.
```

So the body of the loop, expressed in pseudocode, can be the preceding three actions. The entire pseudocode can be

- 1. Display instructions to the user.
- 2. Initialize variables.
- 3. Repeat the following for the appropriate number of times:

```
{
    Read a number into the variable next.
    sum = sum + next
    Display the number and the sum so far.
}
```

Note that the pattern need not start with the first action in the pseudocode. Some actions might need to occur before or after the loop is executed.

#### **Initializing Statements**

A loop depends on correct initial values Consider the pseudocode we designed in the previous section. Notice that the variable sum is expected to have a value every time the instruction

```
sum = sum + next
```

is executed within the loop body. In particular, sum must have a value the first time the loop is iterated. So sum must be initialized to a value before the loop starts. When trying to decide on the correct initializing value for a variable, consider what you want to happen after one loop iteration. For our current loop, the value of sum should be set to the first value of next after one loop iteration. The only way that sum + next can evaluate to next is if sum is zero. This means that the value of sum must be initialized to zero. Thus, one of the initializations must be

```
sum = 0
```

The only other variable used in the loop is next. The first statement performed that involves next is

Read a number into the variable next.

This statement gives next a value, so next does not need to have a value before the loop is started. Thus, the only variable that needs to be initialized is sum. We can rewrite the pseudocode as follows:

- 1. Display instructions to the user.
- 2. sum = 0
- 3. Repeat the following for the appropriate number of times:

```
{
    Read a number into the variable next.
    sum = sum + next
    Display the number and the sum so far.
}
```

Variables are not always initialized to zero. To see this, consider another example. Suppose your loop computes the product of n numbers as follows:

```
for (int count = 1; count <= n; count++)
{
    Read a number into the variable next.
    product = product * next;
}</pre>
```

In this case, let's say that all variables are of type int. If you initialize the variable product to 0, no matter how many numbers are read in and multiplied, the value of product will still be 0. So 0 clearly is not the correct

initialization value for product. The correct initializing value for product is 1. To see that 1 is the correct initial value, notice that the first time through the loop, you want product to be set equal to the first number read in. Initializing product to 1 will make this happen. Thus, the loop, and its correct initialization statement, is

```
int product = 1;
for (int count = 1; count <= n; count++)
{
    Read a number into the variable next.
    product = product * next;
}</pre>
```

#### **Controlling the Number of Loop Iterations**

We now will discuss some standard techniques for ending a loop. If you are lucky, you will be able to specify exactly how many times the loop body must be repeated before the loop starts. For example, suppose that we want to know the average score on a given exam in a course. We need the number of students in the class, so we read that number into the integer variable numberOfStudents. In this simple case, we can use a for loop to repeat the loop body numberOfStudents times. The following will do nicely:

```
double next, average, sum = 0;
for (int count = 1; count <= numberOfStudents; count++)
{
    next = keyboard.nextDouble();
    sum = sum + next;
}
if (numberOfStudents > 0)
    average = sum/numberOfStudents;
else
    System.out.println("No scores to average.");
```

Notice that the for loop mechanism controls the repetition of the loop body by using the variable count to count from 1 to numberOfStudents. Loops such as this one that know the number of loop iterations before the loop starts are called **count-controlled loops**. In this particular example, count is not used within the loop body, but in other situations, a counter might be. Count-controlled loops do not need to be implemented as for loops, but that is the easiest way to do so. Notice that if no students are in the class, the loop body is iterated zero times and the if-else statement prevents a division by zero.

Knowing the number of loop iterations ahead of time is not always possible. One straightforward way of ending a loop is simply to ask the user if it is time to end the loop. This technique is called **ask before iterating**. For

A counter can control a loop's repetition

A loop's repetition can be controlled by asking the user whether to continue

90

example, the following code helps a customer figure the cost of purchasing multiples of several items:

```
do
{
    System.out.println("Enter price $");
    price = keyboard.nextDouble();
    System.out.print("Enter number purchased:");
    number = keyboard.nextInt();
    System.out.println(number + " items at $" + price);
    System.out.println("Total cost $" + price * number);
    System.out.println("Want to make another purchase?");
    System.out.println("Enter yes or no.");
    answer = keyboard.next();
} while (answer.equalsIgnoreCase("yes"));
```

If you know that each user will make at least one purchase, this do-while loop will work fine. In other situations, a while loop would be best.

This code works well if each customer makes only a few purchases. The technique becomes tedious for the user, however, if the total number of loop iterations is not fairly small. For lengthy input lists, you can sometimes use a **sentinel value** to signal the end of the input. A sentinel value must be different from all possible actual data values. For example, suppose you want some code to compute the highest and lowest scores on an exam. If you know that at least one person completed the exam, and no one is ever given a negative score, you can ask the user to enter a negative number after entering the last score. The negative number is the sentinel value, not one of the exam scores. It is just an end marker.

The code for computing the highest and lowest scores could be as follows:

```
System.out.println("Enter scores for all students.");
   System.out.println("Enter a negative number after");
   System.out.println("you have entered all the scores.");
   Scanner keyboard = new Scanner(System.in);
   double max = keyboard.nextDouble();
   double min = max; //The max and min so far are the first score.
   double next = keyboard.nextDouble();
   while (next >= 0)
         if (next > max)
             max = next;
        else if (next < min)</pre>
             min = next;
        next = keyboard.nextDouble();
   System.out.println("The highest score is " + max);
   System.out.println("The lowest score is " + min);
If the user enters the scores
    100
```

A user can signal the end of repetition by entering a sentinel value

```
10
-1
```

the output will be

```
The highest score is 100 The lowest score is 10
```

The sentinel value here is -1; it is not used in the computation. That is, the lowest score is 10, not -1. The -1 is just an end marker.

The three previous techniques—using a counter, asking the user, and detecting a sentinel value—cover most situations you are likely to encounter. The next case study involves a sentinel value and uses a boolean variable to end the loop's iteration.

#### **CASE STUDY** Using a Boolean Variable to End a Loop

In this case study, we will not solve a complete problem, but we will design a loop for a commonly occurring subtask and place it in a demonstration program. In doing so, you will become familiar with one of the most common uses of boolean variables.

Our loop will read a list of numbers and compute the sum of all the numbers on the list. The numbers will all be nonnegative. For example, they might be the number of hours worked by each person on a programming team. Because nobody works a negative number of hours, we know that the numbers are all nonnegative, and so we can use a negative number as a sentinel value to mark the end of the list. For this task, we will assume that the numbers will all be integers, but the same technique would work for other kinds of numbers and even for nonnumeric data.

You will get a better grasp of the problem and possible solutions if we first design the loop in pseudocode. Let's begin with the following:

```
int sum = 0;
Do the following for each number on the list:
if (the number is negative)
    Make this the last loop iteration.
else
    sum = sum + the number
```

Because we know that a negative number marks the end of the list, we can refine the pseudocode as follows:

```
int next, sum = 0;
while (there are more numbers to read)
{
    next = keyboard.nextInt();
    if (next < 0)
        Make this the last loop iteration.
    else
        sum = sum + next;
}</pre>
```

Task specification

First-draft pseudocode

Refined pseudocode

We can finish converting this pseudocode to Java code in a number of different ways. One way is to use a boolean variable. A nice thing about using a boolean variable is that our code can read much like an English sentence. For example, let's use a boolean variable named thereAreMoreNumbersToRead. Simply declaring this boolean variable and substituting it for the phrase "there are more numbers to read" in our pseudocode yields the following:

```
int next, sum = 0;
boolean thereAreMoreNumbersToRead = initial value;
while (thereAreMoreNumbersToRead)
{
    next = keyboard.nextInt();
    if (next < 0)
        Make this the last loop iteration.
    else
        sum = sum + next;
}</pre>
```

Completing the conversion of this loop to working Java code is straightforward. We can translate the phrase *Make this the last loop iteration* by observing that the loop ends when the boolean variable thereAreMoreNumbersToRead is false. So the way to end the loop is to set thereAreMoreNumbersToRead equal to false. Thus, *Make this the last loop iteration* will translate into

thereAreMoreNumbersToRead = false;

All that is left to do is to determine the initial value for thereAreMoreNumbersToRead. We know that even if the list of numbers is empty, we will have at least the sentinel value to read. Therefore, we know that the loop body must be iterated at least once. So to get the loop started, thereAreMoreNumbersToRead must be true, meaning that we must initialize it to true. Thus, we get the following code:

```
int next, sum = 0;
boolean thereAreMoreNumbersToRead = true;
while (thereAreMoreNumbersToRead)
{
    next = keyboard.nextInt();
    if (next < 0)
        thereAreMoreNumbersToRead = false;
    else
        sum = sum + next;
}</pre>
```

When the loop ends, the variable sum contains the sum of the numbers on the input list, not including the sentinel value.

The loop is ready to use in a program. Since the variable name thereAreMoreNumbersToRead is a bit long, we shorten it to areMore and produce the program shown in Listing 4.6.

Using a boolean variable for loop control

#### LISTING 4.6 Using a Boolean Variable to End a Loop

```
import java.util.Scanner;
Illustrates the use of a boolean variable to end loop iteration.
public class BooleanDemo
    public static void main(String[] args)
    {
        System.out.println("Enter nonnegative numbers.");
        System.out.println("Place a negative number at the end");
        System.out.println("to serve as an end marker.");
        int sum = 0;
        boolean areMore = true;
        Scanner keyboard = new Scanner(System.in);
        while (areMore)
        {
             int next = keyboard.nextInt();
             if (next < 0)
                 areMore = false;
             else
                 sum = sum + next;
        System.out.println("The sum of the numbers is " + sum);
    }
}
```

#### Sample Screen Output

```
Enter nonnegative numbers.

Place a negative number at the end
to serve as an end marker.

1 2 3 -1

The sum of the numbers is 6
```

#### PROGRAMMING EXAMPLE

#### **Spending Spree**

Imagine that you have won a \$100 gift certificate in a contest. You must spend the money in a particular store, but you can buy at most only three items. The store's computer tracks the amount of money you have left to spend as well as the number of items you have bought. Each time you choose an item, the computer will tell you whether you can buy it. Although we have chosen small

numbers for our example, we want to write a program for the computer so that both the dollar amount available and the number of items you can buy are easily changed.

Clearly, we have a repetitive process here. You will continue buying as long as you have enough money and have bought fewer than three items. Our loop control will be based on these two criteria. We can reflect this situation in the following pseudocode, which is likely not our first draft:

#### Algorithm for the store's computer program

```
1. amountRemaining = amount of gift certificate
2. totalSpent = 0
3. itemNumber = 1
4. while (we have money left to spend and (itemNumber <=max number
  of items))
  {
      Display amount of money left and number of items that can
      be bought.
      Read cost of proposed purchase.
      if (we can afford the purchase)
      {
          Display a message.
          totalSpent = totalSpent + cost of item
          Update amountRemaining
           if (amountRemaining > 0)
               Display amount of money left.
               itemNumber++
          }
          else
          {
               Display a message (no more money).
               Make this the last loop iteration.
          }
      }
      else
          Display a message (item is too expensive).
  }
  Display amount of money spent and farewell message.
```

We want to focus on how we will implement the criteria for ending the loop. Just as in the previous case study, we will use a boolean variable to indicate whether we have money left to spend. We can name this variable haveMoney. Before the loop, we can make this variable true, and when we are ready to exit the loop, we can change the value of haveMoney to false.

Listing 4.7 shows our completed program and some sample output. Notice our use of named constants for both the amount of the gift certificate—our spending money—and the maximum number of items we can purchase. For simplicity, we assume that all our dollar amounts are integers.

The next section uses a break statement to exit this loop. Doing so is typically an inferior technique.

#### LISTING 4.7 Spending Spree Program (part 1 of 2)

```
import java.util.Scanner;
public class SpendingSpree
{
    public static final int SPENDING MONEY = 100;
    public static final int MAX_ITEMS = 3;
    public static void main(String[] args)
    {
        Scanner keyboard = new Scanner(System.in);
        boolean haveMoney = true;
        int leftToSpend = SPENDING_MONEY;
        int totalSpent = 0;
        int itemNumber = 1;
        while (haveMoney && (itemNumber <= MAX_ITEMS))</pre>
        {
            System.out.println("You may buy up to " +
                                (MAX ITEMS - itemNumber + 1) +
                                " items");
            System.out.println("costing no more than $" +
                                leftToSpend + ".");
            System.out.print("Enter cost of item #" +
                              itemNumber + ": $"):
            int itemCost = keyboard.nextInt();
            if (itemCost <= leftToSpend)</pre>
                System.out.println("You may buy this item. ");
                totalSpent = totalSpent + itemCost;
                System.out.println("You spent $" + totalSpent +
                                    " so far.");
                leftToSpend = SPENDING_MONEY - totalSpent;
                if (leftToSpend > 0)
                     itemNumber++;
                else
                {
                    System.out.println("You are out of money.");
                    haveMoney = false;
                }
            }
```

(continued)

#### LISTING 4.7 Spending Spree Program (part 2 of 2)

#### Sample Screen Output

```
You may buy up to 3 items costing no more than $100.
Enter cost of item #1: $80 You may buy this item.
You spent $80 so far.
You may buy up to 2 items costing no more than $20.
Enter cost of item #2: $20 You may buy this item.
You spent $100 so far.
You are out of money.
You spent $100, and are done shopping.
```

# The break Statement and continue Statement in Loops (Optional)

As we have presented loops so far, the while, do-while, and for statements always exit when their controlling boolean expression—*Boolean\_Expression*—becomes false. For the previous program in Listing 4.7, this controlling expression involves the boolean variable haveMoney. So when haveMoney becomes false, the controlling expression is false and the loop ends.

In addition, a loop can exit when it encounters a break statement. When a break statement executes, the immediately enclosing loop ends, and the remainder of the loop body does not execute. Java allows a break statement to be used within a while loop, a do-while loop, or a for loop. This is the same break statement that we used earlier in switch statements.

The boolean variable haveMoney occurs three times in the program in Listing 4.7. If we omitted its use in the first two occurrences and replaced the statement

```
haveMoney = false;
```

with

#### break;

the loop in the resulting program would have the form shown in Listing 4.8. When leftToSpend is no longer positive, the println method executes, followed by the break statement, which ends the iteration. The next statement to execute would be the one after the body of the while statement.

If the loop containing a break statement is within a larger loop, the break statement ends only the innermost loop. Similarly, if the break statement is within a switch statement that is inside a loop, the break statement ends the switch statement but not the loop. The break statement ends only the *innermost* loop or switch statement that contains the break statement.

A loop without a break statement has a simple, easy-to-understand structure. One boolean expression is tested to decide whether to end the loop. When you add a break statement, the loop might end because either the controlling boolean expression is false or a break statement executes. Thus, using a break statement within a loop can make the loop more difficult to understand.

For example, the loop in Listing 4.8 begins with

```
while (itemNumber <= MAX_ITEMS)</pre>
```

The loop appears to have only one condition that causes it to end. To realize that another condition exists, you need to study the body of the loop to discover the break statement. In contrast, the loop in Listing 4.7 begins with

```
while (haveMoney && (itemNumber <= MAX_ITEMS))</pre>
```

#### LISTING 4.8 Ending a Loop with a break Statement

```
while (itemNumber <= MAX_ITEMS)
{
    ...
    if (itemCost <= leftToSpend)
    {
        if (leftToSpend > 0)
            itemNumber++;
        else
        {
            System.out.println("You are out of money.");
            break;
        }
    }
    else
    ...
}
System.out.println(...);
```

A break statement within a loop ends its iteration A continue statement within a loop ends the current iteration You quickly can see that the loop ends when you either run out of money or exceed the maximum number of items.

A continue statement within the body of a loop ends its current iteration and begins the next one. Using a continue statement in this way has the same problems as using a break statement. The continue statement, like the break statement, can and should be avoided in a loop.

# PROGRAMMING TIP Avoid the break and continue Statements in Loops

Because of the complications they introduce, break statements and continue statements within loops should be avoided. Any loop that includes either of these statements can be written without one.

#### **SELF-TEST QUESTIONS**

- 14. Write a Java loop that will display the phrase One more time four times. Also give any declarations or initializing statements that are needed.
- 15. Write a Java loop that will set the variable result equal to 2<sup>5</sup>. Initialize the value of result to 1 and then multiply it by 2 for each of five loop iterations. Also give any declarations or initializing statements that are needed.
- 16. Write a Java loop that will read a list of numbers of type double and then display their average. The numbers are all greater than or equal to 1.0. The input data ends with a sentinel value, which you must specify. Also give any declarations or initializing statements that are needed.
- 17. What output is produced by the following code?

18. What output is produced by the following code?

```
for (int n = 1; n <= 5; n++)
{
   if (n == 3)
        break;
   System.out.println("Hello");
}
System.out.println("After the loop");</pre>
```

19. What output is produced by the following code?

```
for (int n = 1; n <= 5; n++)
{
   if (n == 3)
        System.exit(0);
   System.out.println("Hello");
}
System.out.println("After the loop");</pre>
```

20. Revise the loop shown in Listing 4.6 to use a break statement instead of the boolean variable areMore. Comment on how your loop compares with the original one.

#### **Loop Bugs**

Programs containing loops are more likely to have mistakes than the simpler programs you saw before you started using loops. Fortunately, the kinds of mistakes you are most likely to make when writing a loop form a pattern, so we can tell you what to look for. Moreover, some standard techniques will help you locate and fix bugs in your loops.

The two most common kinds of loop errors are

Two common loop bugs

- Unintended infinite loops
- Off-by-one errors

Let's consider them in order.

We have already discussed infinite loops, but we need to emphasize one subtlety about them. A loop might terminate for some input data values but repeat infinitely for other values. Let's consider an example. Suppose a friend's checking account is overdrawn. The bank charges a penalty each month that the balance is negative. Our friend wants a program that will tell him how

long it will take to get a nonnegative account balance if he deposits a fixed amount each month. We design the following code:

Certain data can cause an infinite loop

We place this code in a complete program and test it using some reasonable data, like \$15 for the penalty and \$50 for the size of the deposit. The program runs fine. So we give it to our friend, who runs it and finds that it goes into an infinite loop. What happened? Our friend obviously does not have a head for numbers and has decided to make small deposits of only \$10 per month. But the bank charges a penalty of \$15 per month when an account balance is negative. So the account becomes more overdrawn every month, even though your friend makes deposits.

Code should try to guard against user error This situation might seem impossible. Our friend would not make such a stupid mistake. Don't count on it! It can happen even if our friend is not stupid. People are sometimes careless and often unpredictable. One way to fix this bug is to add code that will test to see whether the loop is infinite. For example, we might change the code to the following:

Off-by-one errors are caused by an incorrect boolean expression

The other common kind of loop bug is an **off-by-one error**. This error causes your loop to repeat its body either one too many times or one too few times. These sorts of errors can result from a careless design of a controlling boolean expression. For example, if we use < in the controlling boolean expression when we should use <=, our loop could easily repeat the body the wrong number of times.

Another common problem with the controlling boolean expression of a loop has to do with the use of == to test for equality. This equality operator works satisfactorily for integers and characters, but it is not reliable for floating-point numbers because they are approximate quantities; == tests for exact equality. The result of such a test is unpredictable. When comparing floating-point numbers, always use something involving less-than or greater-than, such as <=. Using == or != to compare floating-point numbers can produce an off-by-one error, an unintended infinite loop, or even some other type of error.

Off-by-one errors can easily go unnoticed. If a loop iterates one too many times—or one too few times—the results might still look reasonable but be off by enough to cause trouble later on. Always make a specific check for off-by-one errors by comparing your loop results to results you know to be true by some other means, such as a pencil-and-paper calculation of a simple case.

Do not compare floating-point values using == or !=

Off-by-one errors might be unnoticed

#### ■ PROGRAMMING TIP Always Retest

Whenever you find a bug in a program and "fix" it, always retest the program. Yet another bug might be waiting, or your "fix" may have introduced a new bug. The process of retesting a modified program is called **regression testing**.

#### **Tracing Variables**

If your program misbehaves but you cannot see what is wrong, your best bet is to trace some key variables. **Tracing variables** means watching the variables change value while the program is running. A program typically does not display the value of a variable every time it changes, but seeing how the variables change can help you debug your program.

as their values change during execution

Trace variables

Many systems have a built-in utility that lets you easily trace variables without making any changes to your program. These debugging systems vary from one installation to another. If you have such a debugging facility, learning how to use it is worthwhile. If you do not have such a debugging facility, you can trace variables simply by inserting some extra, temporary println statements in your program.

For example, suppose you want to trace the variables in the following code, which contains an error:

You can trace the variables by adding println statements, as follows:

```
count = 0;
System.out.println("count == " + count);
                                                             //*
System.out.println("balance == " + balance);
                                                             //*
System.out.println("penalty == " + penalty);
                                                             //*
System.out.println("deposit == " + deposit);
                                                             //*
while (balance < 0)</pre>
    balance = balance + penalty;
    System.out.println("balance + penalty == " + balance); //*
    balance = balance - deposit;
    System.out.println("balance - deposit == " + balance); //*
    System.out.println("count == " + count);
                                                             //*
System.out.println("Nonnegative balance in " + count +
                    " months.");
```

After you have discovered the error and fixed the bugs in the code, you can remove the trace statements. Tagging these statements with a distinctive comment, as we have done here, will facilitate locating them.

Inserting all the trace statements in the preceding example might seem like a lot of bother, but it is not so very much work. If you wish, you can first try tracing only some of the variables to see if that gives you enough information to find the problem. However, it is usually fastest to just trace all, or almost all, of the variables right from the start.



# PROGRAMMING TIP Use a DEBUG Flag When Tracing Variables

Sometimes while debugging a program, you want to temporarily skip any statements you have added to trace the values of certain variables. You can conveniently do this by defining a boolean constant DEBUG, as follows:

```
public static final boolean DEBUG = true;
...
if (DEBUG)
{
     <Statements that display the values of certain variables>
}
```

In this example, the statements within the body of the if statement will execute. Later, if you wish to skip them, you can change the value of DEBUG to false.

#### **Assertion Checks**

An **assertion** is a statement that says something about the state of your program. An assertion can be either true or false but should be true if there are no mistakes in your program. For example, all the comments in the following code are assertions:

An assertion states a truth if a program's logic is

```
//n == 1
while (n < limit)
{
    n = 2 * n;
}
//n >= limit
//n is the smallest power of 2 >= limit
```

Note that while each of these assertions can be either true or false, depending on the values of n and limit, they all should be true if the program is performing correctly. An assertion "asserts" that something is true about your program code when program execution reaches the location of the assertion. Although our example involves a loop, you can write assertions for other situations as well.

In Java, you can actually check to see whether an assertion is true and, if it is not true, you can stop the program and display an error message. An assertion check in Java has the following form:

An assert statement checks an assertion

```
assert Boolean_Expression;
```

If you run your program in a certain way, and if *Boolean\_Expression* is false, the program ends after displaying an error message saying that an assertion failed. However, if *Boolean\_Expression* is true, nothing special happens and execution continues.

For example, the previous code can be written as follows, with two of the comments replaced by assertion checks:

```
assert n == 1;
while (n < limit)
{
    n = 2 * n;
}
assert n >= limit;
//n is the smallest power of 2 >= limit.
```

Note that we translated only two of the three comments into assertion checks. Not all assertion comments lend themselves to becoming assertion checks. For example, the final comment is an assertion. It is either true or false, and if the program code is correct, it will be true. However, there is no simple way to convert this last comment into a boolean expression. Doing so would not be impossible, but you would need to use code that would itself be more complicated than what you would be checking. Your decision as to whether to

Assertion checking can be on or off

translate a comment into an assertion check will depend on the details of the particular case.

You can turn assertion checking on and off. You can turn it on when debugging code so that a failed assertion will stop your program and display an error message. Once your code is debugged, you can turn assertion checking off so that the assertion checks are ignored, making your code run more efficiently. Thus, you can leave the assertion checks in your program but ignore them after your program is debugged.

The normal way of running a program has assertion checking turned off. To run your program with assertion checking turned on, use the following command:

```
java -enableassertions YourProgram
```

If you are using an integrated development environment (IDE), check its documentation for a way to set options for assertion checking.

#### **RECAP** Assertion Checking

#### **SYNTAX**

```
Assert Boolean_Expression;
```

You can place an assertion check anywhere in your code. If assertion checking is turned on and <code>Boolean\_Expression</code> is false, your program will display a suitable error message and end execution. If assertion checking is not turned on, the assertion check is treated as a comment.

#### **EXAMPLE**

```
assert n >= limit;
```

#### **SELF-TEST QUESTIONS**

- 21. What is the bug in the code in the section "Tracing Variables"?
- 22. Add some suitable output statements to the following code, so that all variables are traced:

```
int sum = 0;
for (int n = 1; n < 10; n++)
    sum = sum + n;
System.out.println("1 + 2 + ... + 9 + 10 == " + sum);</pre>
```

- 23. What is the bug in the code in the previous question?
- 24. What is an assertion? Give some examples of assertions.
- 25. Suppose that you did not have assertion checking in Java. (Earlier versions of Java did not.) Write some code to simulate the following assertion check, where balance is a variable of type double:

```
assert balance > 0;
```

#### 4.3 GRAPHICS SUPPLEMENT

Painting is silent poetry, and poetry is painting that speaks.

```
—PLUTARCH (CA. 46-127)
```

In this section we create a JavaFX application that uses a loop to produce its drawing. The program will also use an if statement and the method setFill, both of which are described in the previous chapter. In addition, we introduce the methods setFont and fillText and use them to write text in the window.

#### PROGRAMMING EXAMPLE A Multiface JavaFX Application

Listing 4.9 contains a JavaFX application that displays a sequence of seven faces. The first five faces alternate in color between light gray and white, and each has a bit more of a smile than the one before. The sixth face is throwing a kiss to the user, and the seventh face is blushing (presumably because it is shy about kissing). Think of the seven faces as an animation or a sequence of timelapse snapshots. (There is no reason for the faces to alternate between light gray and white, except to make the program more interesting.)

The first five faces are the same except for minor variations, and so they are drawn within a for loop whose loop control variable is i. The body of the for loop draws a face, with changes given in terms of i. For each value of i, a face is drawn at the point (X\_FACEO + 50 \* i, Y\_FACEO + 30 \* i). So, when i is zero, the first face is drawn at the point (X\_FACEO, Y\_FACEO). For each successive value of i, another face is drawn 50 pixels further to the right and 30 pixels lower on the screen. X\_FACE0 and Y\_FACE0 are named constants. Instead of computing 50 \* i and 30 \* i over and over, we compute them once and store them in the variables x0ffset and y0ffset, respectively.

# LISTING 4.9 A JavaFX Application That Uses Looping and Branching (part 1 of 4)

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.shape.ArcType;
import javafx.scene.paint.Color;
import javafx.scene.text.Font;
public class MultipleFaces extends Application
    public static final int WINDOW_WIDTH = 450;
    public static final int WINDOW_HEIGHT = 300;
    public static final int FACE_DIAMETER = 50;
    public static final int X_FACE0 = 10;
    public static final int Y_FACE0 = 5;
    public static final int EYE_WIDTH = 5;
    public static final int EYE_HEIGHT = 10;
    public static final int X_RIGHT_EYE0 = 20;
    public static final int Y_RIGHT_EYE0 = 15;
    public static final int X_LEFT_EYE0 = 45;
    public static final int Y_LEFT_EYE0 = Y_RIGHT_EYE0;
    public static final int NOSE DIAMETER = 5;
    public static final int X_NOSE0 = 32;
    public static final int Y_NOSE0 = 25;
    public static final int MOUTH_WIDTH = 30;
    public static final int MOUTH HEIGHT0 = 0;
    public static final int X_MOUTHO = 20;
    public static final int Y_MOUTHO = 35;
    public static final int MOUTH START ANGLE = 180;
    public static final int MOUTH_EXTENT_ANGLE = 180;
    public static void main(String[] args)
    {
       launch(args);
    }
   @Override
    public void start(Stage primaryStage) throws Exception
    {
        Group root = new Group();
        Scene scene = new Scene(root);
```

## LISTING 4.9 A JavaFX Application That Uses Looping and Branching (part 2 of 4)

```
Canvas canvas = new Canvas(WINDOW_WIDTH, WINDOW_HEIGHT);
GraphicsContext gc = canvas.getGraphicsContext2D();
int i, xOffset, yOffset; //Want i to exist after the loop ends
for (i = 0; i \le 4; i++)
{//Draw one face:
    x0ffset = 50 * i;
    y0ffset = 30 * i;
    //Draw face circle:
    if (i \% 2 == 0) // if i is even
    {//Make face light gray
        gc.setFill(Color.LIGHTGRAY);
        gc.fillOval(X_FACEO + xOffset, Y_FACEO + 30 * i,
                     FACE_DIAMETER, FACE_DIAMETER);
    gc.setFill(Color.BLACK);
    gc.stroke0val(X_FACE0 + x0ffset, Y_FACE0 + y0ffset,
                  FACE DIAMETER, FACE DIAMETER);
    //Draw eyes:
    gc.setFill(Color.BLACK);
    gc.fillOval(X_RIGHT_EYEO + xOffset, Y_RIGHT_EYEO + yOffset,
                 EYE_WIDTH, EYE_HEIGHT);
    gc.fillOval(X_LEFT_EYEO + xOffset, Y_LEFT_EYEO + yOffset,
            EYE_WIDTH, EYE_HEIGHT);
    //Draw nose:
    gc.setFill(Color.BLACK);
    gc.fillOval(X_NOSEO + xOffset, Y_NOSEO + yOffset,
                NOSE_DIAMETER, NOSE_DIAMETER);
    //Draw mouth:
    gc.setFill(Color.BLACK);
    gc.strokeArc(X MOUTHO + xOffset, Y MOUTHO + yOffset,
                 MOUTH_WIDTH, MOUTH_HEIGHTO + 3 * i + 1,
                 MOUTH_START_ANGLE, MOUTH_EXTENT_ANGLE,
                 ArcType.OPEN);
}
//i is 5 when the previous loop ends
x0ffset = 50 * i;
vOffset = 30 * i;
                                                    After the last iteration of the loop
                                                    body, the value of I is incremented
//Draw kissing face:
                                                    one last time to become 5.
//Draw face circle:
gc.setFill(Color.BLACK);
gc.strokeOval(X_FACEO + xOffset, Y_FACEO + yOffset,
              FACE_DIAMETER, FACE_DIAMETER);
//Draw eyes:
gc.setFill(Color.BLACK);
                                                                    (continued)
```

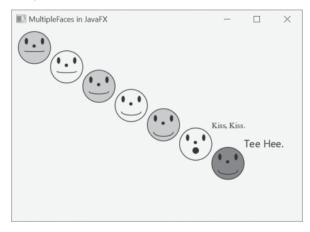
# LISTING 4.9 A JavaFX Application That Uses Looping and Branching (part 3 of 4)

```
gc.fillOval(X_RIGHT_EYEO + xOffset, Y_RIGHT_EYEO + yOffset,
            EYE_WIDTH, EYE_HEIGHT);
gc.fillOval(X_LEFT_EYEO + xOffset, Y_LEFT_EYEO + yOffset,
            EYE_WIDTH, EYE_HEIGHT);
//Draw nose:
gc.setFill(Color.BLACK);
gc.fillOval(X_NOSEO + xOffset, Y_NOSEO + yOffset,
            NOSE DIAMETER, NOSE DIAMETER);
//Draw mouth in shape of a kiss:
gc.setFill(Color.BLACK);
gc.fillOval(X_MOUTHO + xOffset + 10, Y_MOUTHO + yOffset,
            MOUTH_WIDTH - 20, MOUTH_WIDTH - 20);
//Add text in Times New Roman, 12 point:
gc.setFont(Font.font("Times New Roman", 12));
gc.fillText("Kiss, Kiss.",
            X_FACEO + xOffset + FACE_DIAMETER, Y_FACEO + yOffset);
//Draw blushing face:
i++;
x0ffset = 50 * i;
y0ffset = 30 * i;
//Draw face circle:
gc.setFill(Color.GRAY);
gc.fillOval(X_FACEO + xOffset, Y_FACEO + yOffset,
            FACE_DIAMETER, FACE_DIAMETER);
gc.setFill(Color.BLACK);
gc.strokeOval(X_FACEO + xOffset, Y_FACEO + yOffset,
              FACE_DIAMETER, FACE_DIAMETER);
//Draw eyes:
gc.setFill(Color.BLACK);
gc.fillOval(X_RIGHT_EYEO + xOffset, Y_RIGHT_EYEO + yOffset,
            EYE_WIDTH, EYE_HEIGHT);
gc.fillOval(X_LEFT_EYEO + xOffset, Y_LEFT_EYEO + yOffset,
            EYE_WIDTH, EYE_HEIGHT);
//Draw nose:
gc.setFill(Color.BLACK);
gc.fillOval(X_NOSEO + xOffset, Y_NOSEO + yOffset,
            NOSE_DIAMETER, NOSE_DIAMETER);
//Draw mouth:
gc.setFill(Color.BLACK);
gc.strokeArc(X_MOUTHO + xOffset, Y_MOUTHO + yOffset, MOUTH_WIDTH,
             MOUTH\_HEIGHTO + 3 * (i - 2),
             MOUTH_START_ANGLE, MOUTH_EXTENT_ANGLE, ArcType.OPEN);
//Add text in Courier New Font, 16 point:
gc.setFont(Font.font("Courier New ", 16));
gc.fillText("Tee Hee.",
            X_FACE0 + x0ffset + FACE_DIAMETER, Y_FACE0 + y0ffset):
                                                                  (continued)
```

# LISTING 4.9 A JavaFX Application That Uses Looping and Branching (part 4 of 4)

```
root.getChildren().add(canvas);
primaryStage.setTitle("MultipleFaces in JavaFX");
primaryStage.setScene(scene);
primaryStage.show();
}
```

### Program Output



The following code adds the color light gray to the face whenever i is an even number:

Draw a yellow face, then its black outline

After this, the black outline of the circle is drawn by the statements

Each light gray face has its interior drawn before the black outline of the circle so that the black outline shows on top of the filled circle.

The next few lines of the loop body draw the eyes and nose, which are the same for each face. The mouth is drawn by the following statements at the end of the loop body:

Each mouth is drawn in the same way but differs a little for each value of i. The height of each mouth increases by 3 pixels as i is increased by 1. The height of the first mouth, when i is zero, is MOUTH\_HEIGHTO, which is a named constant set to zero. Thus, the first mouth is straight across with no curve. The second mouth, when i is 1, is 3 pixels in height, so its curve is more pronounced to look more like a smile. The smile continues to grow for the first five faces.

The last two faces are given by code that comes after the loop body. However, the code for each of these two faces is just a minor variation on the loop body. In particular, the last two faces are positioned in terms of i, like the faces produced by the for loop. Just before the for loop ends, the value of i is increased by 1, so the next face is positioned correctly in the sequence. Then, before the last face is drawn, i is incremented again, and so the last face is also correctly positioned in the sequence of faces.

The mouth of the next-to-last face is drawn as a black-filled circle to make it appear to be in a kissing position. The last face is gray and has a full smile. The full smile is the same as the smile drawn for the fifth face, when i was equal to 4. Since i is now 6, we use a mouth height of i-2 for the last face.

The last two faces are labeled with some text by calls to the methods setFont and fillText, which is explained in the next section.

### **Drawing Text**

The method setFont is used to change the current font. You will need to know the name of a font installed on the system. If you specify a font that isn't installed on your system, then a default font will be used instead. You can also specify the point size of the font. A larger point size results in a larger font. The following sets the current font to Times New Roman in 12 point:

```
gc.setFont(Font.font("Times New Roman", 12));
```

The method fillText is similar to the methods for drawing ovals, but fillText displays text rather than a drawing. For example, the following writes the word Hello starting at the point (10,20) in the current font:

```
gc.fillText("Hello", 10, 20);
```

The invocation

from Listing 4.9 writes the phrase Kiss starting at the point whose x and y coordinates are X\_FACEO + x0ffset + FACE\_DIAMETER and Y\_FACEO + y0ffset, respectively.

### **RECAP The setFont and fillText Methods**

### **SYNTAX**

```
gc.setFont(Font.font("Font name", point_size));
```

The method setFont sets the current font to the named font in the specified point size. Text that is subsequently drawn using fillText or strokeText will appear in this font.

### **EXAMPLE**

```
gc.setFont(Font.font("Courier New", 24));
```

### **SYNTAX**

```
gc.fillText(String, X, Y);
```

The method fillText writes the text given by the argument *String* within the program's window at the point (X, Y).

### **EXAMPLE**

```
gc.fillText("Hello", 10, 20);
```

### **SELF-TEST QUESTION**

26. Write a loop that can be used in a JavaFX application to draw the following row of identical circles:













### **CHAPTER SUMMARY**

- A loop is a programming construct that repeats an action some number of times. The part that is repeated is called the body of the loop. Every repetition of the loop body is called a loop iteration.
- Java has three kinds of loop statements: the while statement, the do-while statement, and the for statement.

- Both the while statement and the do-while statement repeat the body of the loop while a boolean expression is true. The do-while statement executes its body at least once, but the while statement might not execute its body at all.
- The logic of a for statement is identical to that of a while loop. Its initialization, test, and update steps are given together, rather than dispersed throughout the loop. The for statement often is used for loops controlled by a counter.
- The for-each statement is a variation of the for statement that iterates through all the elements in a collection of data such as an enumeration.
- One way to end an input loop is to place a sentinel value at the end of the data and have the loop check for the sentinel value.
- A variable of type boolean can be used to control a loop statement.
- The most common kinds of loop bugs are unintended infinite loops and off-by-one errors.
- Tracing a variable means to display its value at selected places in the program. Tracing can be done using special debugging utilities or by inserting temporary output statements.
- An assertion is a statement—made at a certain point within a method—of what should be true if the method is correct. Java provides an assertion check to test whether an assertion is actually true.
- You can display text in a JavaFX application by using the method setFont and fillText.

### **Exercises**

- 1. Write a fragment of code that will read words from the keyboard until the word done is entered. For each word except done, report whether its first character is equal to its last character. For the required loop, use a
  - a. while statement
  - b. do-while statement
- 2. Develop an algorithm for computing the quarterly balance in an equity fund. You can make one switch (the increase or decrease in the rate of return according to the increase or decrease in the level of risk) in a quarter. Interest is added to the fund at the end of each quarter. The quarterly interest rate is the yearly percentage rate divided by 4.
- 3. Develop an algorithm for a simple game of guessing at a secret five-digit code. When the user enters a guess at the code, the program returns two values: the number of digits in the guess that are in the correct position

and the sum of those digits. For example, if the secret code is 53840, and the user guesses 83241, the digits 3 and 4 are in the correct position. Thus, the program should respond with 2 and 7. Allow the user to guess a fixed number of times.

- 4. Write a fragment of code that will compute the product of the first n positive even integers. For example, if n is 6, you should compute  $2 \times 4 \times 6 \times 8 \times 10 \times 12$ .
- 5. Convert the following code so that it uses nested while statements instead of for statements:

```
int s = 0;
int t = 1;
for (int i = 0; i < 10; i++)
{
    s = s + i;
    for (int j = i; j > 0; j--)
    {
        t = t * (j - i);
    }
    s = s * t;
    System.out.println("T is " + t);
}
System.out.println("S is " + s);
```

- 6. Write a for statement to compute the sum  $1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5} + \cdots + \frac{1}{n}$ .
- 7. Repeat the previous question, but use the comma operator and omit the for statement's body.
- 8. Write a loop that will count the number of blank characters in a given string.
- 9. Write a loop that will create a new string that is the reverse of a given string.
- 10. Write a program that will compute statistics for eight coin tosses. The user will enter either an h for heads or a t for tails for the eight tosses. The program will then display the total number and percentages of heads and tails. Use the increment operator to count each h and t that is entered. For example, a possible sample dialogue between the program and the user might be

For each coin toss enter either h for heads or t for tails.
First toss: h
Second toss: t
Third toss: t
Fourth toss: h
Fifth toss: t
Sixth toss: h
Seventh toss: t

Eighth toss: t Number of heads: 3 Number of tails: 5 Percent heads: 37.5 Percent tails: 62.5

- 11. Suppose we attend a party. To be sociable, we will shake hands with everyone else. Write a fragment of code using a for statement that will compute the total number of handshakes that occur. (*Hint*: Upon arrival, each person shakes hands with everyone who is already there. Use the loop to find the total number of handshakes as each person arrives.)
- 12. Define an enumeration for each of the months in the year. Use a for-each statement to display each month.
- 13. Write a fragment of code that computes the final score of a bowling game. Use a loop to read the number of pins toppled by three players during five turns each. Display the final score afterward.
- 14. Suppose that you work for an ice cream company. The company wants to know the optimal cost for an ice cream cone that holds a specified volume. Write a fragment of code that uses an ask-before-iterating loop. During each iteration of the loop, your code will ask the user to enter the volume and the radius of the cone. Compute and display the height and cost of the cone. Use the following formulas, where *V* is the volume, *r* is the radius, *h* is the height, and *C* is the cost.

$$h = \frac{3V}{\pi r^2} \qquad l = \sqrt{r^2 + h^2} \qquad C = \pi r l$$

- 15. Suppose that we want to compute the geometric mean of a list of positive values. To compute the geometric mean of k values, multiply them all together and then compute the kth root of the value. For example, the geometric mean of 2, 5, and 7 is  $\sqrt[3]{2 \times 5} \times 7$  Use a loop with a sentinel value to allow a user to enter an arbitrary number of values. Compute and display the geometric mean of all the values, excluding the sentinel. (*Hint*: Math.pow(x, 1.0/k) will compute the kth root of x.)
- 16. Imagine a program that compresses files by 80 percent and stores them on storage media. Before the compressed file is stored, it must be divided into blocks of 512 bytes each. Develop an algorithm for this program that first reads the number of blocks available on the storage media. Then, in a loop, read the uncompressed size of a file and determine whether the compressed file will fit in the space left on the storage media. If so, the program should compress and save the file. It continues until it encounters a file that will exceed the available space on the media.

For example, suppose the media can hold 1000 blocks. A file of size 1100 bytes will compress to size 880 and require 2 blocks. The available space is now 998 blocks. A file of size 20,000 bytes will compress to size 16,000 and require 32 blocks. The available space is now 966.

17. Create an applet that draws a pattern of circles whose centers are evenly spaced along a horizontal line. Use six constants to control the pattern: the number of circles to draw, the diameter of the first circle, the *x*- and *y*-coordinates of the center of the first circle, the distance between adjacent centers, and the change in the diameter of each subsequent circle.

**Graphics** 

18. What does the following fragment of code display? What do you think the programmer intended the code to do, and how would you fix it?

```
int sum = 0;
int num = 30;
for (int j = 0; j >= num; j+=2)
        sum += j;
System.out.println("The sum is " + sum);
```

19. What does the following fragment of code display? What do you think the programmer intended the code to do, and how would you fix it?

### **PRACTICE PROGRAMS**

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

- 1. Repeat Practice Program 4 of Chapter 3, but use a loop that reads and processes sentences until the user says to end the program.
- 2. Write a program that implements your algorithm from Exercise 2.
- 3. Repeat Practice Program 5 of Chapter 3, but use a loop so the user can convert other temperatures. If the user enters a letter other than *C* or *F*—in either uppercase or lowercase—after a temperature, print an error message and ask the user to reenter a valid selection. Do not ask the user to reenter the numeric portion of the temperature again, however. After each conversion, ask the user to type Q or q to quit or to press any other key to repeat the loop and perform another conversion.

Graphics

- 4. Repeat the previous project, but use JOptionPane windows for input and output. Offer the user Yes and No buttons to end execution instead of asking for character input of Q or q. JOptionPane is described in the graphics supplements of Chapters 2 and 3.
- 5. Write a program to read a list of nonnegative integers and to display the largest integer, the smallest integer, and the average of all the integers. The user indicates the end of the input by entering a negative sentinel value that is not used in finding the largest, smallest, and average values. The average should be a value of type double so that it is computed with a fractional part.
- 6. Write a program to read the temperature of a particular location at a particular time of day for each day of a week. Find and display the highest and the lowest values among the temperatures recorded. Also, find the average temperature of the location and display it. For example, if the input is

```
21 30 25.8 27.3 24 29 22.7
```

the output would be

Highest temperature is 30 Lowest temperature is 21 Average temperature is 26

7. Combine the programs from Programming Projects 5 and 6 to read integer exam scores in the range 0 to 100 and to display the following statistics:

Total number of scores
Total number of each letter grade
Percentage of total for each letter grade
Range of scores: lowest and highest
Average score

As before, enter a negative score as a sentinel value to end the data input and display the statistics.

8. Write a program that simulates the Magic 8 Ball game. Upon running the program, generate a random number such that one of the following 8 responses is output:

It is certain
It is decidedly so
Most likely
Signs point to yes

Reply hazy, try again Ask again later Don't count on it My sources say no

There should be an equal chance for any one of the eight responses to come up. The program should ask the user if he or she would like to repeat the program and loop if the user opts to repeat. Random number generation is discussed in Chapter 6, but for this program you can use the following line of code to generate a random number between 1 and 8:

```
int num = (int) (Math.random() * 8) + 1;
```

9. What's the outcome of rolling a loaded die? Let the computer decide. Write a program that generates a random number in the range 0.0 and 1.0 (see the previous Practice Program about generating a random number). Use the random number in either a switch or an if statement that outputs the result of rolling a loaded die such that the probability of getting a 1, 2, 3, 4, or 5 is 1/8 and the probability of getting a 6 is 3/8.

### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

- 1. Write a program that implements your algorithm from Exercise 3.
- 2. For all of the following words, if you move the first letter to the end of the word, and then spell the result backwards, you will get the original word:

banana dresser grammar potato revive uneven assess

Write a program that reads a word and determines whether it has this property. Continue reading and testing words until you encounter the word *quit*. Treat uppercase letters as lowercase letters.

3. Write a program that reads a bank account balance and an interest rate and displays the value of the account in ten years. The output should show the value of the account for three different methods of compounding interest: annually, monthly, and daily. When compounded annually, the interest is added once per year at the end of the year. When compounded monthly, the interest is added 12 times per year. When computed daily, the interest is added 365 times per year. You do not have to worry about leap years; assume that all years have 365 days. For annual interest, you can assume that the interest is posted exactly one year from the date of deposit. In other words, you do not have to worry about interest being posted on a specific day of the year, such as December 31. Similarly, you can assume that monthly interest is posted exactly one month after it is deposited. Since the account earns interest on the interest, it should have



a higher balance when interest is posted more frequently. Be sure to adjust the interest rate for the time period of the interest. If the rate is 5 percent, you use 5/12 percent when posting monthly interest and 5/365 percent when posting daily interest. Perform this calculation using a loop that adds in the interest for each time period, that is, do not use some sort of algebraic formula. Your program should have an outer loop that allows the user to repeat this calculation for a new balance and interest rate. The calculation is repeated until the user asks to end the program.

- 4. Modify Programming Project 5 from Chapter 2 to check the validity of input data. Valid input is no less than 25 cents, no more than 100 cents, and an integer multiple of 5 cents. Compute the change only if a valid price is entered. Otherwise, print separate error messages for any of the following invalid inputs: a price under 25 cents, a price that is not an integer multiple of 5, and a price that is more than a dollar.
- 5. Repeat Practice Program 7 using JOptionPane, which is described in the graphics supplements of Chapters 2 and 3.
- 6. Write a program that asks the user to enter the size of a triangle (an integer from 1 to 50). Display the triangle by writing lines of asterisks. The first line will have one asterisk, the next two, and so on, with each line having one more asterisk than the previous line, up to the number entered by the user. On the next line write one fewer asterisk and continue by decreasing the number of asterisks by 1 for each successive line until only one asterisk is displayed. (*Hint*: Use nested for loops; the outside loop controls the number of lines to write, and the inside loop controls the number of asterisks to display on a line.) For example, if the user enters 3, the output would be

\*

7. Write a program that simulates a bouncing ball by computing its height in feet at each second as time passes on a simulated clock. At time zero, the ball begins at height zero and has an initial velocity supplied by the user. (An initial velocity of at least 100 feet per second is a good choice.) After each second, change the height by adding the current velocity; then subtract 32 from the velocity. If the new height is less than zero, multiply both the height and the velocity by -0.5 to simulate the bounce. Stop at the fifth bounce. The output from your program should have the following form:

Enter the initial velocity of the ball: 100

Time: 0 Height: 0.0 Time: 1 Height: 100.0

### Graphics



```
Time: 2 Height: 168.0
Time: 3 Height: 204.0
Time: 4 Height: 208.0
Time: 5 Height: 180.0
Time: 6 Height: 120.0
Time: 7 Height: 28.0
Bounce!
Time: 8 Height: 48.0
```

8. You have three identical prizes to give away and a pool of ten finalists. The finalists are assigned numbers from 1 to 10. Write a program to randomly select the numbers of three finalists to receive a prize. Make sure not to pick the same number twice. For example, picking finalists 3, 6, 2 would be valid but picking 3, 3, 11 would be invalid because finalist number 3 is listed twice and 11 is not a valid finalist number. Random number generation is discussed in Chapter 6, but for this problem you can insert the following line of code to generate a random number between 1 and 10:

```
int num = (int) (Math.random() * 10) +1;
```

9. Suppose we can buy a chocolate bar from the vending machine for \$1 each. Inside every chocolate bar is a coupon. We can redeem six coupons for one chocolate bar from the machine. This means that once you have started buying chocolate bars from the machine, you always have some coupons. We would like to know how many chocolate bars can be eaten if we start with *N* dollars and always redeem coupons if we have enough for an additional chocolate bar.

For example, with 6 dollars we could consume 7 chocolate bars after purchasing 6 bars giving us 6 coupons and then redeeming the 6 coupons for one bar. This would leave us with one extra coupon. For 11 dollars, we could have consumed 13 chocolate bars and still have one coupon left. For 12 dollars, we could have consumed 14 chocolate bars and have two coupons left.

Write a program that inputs a value for *N* and outputs how many chocolate bars we can eat and how many coupons we would have left over. Use a loop that continues to redeem coupons as long as there are enough to get at least one chocolate bar.

- 10. Holy digits Batman! The Riddler is planning his next caper somewhere on Pennsylvania Avenue. In his usual sporting fashion, he has left the address in the form of a puzzle. The address on Pennsylvania is a four-digit number where:
  - All four digits are different
  - The digit in the thousands place is three times the digit in the tens place
  - The number is odd
  - The sum of the digits is 27

Write a program that uses a loop (or loops) to find the address where the Riddler plans to strike.

11. Your country is at war and your enemies are using a secret code to communicate with one another. You have managed to intercept a message that reads as follows:

```
:mmZ\dxZmx]Zpgy
```

The message is obviously encrypted using the enemy's secret code. You have just learned that their encryption method is based upon the ASCII code (see Appendix 7). Individual characters in a string are encoded using this system. For example, the character 'A' is encoded using the number 65 and 'B' is encoded using the number 66. Your enemy's secret code takes each letter of the message and encrypts it as follows:

```
if (OriginalChar + Key > 126) then
        EncryptedChar = 32 + ((OriginalChar + Key) - 127)
else
        EncryptedChar = (OriginalChar + Key)
```

For example, if the enemy uses Key = 10 then the message "Hey" would initially be represented as:

Character	ASCII	code
Н	72	
е	101	
У	121	

And "Hey" would be encrypted as:

```
Encrypted H = (72 + 10) = 82 = R in ASCII
Encrypted e = (101 + 10) = 111 = o in ASCII
Encrypted y = 32 + ((121 + 10) - 127) = 36 = $ in ASCII
```

Consequently, "Hey" would be transmitted as "Ro\$." Write a Java program that decrypts the intercepted message. You only know that the key used is a number between 1 and 100. You can assume that the original message consists entirely of ASCII codes that represent only printable characters. Your program should try to decode the message using all possible keys between 1 and 100. When you try the valid key, the message will make sense. For all other keys, the message will appear as gibberish. Since there are only 100 keys this would obviously be a pretty crummy encryption system. This Programming Project will require you to explore a bit on your own how to convert from a char to a number, process the number, then convert it back to a char. See Chapter 2 for String methods. You will want to use charAt().

Important: Note that the secret code has a \ so you will need to escape encode it by using \\ if you hard-code it in your program.

12. Repeat Programming Project 7, but write the program as JavaFX application. Use a constant for the initial velocity of the ball. Draw a circle for the position of the ball at each second. The *y*-coordinate should be proportional to the height of the ball, and the *x*-coordinate should change by a small constant amount.

Graphics

13. Write a JavaFX application that draws a bull's-eye pattern. The center should be a filled-in blue circle with a diameter of 100 pixels. The center circle should be surrounded by five rings that alternate in color from green to blue. Each ring should have a width of 30 pixels.

**Graphics** 

14. Create a JavaFX application that draws a pattern of evenly spaced circles. Use four constants to control the pattern: the number of circles to draw, the radius of the first circle, the change in the radius of each subsequent circle, and the change in the *x*-coordinate of the circle. Cycle the colors of the circles through red, green, and blue.

**Graphics** 

15. (*Challenge*) Repeat the previous project, but position the centers of the circles on a spiral. The center of each circle will depend on both an angle and a distance from the origin. A constant change in both the angle and the distance will result in a spiral pattern.

Graphics

16. Write a JavaFX application that displays a series of pictures of a person with arms, legs, and of course a head. Use a happy face for the head. Use ovals for the body, arms, and legs. Draw a sequence of figures that appear one after the other, as in Listing 4.9. Make the figures assume a running position. Change the color of the person's face in each succeeding figure, going from white to pink to red to yellow to green. Have the smiling face gradually change its mouth shape from a smile on the first person to a frown on the last person. Use a switch statement to choose the color. Embed the switch statement in a loop.

**Graphics** 

17. You have an augmented reality game in which you catch Edoc and acquire Edoc candy. You need 12 candies to evolve an Edoc into a Margorp. An evolution earns you back one candy. Each evolution also earns you 500 experience points. An Edoc or Margorp can each be transferred for one Edoc candy. In support of the game's players, write an Edoc calculator program that inputs the number of Edoc you have caught and the number of Edoc candies in your possession. You can assume the initial number of Margorps is 0. The program should output the maximum number of experience points you can earn through transfers and evolutions. After Edocs evolve into Margorps, your program should consider if transferring the Margorps will result in enough candy to evolve even more Edoc.

For example, if you start with 71 candies and 53 Edoc, the program could output the following. Note that there are many other sequences of transfers

and evolutions, with possibly a different final number of Edoc and Margorp, but the total number of experience points should be the same (the max possible):

```
Transfer 37 Edoc and 0 Margorp resulting in
108 candy, 16 Edoc, and 0 Margorp
Evolve 9 Edoc to get 4500 experience points and resulting in
9 candy, 7 Edoc, and 9 Margorp
Transfer 0 Edoc and 9 Margorp resulting in
18 candy, 7 Edoc, and 0 Margorp
Evolve 1 Edoc to get 500 experience points and resulting in
7 candy, 6 Edoc, and 1 Margorp
Transfer 4 Edoc and 1 Margorp resulting in
12 candy, 2 Edoc, and 0 Margorp
Evolve 1 Edoc to get 500 experience points and resulting in
1 candy, 1 Edoc, and 1 Margorp
Total experience points = 5500
```

### **Answers to Self-Test Questions**

```
1. 0
    1
    2
    3
    4
    count after loop = 5
```

2. Yes, the body of a while loop can execute zero times. No, the body of a do-while loop must execute at least once.

```
3. 0
    count after loop = 1
4. Scanner keyboard = new Scanner(System.in);
    int number;
    System.out.println("Enter a whole number:");
    number = keyboard.nextInt();
    System.out.println("You entered " + number);
    while (number > 0)
    {
        System.out.println("Enter a whole number:");
        number = keyboard.nextInt();
        System.out.println("You entered " + number);
    }
    System.out.println("number after loop = " + number);
```

5. This is an infinite loop. The println statement after the loop will never be executed. The output begins

```
0
-1
-2
-3
.
.
6. while (population <= 0)
{
        System.out.println("Population must be positive.");
        System.out.print("Reenter population: ");
        population = keyboard.nextInt();
}
7. 1
2
3
4</pre>
```

- 8. This loop produces no output. The boolean expression n > 4 is false the first time through the loop, so the loop ends without iterating its body.
- 9. 4 3 2
- 10. The only output is

0

Be sure to notice the semicolon that was added at the end of the first line of the for loop.

```
11. 0.0
    0.5
    1.0
    1.5
    2.0
    2.5

12. for (int n = 1; n <= 5; n++)
        System.out.println(2 * n);
    or
    for (int n = 2; n <= 10; n = n + 2)
        System.out.println(n);</pre>
```

16. You can use any number less than 1.0 as a sentinel value, but to avoid any problems with the approximate nature of double values, the number you choose should be significantly less than 1.0.

```
System.out.println("Enter a list of numbers.");
   System.out.println("All the numbers must be 1.0 or larger.");
   System.out.print("Enter 0 after the last number ");
   System.out.println("on the list.");
   double sum = 0;
   int count = 0;
   Scanner keyboard = new Scanner(System.in);
   double next = keyboard.nextDouble();
   while (next > 0.9)
   //next >= 1.0 has a risk of inaccuracy.
        sum = sum + next;
        count++;
        next = keyboard.nextDouble();
   if (count > 0)
        System.out.println("Average is " + (sum / count));
   System.out.println("No numbers to average.");
17. One
```

17. One Two Three After the loop

Note that the break statement ends the switch statement but does not end the for loop.

```
18. Hello
   Hello
   After the loop 1
19. Hello
```

Hello

Note that After the loop is not displayed because the program ends.

```
20. int sum = 0;
    Scanner keyboard = new Scanner(System.in);
    while (true)
    {
        int next = keyboard.nextInt();
        if (next < 0)
            break;
        else
            sum = sum + next;
    }</pre>
```

This version of the loop hides its stopping criterion within its body. The original version that uses the boolean variable are More is easier to understand.

21. The code contains

```
balance = balance + penalty;
balance = balance - deposit;
but it should contain
balance = balance - penalty;
balance = balance + deposit;
```

Even after it is fixed in this way, it still has the following problem: If penalty is greater than deposit, the loop is infinite.

```
22. int sum = 0;
    System.out.println("sum == " + sum); // *
    for (int n = 1; n < 10; n++)
    {
        sum = sum + n;
        System.out.println("n == " + n); // *
        System.out.println("sum == " + sum); // *
    }
    System.out.println("1 + 2 + . . . . ) + 9 + 10 == " + sum);</pre>
```

- 23. The boolean expression should be n <= 10, not n < 10. This is an off-by-one error.
- 24. An assertion is a statement that says something about the state of your program at a particular point. An assertion should be true if there are no mistakes in the program. The following is an example of an assertion given two times, once as a comment and once as an assertion check:

```
// (timeLeft > 30) && (points < 10)
assert (timeLeft > 30) && (points < 10);

25. if (balance <= 0) //if (balance > 0) is false.
{
         System.out.println("Assertion(balance > 0)failed.");
         System.out.println("Aborting program.");
         System.exit(0);
}
```

26. You are not required to give a complete JavaFx application, but we have embedded the answer in one.

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.paint.Color;
public class Ch4SelfTest26 extends Application
   public static final int DIAMETER = 30;
   public static final int X_CENTER = 100;
   public static final int Y_CENTER = 100;
   public static final int GAP = 100;
   public static void main(String[] args)
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
        Group root = new Group();
        Scene scene = new Scene(root);
        Canvas canvas = new Canvas (800, 200);
        GraphicsContext gc = canvas.getGraphicsContext2D();
        int radius = DIAMETER / 2;
        int x = X_CENTER - radius; // upper left corner
        int y = Y_CENTER - radius;
        for (int i = 1; i <= 6; i++)
        {
              gc.setFill(Color.BLUE);
              gc.fillOval(x, y, DIAMETER, DIAMETER);
              gc.setFill(Color.BLACK);
              gc.strokeOval(x, y, DIAMETER, DIAMETER);
              x += DIAMETER + GAP;
        }
      root.getChildren().add(canvas);
      primaryStage.setTitle("HappyFace in JavaFX");
      primaryStage.setScene(scene);
      primaryStage.show();
  }
}
```

# Defining Classes and Methods

### **5.1 CLASS AND METHOD DEFINITIONS** 307

Class Files and Separate Compilation 309

Programming Example: Implementing a Dog
Class 309

Instance Variables 310

Methods 313

Defining void Methods 316

Defining Methods That Return a Value 317

Programming Example: First Try at Implementing a
Species Class 322

The Keyword this 326

Local Variables 328

Blocks 330

Parameters of a Primitive Type 331

# 5.2 INFORMATION HIDING AND ENCAPSULATION 337

Information Hiding 338
Precondition and Postcondition Comments 338
The public and private Modifiers 340
Programming Example: A Demonstration of Why
Instance Variables Should Be Private 343
Programming Example: Another Implementation of a
Class of Rectangles 344

Accessor Methods and Mutator Methods 346

Programming Example: A Purchase Class 350

Methods Calling Methods 354

Encapsulation 360

Automatic Documentation with javadoc 363

UML Class Diagrams 364

### **5.3 OBJECTS AND REFERENCES** 365

Variables of a Class Type 366
Defining an equals Method for a Class 371
Programming Example: A Species Class 375
Boolean-Valued Methods 378
Case Study: Unit Testing 380
Parameters of a Class Type 382
Programming Example: Class-Type Parameters
Versus Primitive-Type Parameters 386

### **5.4 GRAPHICS SUPPLEMENT** 390

The GraphicsContext Class 390

Programming Example: Multiple Faces, but with a Helping Method 394

Adding Labels to a JavaFX Application 398



Use harms and even destroys beauty. The noblest function of an object is to be contemplated.

-MIGUEL DE UNAMUNO, Niebla (1914)

Recall that an object is named by a variable of a class type. Objects have data, but they also can take actions. These actions are defined by methods. You have already been using some objects and invoking their methods. For example, you have created and used objects of type String. If name is an object of type String, its method length will return its length. In particular, the length of the string object name is the value returned by the expression name.length(). The class String is already defined for you in the Java Class Library. In this chapter, we will show you how to define your own simple classes and how to use objects and methods of those classes.

### **OBJECTIVES**

After studying this chapter, you should be able to

- Describe the concepts of a class and of an object of a class
- Create objects of a class
- Define a Java class and its methods
- Describe how parameters work in a method definition
- Use the modifiers public and private
- Define accessor methods and mutator methods for a class
- Write and use private methods within a class
- Describe information hiding and encapsulation
- Write preconditions and postconditions for a method
- Describe the purpose of javadoc
- Draw simple UML diagrams
- Describe references as well as variables of a class type and parameters of a class type
- Define an equals method and other boolean-valued methods
- Use methods and labels in a JavaFX application.

### **PREREQUISITES**

You need to be familiar with the material in the first four chapters before reading this chapter. You might want to review the section in Chapter 1 entitled "Object-Oriented Programming."

### **5.1** CLASS AND METHOD DEFINITIONS

Concentrate all your thoughts upon the work at hand. The sun's rays do not burn until brought to a focus.

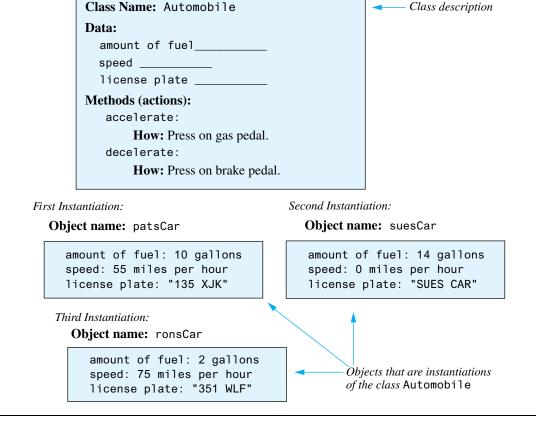
—ALEXANDER GRAHAM BELL, How They Succeeded, Orson Swett Marden, (1901)

A Java program consists of objects of various class types, interacting with one another. Before we go into the details of how you define your own classes and objects in Java, let's review and elaborate on what we already know about classes and objects.

Objects in a program can represent either objects in the real word—like automobiles, houses, and employee records—or abstractions like colors, shapes, and words. A class is the definition of a kind of object. It is like a plan or a blueprint for constructing specific objects. For example, Figure 5.1 describes a class called Automobile. The class is a general description of what an automobile is and what it can do.

Objects in a program can represent realworld things or abstractions

### FIGURE 5.1 A Class as a Blueprint



An instance of a class is an object

A class is like a blueprint for creating objects

A class specifies an object's attributes and defines its behaviors as methods

Use a UML class diagram to help design a class

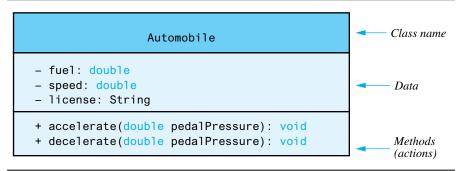
Objects of this class are particular automobiles. The figure shows three Automobile objects. Each of these objects satisfies the class definition of an Automobile object and is an **instance** of the Automobile class. Thus, we can create, or **instantiate**, several objects of the same class. The objects here are individual automobiles, while the Automobile class is a generic description of what an automobile is and does. This is, of course, a very simplified version of an automobile, but it illustrates the basic idea of what a class is. Let's look at some details.

A class specifies the attributes, or data, that objects of the class have. The Automobile class definition says that an Automobile object has three attributes or pieces of data: a number telling how many gallons of fuel are in the fuel tank, another number telling how fast the automobile is moving, and a string that shows what is written on the license plate. The class definition has no data—that is, no numbers and no string. The individual objects have the data, but the class specifies what kind of data they have.

The class also specifies what actions the objects can take and how they accomplish those actions. The Automobile class specifies two actions: accelerate and decelerate. Thus, in a program that uses the class Automobile, the only actions an Automobile object can take are accelerate and decelerate. These actions are described within the class by methods. All objects of any one class have the same methods. In particular, all objects of the class Automobile have the same methods. As you can see in our sample Automobile class, the definitions of the methods are given in the class definition and describe how objects perform the actions.

The notation in Figure 5.1 is a bit cumbersome, so programmers often use a simpler graphical notation to summarize some of the main properties of a class. This notation, illustrated in Figure 5.2, is called a **UML class diagram**, or simply a **class diagram**. **UML** is an abbreviation for **Universal Modeling Language**. The class described in Figure 5.2 is the same as the one described in Figure 5.1. Any annotations in Figure 5.2 that are new will be explained later in the chapter.

FIGURE 5.2 A Class Outline as a UML Class Diagram



Notice a few more things about a class and the objects that instantiate the class. Each object has a name. In Figure 5.1, the names are patsCar, suesCar, and ronsCar. In a Java program, these object names would be variables of type Automobile. That is, the data type of the variables is the class type Automobile.

Before we get further into the nitty-gritty of defining a simple class, let's review some of the things we said in Chapter 1 about storing classes in files and compiling them.

### **Class Files and Separate Compilation**

Whether you use a class taken from this book or one that you write yourself, you place each Java class definition in a file by itself. There are exceptions to this rule, but we will seldom encounter them, and we need not be concerned about them yet. The name of the file should begin with the name of the class and end in .java. So if you write a definition for a class called Automobile, it should be in a file named Automobile.java.

Each class is in a separate file

You can compile a Java class before you have a program in which to use it. The compiled bytecode for the class will be stored in a file of the same name, but ending in .class rather than .java. So compiling the file Automobile. java will create a file called Automobile.class. Later, you can compile a program file that uses the class Automobile, and you will not need to recompile the class definition for Automobile. This naming requirement applies to full programs as well as to classes. Notice that every program having a main method has a class name at the start of the file; this is the name you need to use for the file that holds the program. For example, the program you will see later in Listing 5.2 should be in a file named DogDemo.java. As long as all the classes you use in a program are in the same directory as the program file, you need not worry about directories. In Chapter 6, we will discuss how to use files from more than one directory.

## PROGRAMMING EXAMPLE

Implementing a Dog Class

To introduce the way that Java classes are defined let's create a simple class to represent a dog. Thus, we name our class Dog in Listing 5.1. Although its simplicity makes this first example easier to explain, it violates several important design principles. As we progress through this chapter we will discuss the weaknesses of the example's design and show how to improve it.

Each object of the Dog class stores the name, breed, and age of a dog. Additionally, each object has two actions, defined by the methods writeOutput and getAgeInHumanYears. The writeOutput method outputs the data stored about the dog and the getAgeInHumanYears method approximates the dog's equivalent age as if it were a human Both the data items and the methods are

Instance variables and methods are members of a class.

sometimes called **members** of the object because they belong to the object. We will call the data items **instance variables**. In the following subsections we will discuss the instance variables and then the methods.

### LISTING 5.1 Definition of a Dog Class

```
public class Dog
                                        Later in this chapter we will see that
{
                                        the modifier public for instance
    public String name;
                                        variables should be replaced with
    public String breed;
                                        private.
    public int age;
    public void writeOutput()
    {
        System.out.println("Name: " + name);
        System.out.println("Breed: " + breed);
        System.out.println("Age in calendar years: " +
                                   age);
        System.out.println("Age in human years: " +
                             getAgeInHumanYears());
        System.out.println();
    }
    public int getAgeInHumanYears()
        int humanAge = 0;
        if (age <= 2)
        {
             humanAge = age * 11;
        }
        else
        {
             humanAge = 22 + ((age-2) * 5);
        }
             return humanAge;
    }
}
```

### **Instance Variables**

The following three lines from the start of the class definition in Listing 5.1 define three instance variables:

```
public String name;
public String breed;
public int age;
```

The word public simply means that there are no restrictions on how these instance variables are used. You will soon see that using public here is a bad idea, but let's ignore that for now. Each of these lines declares one instance

variable. Notice that each instance variable has a data type. For example, the instance variable name is of type String.

You can think of an object of the class as a complex item having instance variables inside of it. In this case, the instance variables are called name, breed, and age. Each object, or instance, of the class has its own copy of these three instance variables, which is why they are called instance variables. The program in Listing 5.2 demonstrates how to use the Dog class and handle these instance variables.

### LISTING 5.2 Using the Dog Class and Its Methods

```
public class DogDemo
   public static void main(String[] args)
        Dog balto = new Dog();
        balto.name = "Balto";
        balto.age = 8;
        balto.breed = "Siberian Husky";
        balto.writeOutput();
        Dog scooby = new Dog();
        scooby.name = "Scooby";
        scooby.age = 42;
        scooby.breed = "Great Dane";
        System.out.println(scooby.name + " is a " +
                           scooby.breed + ".");
        System.out.print("He is " + scooby.age +
                          " years old, or ");
        int humanYears = scooby.getAgeInHumanYears();
        System.out.println(humanYears + " in human years.");
   }
}
```

### Sample Screen Output

```
Name: Balto
Breed: Siberian Husky
Age in calendar years: 8
Age in human years: 52
Scooby is a Great Dane.
He is 42 years old, or 222 in human years.
```

The following line from Listing 5.2 creates an object of type Dog and attaches the name balto to the object:

```
Dog balto = new Dog();
```

The variables balto and scooby reference distinct Dog objects, each with their own instance variables of name, breed, and age. You can refer to one of these instance variables by writing the object name followed by a dot and then the instance variable's name. For example,

```
balto.name
```

Since name is of type String, balto.name is a variable of type String and can be used anywhere that you can use a variable of type String. For example, all of the following are valid Java statements:

```
balto.name = "Balto";
System.out.println("The dog's name is " + balto.name);
String niceName = balto.name;
```

Since each object of type Dog has its own three instance variables, if your program also contained the statement

```
Dog scooby = new Dog();
```

Then balto.name and scooby.name would be two different instance variables that might have different string values. In Listing 5.2 they do have different values since balto.name is set to "Balto" and scooby.name is set to "Scooby".

### FAQ Why do we need new?

In Java, new is a unary operator that we use to create objects of a class. When new is used in an expression such as

```
Dog scooby = new Dog();
```

it creates an object of the class Dog. The new operator then returns the memory address of the object. The preceding Java statement assigns this address to the variable scooby. An object can have variables inside of it, namely, the instance variables of the object. The new operator places these instance variables inside of the object when it creates the object.

# FAQ If the program in Listing 5.2 is a class, why doesn't it have instance variables?

A program is simply a class that has a method named main. But a program can have other methods and can have instance variables, even though none of the programs we have written so far have instance variables or any methods other than main.

### Methods

When you use a method, you are said to invoke or call it. You have already invoked methods. For example, your programs have invoked the method nextInt using objects of the class Scanner. You have also invoked the method println of the object System.out, as in the following statement:

You invoke, or call, a method

System.out.println("Hello out there!");

Java has two kinds of methods:

- Methods that return a single item
- Methods that perform some action other than returning an item

Two kinds of methods

The method nextInt is an example of a method that returns a single value, one of type int. The method println is an example of a method that performs some action other than returning a single value. Methods that perform some action other than returning a value are called **void methods**.

### **REMEMBER Two Kinds of Methods**

Java has two kinds of methods: those that return a single value or object and those that perform some action other than returning an item. These two different kinds of methods are normally used in slightly different ways.

Let's review how you invoke a method. The method nextInt of the class Scanner is a method that returns a single value. Suppose the declaration

```
int theNextInteger;
```

is in a program. The following statement invokes the method nextInt using the object keyboard, which we assume is an object of the class Scanner:

```
theNextInteger = keyboard.nextInt();
```

Let's look at this method invocation in more detail.

A method defined in a class is usually invoked using an object of that class. You write the receiving object name—such as keyboard—followed by a dot, and then the name of the method—such as nextInt—and finally a set of parentheses that can contain arguments for the method. If the method is one that returns a single quantity, such as the method nextInt, you can use this method invocation anywhere that you can use an item of the type returned by the method. The method nextInt returns a value of type int, and so you can use the expression

```
keyboard.nextInt()
```

Calling a method that returns a value

anywhere that it is valid to use a value of type int. The expression behaves as if it were replaced by the value returned. For example, since the assignment statement

```
int data = 6;
is valid, so is the statement
  int data = keyboard.nextInt();
```

Methods that perform some action other than returning a single quantity are invoked in a similar way. But since they do not return a value, their invocations stand alone; they are not embedded in another Java statement. For example, the following statement includes an invocation of the method println:

```
System.out.println("Hello out there!");
```

This method call causes the sentence Hello out there! to be displayed on the screen.

Calling the method writeOutput for the class Dog, as in Listing 5.2, has a similar effect, except that you do not have to tell writeOutput what to write by including arguments inside the parentheses. Instead, the method writeOutput gets the information it needs from its receiving object.

For example, the latter part of the program in Listing 5.2 sets the values of the instance variables of the object balto using the following three assignment statements:

```
balto.name = "Balto";
balto.age = 8;
balto.breed = "Siberian Husky";
```

The program then uses the following statement to display these values:

```
balto.writeOutput();
```

The method writeOutput gets data from the object balto to produce the output

```
Name: Balto
Breed: Siberian Husky
Age in calendar years: 8
Age in human years: 52
```

At the end of Listing 5.2 we perform essentially the same task as the writeOutput method by accessing the instance variables directly from the scooby object. While this can be useful to generate a customized message, if we are happy with the writeOutput output then the last four lines of main can be simplified down to

```
scooby.writeOutput();
```

Calling a void method

### **REMEMBER Invoking (Calling) a Method**

You invoke a method by writing the name of the receiving object followed by a dot, the name of the method, and finally a set of parentheses that can contain arguments providing information for the method.

### **RECAP** Calling a Method That Returns a Quantity

If a method returns a single quantity, you can invoke it anywhere that you can use a value of the type returned by the method. For example, the following statement includes an invocation of the method getAgeInHumanYears, and the value returned is assigned to the int variable humanYears:

humanYears = scooby.getAgeInHumanYears();

### **RECAP Calling a void Method**

If a method performs some action other than returning a single quantity, you write its invocation followed by a semicolon. The resulting Java statement performs the action defined by the method. For example, the following is an invocation of the method writeOutput for the object balto:

balto.writeOutput();

This method invocation displays several lines of output on the screen.

# FAQ What about main? If it is indeed a method, why don't I invoke it?

When you run a program, the system invokes the void method named main. Of course, this is a special kind of method invocation—one that you do not write—but it is a method invocation nonetheless.

### **Defining void Methods**

A definition of a void method

Let's look at the definition of the method writeOutput to see how method definitions are written. The definition is given in Listing 5.1 and is repeated here:

All method definitions appear inside the definition of the class to which they belong. If you look at Listing 5.1, you will see that this method definition is inside the definition of the class Dog. This means that the method can be used only with objects of the class Dog.

For now, our method definitions begin with the keyword public. The word public indicates that there are no special restrictions on the use of the method. Later in this chapter, you will see that the word public can sometimes be replaced by other modifiers that restrict the use of the method.

For a method like writeOutput that does not return a value, you next write the keyword void. This keyword indicates that the method does not return a value and is the reason why this kind of method is called a void method. After the keyword void, you write the name of the method and a pair of parentheses. The parentheses enclose representations of any arguments that the method will need. In our example, no extra information is needed, and so there is nothing inside the parentheses. Later in the chapter, you will see examples of the sorts of things that might appear inside these parentheses for other method definitions. This first part of the method definition is called the heading for the method. The heading is normally written on a single line, but if it is too long for one line, it can be broken into two or more lines.

After the heading comes the rest of the method definition, which is called the **body**. The statements in the body of the method definition are enclosed between braces{}. Any statement or declaration that you can place in a program can appear within the body. You can use instance variables within the body. Any other variables used in a method definition must be declared within that method definition. Such variables are called **local variables**.

When a void method is invoked, it is as if the method invocation were replaced by the body of the method definition and its statements were then executed. There are some subtleties about this replacement process, but for the simple examples we will look at now, think of the body of the method definition as literally replacing the method invocation. Eventually, you'll want to think of the method definition as defining an action to be taken, rather than as a list of statements to substitute for the method invocation, but this

A method definition has a heading and a body

Local variables are those declared within a method's body substitution idea is correct and is a good way to start understanding method invocations.

For example, you can imagine replacing the method invocation

```
balto.writeOutput();
```

with the body of the method writeOutput. In this case, it is as if the preceding method invocation were replaced by the following statements:

The names—name, breed, and age—refer to the instance variables of the receiving object balto. So, to be more precise, the method invocation is equivalent to the statements

### REMEMBER main Is a void Method

It is indeed true that main is a void method. For now, those extra words like static and String[]args in its heading will have to remain a mystery. Just put them in, and eventually we will explain them all. Only a class that is run as a program needs a main method, but any class can have one. If a class has a main method but the class is not run as a program, main is simply ignored.

### **Defining Methods That Return a Value**

You define a method that returns a value in basically the same way that you define a void method, with one added concern—namely, specifying the value returned. Let's consider the method getAgeInHumanYears from the class Dog. This method estimates a dog's equivalent age in human years. We called this method as follows:

```
int humanYears = scooby.getAgeInHumanYears();
```

This statement sets the value of the variable humanYears equal to the value returned by the method invocation

```
scooby.getAgeInHumanYears()
```

The definition of the method getAgeInHumanYears tells the computer how to compute the value returned.

Let's look at that method definition in Listing 5.1. Like a void method definition, the definition of a method that returns a value can be divided into two parts: the method heading and the method body. Here is the heading for the method getAgeInHumanYears:

```
public int getAgeInHumanYears()
```

The heading for a method that returns a value is almost the same as the heading for a void method. The only difference is that a method that returns a value uses a type name instead of the keyword void. The heading begins with the keyword public, followed by a type name—which is the type of the value to be returned—followed by the name of the method and a pair of parentheses. As is true of void methods, the parentheses enclose representations of any arguments that the method will need. In this example, the parentheses are empty. As before, the keyword public indicates that there are no special restrictions on the use of the method.

The body of a method definition that returns a value is just like the body of a void method definition, except that it must contain at least one return statement:

```
return Expression;
```

A return statement says that the value returned by the method is the value of *Expression*. *Expression* can be any expression that produces a value of the type specified in the heading of the method definition. For example, the definition of the method getAgeInHumanYears contains the statement

```
return 22 + ((age - 2) * 5);
```

When a method that returns a value is invoked, the statements in the body of the method definition are executed. For example, when the assignment statement

```
int humanYears = scooby.getAgeInHumanYears();
```

executes, the body of the method definition for getAgeInHumanYears is executed. The statements in that body are as follows:

```
int humanAge = 0;
if (age <= 2)
{
    humanAge = age * 11;
}
else
{
    humanAge = 22 + ((age - 2) * 5);
}
return humanAge;</pre>
```

The heading of a method that returns a value contains the return type

The body of a method that returns a value contains a return statement

The instance variable age refers to the instance variable of the receiving object, which in this case is scooby. The value of age in Listing 5.2 is set to 42. Using the formula that each dog year is approximately equivalent to 11 human years up to age 2, and then each dog year is approximately equivalent to 5 human years thereafter, we return the appropriate human age for the dog. The variable humanAge is set to the calculated value and returned at the end of the method.

When a return statement executes, not only does it provide the value returned by the method but it also ends the method's execution. If more statements follow the return statement, they are not executed.

A method that returns a value may perform some other action as well, such as reading a value from the keyboard, but it definitely must return a value.

Execution of a return statement ends a method's execution

### **REMEMBER Naming Methods**

Java will let you use any valid identifier—but not a keyword—as the name for a method. However, you should choose clear, meaningful names to make your code easier to read. Since methods perform actions, you should use a verb or verb phrase as the name of a method. The normal convention is to begin all method names with a lowercase letter. Recall that, by convention, we begin class names with an uppercase letter.

### PROGRAMMING TIP Use One return Statement

Although you can use more than one return statement within the body of a method that returns a value, you typically should use only one. Placing that one return statement at or near the physical end of the method's body makes your method easier to read.

We used a single return statement in the definition of the method getAgeInHumanYears. Instead, we could have used multiple return statements, one for the case where age  $\leq 2$  and another when age > 2:

```
if (age <= 2)
{
    return age * 11;
}
else
{
    return 22 + ((age-2) * 5);
}</pre>
```

Some programmers find this to be clear, particularly since the return statements are at or near the end of the method definition. However, if the logic of the method were more complicated, and a return statement occurred far from the physical end of the method definition, understanding the logic would be more difficult. We prefer to use only one return statement in a method.

### FAO I've heard of functions. Does Java have functions?

No, Java does not have functions. In some other programming languages, methods that return a value are called *functions*, as they correspond to the mathematical notion of a function. However, in Java, regardless of whether a method returns a value or not, it is called a *method*, not a *function*.

### FAQ Can a void method contain a return statement?

Since a void method returns no value, it typically does not have any return statement. However, you can write a return statement within a void method without an accompanying expression, as follows:

### return;

This statement is just like the other return statements you have seen, except that you do not include any expression for the value returned. When executed, this return statement simply ends the execution of the void method.

Some programmers use this statement to end a method invocation early, such as when the method discovers some sort of problem. For example, you might add the following method to the definition of the class SpeciesFirstTry in Listing 5.3.

The method's execution would end at the return statement if the rest of the method would involve a division by zero.

(continued)

Sometimes, using a return statement within a void method is the clearest and easiest approach, but more often, a better solution is possible. Such is the case with our example. Adding an else portion to the if statement, as follows, clarifies the logic of the method:

### **RECAP Method Definitions**

Every method belongs to some class and is available to objects created from that class. The definition of a method is given in the definition of the class to which it belongs. Each method either returns a single quantity or does not return any value. The latter kind of method is called a void method.

### **SYNTAX**

```
public Return_Type Method_Name(Parameters)
{
    Statements
}
```

where *Return\_Type* is either void or the data type of the quantity returned by the method. In the latter case, *Statements* must contain at least one return statement of the form

```
return Expression;
```

A return statement defines the value returned by the method and ends the method's execution. A void method does not need a return statement, but it can have one if you want to end the method invocation (continued)

before the physical end of the code. If that is the case, the return statement omits *Expression*. Using a return statement in a void method is not typical.

So far, we have not discussed *Parameters*, but we will do so shortly. If there are no *Parameters*, the parentheses are empty.

### **EXAMPLES**

```
public void writeOutput()
{
    System.out.println("Name: " + name);
    System.out.println("Breed: " + breed);
    System.out.println("Age in calendar years: " + age);
}
public int halveThePopulation()
{
    return population / 2;
}
```

### PROGRAMMING EXAMPLE

First Try at Implementing a Species Class

The next example in Listing 5.3 is designed to hold records of endangered species. This class is slightly more complex than the Dog class but still violates several important design principles. Later we will improve on this example as we discuss these principles. Thus, we name our class SpeciesFirstTry.

LISTING 5.3 A Species Class Definition-First Attempt (part 1 of 2)

```
We will give a better version of
import java.util.Scanner;
                                              this class later in this chapter.
public class SpeciesFirstTry
{
    public String name;
                                        Later in this chapter you will see that the
    public int population;
                                       modifier public for instance variables
    public double growthRate;
                                       should be replaced with private.
    public void readInput()
    {
         Scanner keyboard = new Scanner(System.in);
         System.out.println("What is the species' name?");
         name = keyboard.nextLine();
         System.out.println("What is the population of the " +
                               "species?");
         population = keyboard.nextInt();
                                                               (continued)
```

## LISTING 5.3 A Species Class Definition-First Attempt (part 2 of 2)

```
System.out.println("Enter growth rate " +
                            "(% increase per year):");
        growthRate = keyboard.nextDouble();
    public void writeOutput()
        System.out.println("Name = " + name);
        System.out.println("Population = " + population);
        System.out.println("Growth rate = " + growthRate + "%");
    }
    public int getPopulationIn10()
        int result = 0;
        double populationAmount = population;
        int count = 10;
        while ((count > 0) && (populationAmount > 0))
            populationAmount = populationAmount +
                                (growthRate / 100) *
                                populationAmount;
            count - - ;
        }
        if (populationAmount > 0)
                 result = (int)populationAmount;
        return result;
    }
}
```

Each object of this class has three pieces of data: a name, a population size, and a growth rate. The data is contained in three instance variables, name, population, and growthRate. The objects have three actions, defined by the methods readInput, writeOutput, and getPopulationIn10.

The code in Listing 5.4 creates an object of type SpeciesFirstTry and attaches the name speciesOfTheMonth to this object. Based on the population and growth rate it outputs the expected population in ten years.

LISTING 5.4 Using the Species Class and Its Methods (part 1 of 2)

## LISTING 5.4 Using the Species Class and Its Methods (part 2 of 2)

```
speciesOfTheMonth.readInput();
        speciesOfTheMonth.writeOutput();
        int futurePopulation =
            speciesOfTheMonth.getPopulationIn10();
        System.out.println("In ten years the population will be "
                           + futurePopulation);
        //Change the species to show how to change
        //the values of instance variables:
        speciesOfTheMonth.name = "Klingon ox";
        speciesOfTheMonth.population = 10;
        speciesOfTheMonth.growthRate = 15;
        System.out.println("The new Species of the Month:");
        speciesOfTheMonth.writeOutput();
        System.out.println("In ten years the population will "
                 "be " + speciesOfTheMonth.getPopulationIn10());
   }
}
```

#### Sample Screen Output

```
Enter data on the Species of the Month:
What is the species' name?
Ferengie fur ball
What is the population of the species?
1000
Enter growth rate (% increase per year):
-20.5
Name = Ferengie fur ball
Population = 1000
Growth rate = 20.5%
In ten years the population will be 100
The new Species of the Month:
Name = Klingon ox
Population = 10
Growth rate = 15.0%
In ten years the population will be 40
```

Like all objects of type SpeciesFirstTry, the object speciesOfTheMonth has three instance variables called name, population, and growthRate. Rather than set the values of the instance variable from the main method as in Listing 5.2,

instead we invoke the readInput method to input values from the keyboard. The input values are stored with the instance variables associated with the speciesOfTheMonth object.

The statements in that body of the getPopulationIn10 are as follows:

The instance variable population refers to the instance variable of the receiving object, which in this case is speciesOfTheMonth. The value of population is copied into the variable populationAmount, and then the while loop is executed. Each iteration of the loop increases the value of populationAmount by the amount that the population will change in one year, and the loop is iterated ten times. When the while loop ends, the value of populationAmount is the projected size of the population in ten years. At that point, populationAmount has the value we want the method to return For now, let's assume that populationAmount is positive—that is, the species is not extinct. Thus, the if statement will set result to the value (int) populationAmount. The (int) is a type cast that changes the double value to an int value so that you do not have a fraction of an animal. The value of result is returned by the method invocation via the statement:

```
return result;
```

The effect is like replacing the method invocation with (int)population Amount. In this case, the assignment statement

```
int futurePopulation = speciesOfTheMonth.getPopulationIn10();
```

sets the variable futurePopulation to the value of (int) populationAmount.

If populationAmount happens to be zero or negative, the statement leaves result unchanged from its initial value of zero. So the return statement, and hence the method invocation, returns zero. This is a minor detail that ensures that the projected population will not be negative. After all, in the real world, once a population reaches zero individuals, it just stays at zero.

## The Keyword this

Look back at the class definition of the class SpeciesFirstTry in Listing 5.3, and then look at the program in Listing 5.4 that uses this class. Notice that instance variables are written differently, depending on whether they are within the class definition or someplace outside the class definition, such as in a program that uses the class. Outside the class definition, you name an instance variable by giving the name of an object of the class followed by a dot and the name of the instance variable, as in the following reference to the instance variable name that appears in Listing 5.4:

```
speciesOfTheMonth.name = "Klingon ox";
```

However, inside the definition of a method of that same class, you can simply use the instance variable name without any object name or dot. For example, the following line occurs inside the definition of the method readInput of the class SpeciesFirstTry in Listing 5.3:

```
name = keyboard.nextLine();
```

As you know, every instance variable, including name, is an instance variable of some object. In cases like this, the object is understood to be there, but its name usually is omitted. This understood object has the somewhat unusual name of this. Although this is frequently omitted—but understood to be there—you can include it if you want. For example, the preceding assignment of the instance variable name is equivalent to the following:

```
this.name = keyboard.nextLine();
```

As another example, the following method is equivalent to the version of writeOutput used in Listing 5.3:

```
public void writeOutput()
{
    System.out.println("Name = " + this.name);
    System.out.println("Population = " + this.population);
    System.out.println("Growth rate = " + this.growthRate + "%");
}
```

The keyword this stands for the receiving object. For example, in the invocation

```
speciesOfTheMonth.writeOutput();
```

the receiving object is speciesOfTheMonth. So this invocation of the method writeOutput is equivalent to

Within a class definition, this is a name for the receiving object

```
System.out.println("Growth rate = " +
    speciesOfTheMonth.growthRate + "%");
}
```

which we got by replacing this with speciesOfTheMonth.

The keyword this is like a blank waiting to be filled in with the object that receives the method invocation. Because you would be using this so often if it were required, Java lets you omit it, along with the dot that follows it, but the this and the dot are understood to be there implicitly. Many programmers seldom use the keyword this when doing so is optional, but some situations do require it. On the other hand, some programmers always use the keyword this to make it clear that the object is being referenced.

#### **RECAP The Keyword** this

Within a method definition, you can use the keyword this as a name for the object receiving the method call.

## **SELF-TEST QUESTIONS**

- 1. Consider the program in Listing 5.4. Suppose you wanted to add another species object called speciesOfTheYear, and suppose you wanted the user to provide its name, population, and growth rate. What code do you need to add to the program? (*Hint:* Only a few lines of code are needed.)
- 2. Suppose Employee is a class containing a void method named readInput, and dilbert is an object of the class Employee that was named and created by the following statement:

```
Employee dilbert = new Employee();
```

Write an invocation of the method readInput using dilbert as the receiving object. The method readInput needs no information in parentheses.

- 3. Let's say you want to assign a number as well as a name to each species in the world, perhaps to make it easier to catalog them. Modify the definition of the class SpeciesFirstTry in Listing 5.3 so that it allows for a number. The number is to be of type int. (*Hint:* You mostly just have to add stuff.)
- 4. Suppose every species in the world has a peculiar birthing pattern. After a female is born, a male is born, then a female, and so on. Give the definition

of a method, called getFemalePopulation, that you could add to the definition of the class SpeciesFirstTry in Listing 5.3 to return the number of females in the population. Also, give the definition of a method called getMalePopulation that similarly returns the number of males in the population. If the population is an odd number, you have one species member left over after pairing males and females. Assume that species member is a female. For example, if the population is 7, there are 3 males and 4 females. But if the population is 8, there are 4 males and 4 females. (*Hint:* The definitions are very short.)

- 5. Revise the definition of the method writeOutput in Listing 5.3, using the keyword this. Do not change the meaning of the definition at all. You will just write it slightly differently. (*Hint:* All you need to do is add this and dots in certain places.)
- 6. Revise the definition of the method readInput in Listing 5.3, using the keyword this.
- 7. Revise the definition of the method getPopulationIn10 in Listing 5.3, using the keyword this.
- 8. What is the meaning of (int) that appears in the definition of the method getPopulationIn10 in Listing 5.3, and why is it needed?

#### **Local Variables**

Notice the definition of the method getPopulationIn10 given in Listing 5.3. That method definition includes the declaration of variables called populationAmount and count. As we mentioned earlier in this chapter, a variable declared within a method is called a local variable. We say the variable is local because its meaning is local to—that is, confined to—the method definition.

Suppose you have two methods defined within the same class. If each method declares a variable of the same name—result, for example—we would have two different variables that just happened to have the same name. Any change made to the value of result within one method would not affect the variable named result in the other method. It would be as if the two methods were executed on different computers, or as if the computer changed the name of result in one of the two methods to result2.

All variables declared in a program's main method are local to main. If one happens to have the same name as a variable declared in some other method, they are two different variables that just happen to have the same name. For example, look at the class definition and program in Listing 5.5. First consider the program, which is shown in the lower half of the listing. The method main in the program includes the declaration of a variable named newAmount. Now look at the class definition in the upper half of the listing. The method

The meaning of a local variable is confined to the method containing its declaration

### LISTING 5.5 Local Variables

```
This class definition is in a file
        named BankAccount.java.
This class is used in the program LocalVariablesDemoProgram.
public class BankAccount
{
    public double amount;
                                                    This does not change
    public double rate;
                                                    the value of the variable
    public void showNewBalance()
                                                    newAmount in main.
        double newAmount = amount + (rate / 100.0)
                                             amount;
        System.out.println("With interest added, the new amount
                              is $" + newAmount);
    }
                                             Two different variables named
}
                                             newAmount
        This program is in a file named
       LocalVariableDemoProgram.java.
/**
A toy program to illustrate how local variables behave.
public class LocalVariablesDemoProgram
{
    public static void maxin(String[] args)
    {
        BankAccount myAccount = new BankAccount();
        myAccount.amount = 100.00;
        myAccount.rate = 5;
        double newAmount = 800.00;
        myAccount.showNewBalance();
        System.out.println("I wish my new amount were $" +
                              newAmount);
    }
}
```

### **Screen Output** Chapter 6 will fix the appearance of dollar amounts.

```
With interest added, the new amount is $105.0 I wish my new amount were \$800.0
```

showNewBalance in the class also declares a variable named newAmount. These two variables are different. In main, newAmount is set equal to 800.00 and then the method showNewBalance is called:

myAccount.showNewBalance();

If you look at the definition of this method and do a little arithmetic, you will see that showNewBalance sets newAmount to 105.00. Yet this assignment has no effect on the other variable named newAmount within main. Displaying newAmount in main after the method invocation shows that its value is still 800.00. Changing the value of newAmount in the method showNewBalance had no effect on the variable named newAmount in main. In this case, the two methods that each use a local variable named newAmount are in different classes in two different files. However, the situation would be the same if the two methods were in the same class definition and thus in the same file.

#### **RECAP Local Variables**

A variable declared within a method definition is called a local variable. One method's local variables have no meaning within another method. Moreover, if two methods each have a local variable with the same name, they are considered two different variables.

#### FAO I've heard about global variables. What are they?

Thus far, we have discussed two kinds of variables: instance variables, whose meaning is confined to an object of a class, and local variables, whose meaning is confined to a method definition. Some programming languages have another kind of variable, called a **global variable**, whose meaning is confined only to the program, that is, it's not confined at all. Java does not have these global variables. However, as you will see in the next chapter, Java does have a kind of variable—the static variable—that in a sense can take the place of global variables.

Java has no global variables

#### **Blocks**

In Chapter 3, you saw that a compound statement is a group of Java statements enclosed in braces {}. The term **block** really means the same thing. However, the two terms tend to be used in different contexts. When you declare a variable within a compound statement, the compound statement is usually called a block.

If you declare a variable within a block—that is, within a compound statement—the variable is local to the block. Recall from the previous chapter that the portion of a program in which a variable has meaning is known as the

A block is a compound statement that declares a local variable

variable's scope. So the scope of a local variable extends from its declaration to the end of the block containing the declaration. This means that when the block ends, all variables declared within the block disappear. You can even use that variable's name to name some other variable outside of the block. If you declare a variable outside a block, you can use it both inside and outside the block, and it will have the same meaning throughout.

#### **RECAP Blocks**

A block is the same as a compound statement, that is, a list of statements enclosed in braces. However, we tend to use the term *block* when a variable declaration occurs within the braces. The variables declared in a block are local to the block, and so these variables disappear when the execution of the block ends.

## **GOTCHA** Variables Declared in a Block

When you declare a variable within a block, you cannot use the variable outside the block. Declaring the variable outside the block will let you use the variable both outside and inside the block.

## Parameters of a Primitive Type

Consider the method getPopulationIn10 for the class SpeciesFirstTry defined in Listing 5.3. It returns the projected population of a species ten years in the future. But what if you want the projection for five years in the future or fifty years in the future? The method would be much more useful if it projected the population for any given number of years into the future. To do this, we need some way of leaving a blank in a method so that each call of the method can fill in the blank with a different value for the number of years. The things that serve as blanks in methods are called **formal parameters**, or simply **parameters**. They are a bit more complicated than simple blanks, but you will not go too far wrong if you think of them as blanks or place holders to be filled in with some value when the method is invoked.

Let's revise the class SpeciesFirstTry to use this new idea. The class SpeciesSecondTry defined in Listing 5.6 includes a method called predictPopulation that has one formal parameter called years. When you invoke this method, you give it the value that you want to have substituted for the parameter years. For example, if speciesOfTheMonth is declared to be of type SpeciesSecondTry, you can use the method predictPopulation to calculate the population in 12 years as follows:

int futurePopulation = speciesOfTheMonth.predictPopulation(12);

The program in Listing 5.7 is like the program in Listing 5.4, but instead it uses the class SpeciesSecondTry and its method predictPopulation. With this

A formal parameter in a method definition represents the actual argument version of the class, we could project a population any number of years into the future. We could even use a variable for the number of years, as follows:

Let's look at the definition of the method predictPopulation in more detail. The heading, shown below, has something new:

```
public int predictPopulation(int years)
```

The word years is a formal parameter. It is a stand-in for a value that will be plugged in when the method is called. The item that is plugged in is called an argument, as you know from earlier chapters. In some other books, arguments are called **actual parameters**. For example, in the following call, the value 10 is an argument:

```
int futurePopulation =
    speciesOfTheMonth.predictPopulation(10);
```

The argument 10 is plugged in for the formal parameter years everywhere that years occurs in the definition of the method predictPopulation in Listing 5.6. After that, the method invocation proceeds as in all previous method invocations you have seen.

Notice that only the *value* of the argument is used in this substitution process. If the argument in a method invocation is a variable, only the value of the variable is plugged in, not the variable name. For example, consider the following, which might occur in some program that uses the class SpeciesSecondTry:

```
SpeciesSecondTry mySpecies = new SpeciesSecondTry();
int yearCount = 12;
int futurePopulation =
   mySpecies.predictPopulation(yearCount);
```

In this case, it is the value 12, not the variable yearCount, that is plugged in for the formal parameter years in the definition of the method predictPopulation. Because only the value of the argument is used, this way of plugging in arguments for formal parameters is known as the call-by-value mechanism. In Java, this is the only mechanism used for parameters of a primitive type, such as int, double, and char. As you will eventually see, parameters of a class type involve a somewhat different substitution mechanism, but for now, we are concerned only with parameters and arguments of primitive types.

The exact details of this parameter substitution are a bit more complicated than what we have described so far. Usually, you need not be concerned with these extra details, but occasionally, you will need to know how the substitution

Java passes arguments to a method using call-by-value mechanism actually works. So here are the exact technical details: The formal parameter that occurs in the method definition is a *local variable* that is initialized to the value of the argument given in the method invocation. For example, the parameter years of the method predictPopulation in Listing 5.6 is a local variable of that method, and int years is its declaration. Given the method call,

Parameters are local variables

```
int futurePopulation =
   mySpecies.predictPopulation(yearCount);
```

the local variable years is set equal to the value of the argument yearCount. The effect is the same as if the method definition began as follows:

```
public int predictPopulation(int years)
{
    years = yearCount;
    int result = 0;
    double populationAmount = population;
    int count = years;
    . . .
This is the effect of plugging in the argument yearCount.
```

#### LISTING 5.6 A Method That Has a Parameter

```
import java.util.Scanner;
                                          We will give an even better version
public class SpeciesSecondTry
                                         of the class later in the chapter.
    <The declarations of the instance variables name, population,
    and growthRate are the same as in Listing 5.3.>
    <The definitions of the methods readInput and writeOutput
    are the same as in Listing 5.3.>
    Returns the projected population of the receiving object
    after the specified number of years.
    */
    public int predictPopulation(int years)
        int result = 0;
        double populationAmount = population;
        int count = years;
        while ((count > 0) && (populationAmount > 0))
        {
            populationAmount = (populationAmount +
            (growthRate / 100) * populationAmount);
            count--;
        }
            if (populationAmount > 0)
                 result = (int)populationAmount;
            return result;
    }
```

#### RECAP Parameter Names Are Local to the Method

In Java, you can choose the name of a method's formal parameter without any concern that this name will be the same as an identifier used in some other method. Formal parameters are really local variables, and so their meanings are confined to their respective method definitions.

Parameters have a type

The data type of a formal parameter in a method heading is written before the parameter. In our example, the data type of the parameter years is int. Every formal parameter has a data type, and the argument that is plugged in for the parameter in a method invocation must match the type of the parameter. Thus, for the method predictPopulation, the argument we give in parentheses when we invoke the method must be of type int.

This rule is not as strict in practice as we have just implied. In many cases, Java will perform an automatic type conversion—a type cast—if you use an argument in a method call that does not match the type of the formal parameter exactly. For example, if the type of the argument in a method call is int and the type of the parameter is double, Java will convert the value of type int to the corresponding value of type double. The following list shows the type conversions that will be performed for you automatically. An argument in a method invocation that is of any of these types will automatically be converted to any of the types that appear to its right if that is needed to match a formal parameter:<sup>1</sup>

Automatic type casting

#### $byte \rightarrow short \rightarrow int \rightarrow long \rightarrow float \rightarrow double$

Note that this list is exactly the same as the one used for automatic type casting for variables, which we discussed in Chapter 2. Thus, we can express the automatic type casting for both arguments and variables as one rule: You can use a value of any of the listed types anywhere that Java expects a value of a type further down on the list.

So far, our discussion of parameters has involved methods that return a value, but everything we have said about formal parameters and arguments

## **RECAP** Parameters of a Primitive Type

In a method definition, a formal parameter is given in the heading, within the parentheses right after the method name. A formal

(continued)

<sup>&</sup>lt;sup>1</sup> An argument of type char will also be converted to a matching number type if the formal parameter is of type int or any type to the right of int in our list of types. However, we do not advocate using this feature.

parameter of a primitive type—such as int, double, or char—is a local variable.

When a method is invoked, each parameter is initialized to the value of the corresponding argument in the method invocation. This type of substitution is known as the call-by-value parameter mechanism. The argument in a method invocation can be a literal constant, such as 2 or 'A'; a variable; or any expression that yields a value of the appropriate type.

Note that if you use a variable of a primitive type as an argument in a method invocation, the method invocation cannot change the value of this argument variable.

applies to void methods as well: void methods can have formal parameters, which are handled in exactly the same way as we just described for methods that return a value.

It is possible, even common, to have more than one formal parameter in a method definition. In that case, each formal parameter is listed in the method heading, and each parameter is preceded by a data type. For example, the following might be the heading of a method definition:

Several parameters are possible in a method

public void doStuff(int n1, int n2, double cost, char code)

Even if more than one parameter has the same type, each parameter must be preceded by a type name.

The number of arguments given in a method invocation must be exactly the same as the number of formal parameters in the heading of the method definition. For example, the following might be an invocation of our hypothetical method doStuff:

```
anObject.doStuff(42, 100, 9.99, Z);
```

As suggested by this example, the correspondence is one of order and type. The first argument in the method call is plugged in for the first parameter in the method definition heading, the second argument in the method call is plugged in for the second parameter in the heading of the method definition, and so forth. Each argument must match its corresponding parameter in data type,

except for the automatic type conversions that we discussed earlier.

One word of warning: Parameters of a class type behave differently from parameters of a primitive type. We will discuss parameters of a class type later in this chapter.

## **ASIDE** Use of the Terms Parameter and Argument

Our use of the terms parameter and argument is consistent with common usage. We use parameter to describe the definition of the data type and variable inside the header of a method and argument to describe items passed into a method when it is invoked. However, people often use these terms interchangeably. Some people use the term parameter both for what we call a formal parameter and for what we call an argument. Other people use the term argument both for what we call a formal parameter and for what we call an argument. When you see the term parameter or argument in other books, you must figure out its exact meaning from the context.

> Arguments must match parameters in number, order, and type

## RECAP Correspondence Between Formal Parameters and Arguments

Within a method definition, formal parameters are given within the parentheses after the method name. In a method invocation, arguments are given within the parentheses after the method name. Arguments must match the formal parameters in the method heading with respect to their number, their order, and their data types.

The arguments are plugged in for their corresponding formal parameters. The first argument in the method invocation is plugged in for the first parameter in the method definition, the second argument in the method invocation is plugged in for the second parameter in the method definition, and so forth. Arguments should be of the same types as their corresponding formal parameters, although in some cases, Java will perform an automatic type conversion when the types do not match exactly.



#### **RECAP Class Definitions**

#### **SYNTAX**

```
public class Class_Name
{
    Instance_Variable_Declarations
    . . .
    Method_Definitions
}
```

Although this is the form we will use most often, you are also allowed to intermix the method definitions and the instance variable declarations.

## **RECAP Method Headings**

#### SYNTAX

The method headings we have seen thus far are all of the form

```
public Type_Name_Or_void Method_Name(Parameter_List)
```

The Parameter\_List is a list of formal parameter names, each preceded by a data type. If the list has more than one entry, the entries are separated by commas. A method might have no parameters at all, in which case nothing is inside the parentheses.

(continued)

#### **EXAMPLES**

```
public double getTotal(double price, double tax)
public void setValue(int count, char rating)
public void readInput()
public int predictPopulation(int years)
```

The syntax for a complete method definition is given in the Recap in Section 5.1.



## **SELF-TEST QUESTIONS**

- 9. What is the difference between the unqualified term *parameter* and the term *formal parameter*?
- 10. Define a method called getDensity that could be added to the definition of the class SpeciesSecondTry in Listing 5.6. This method has one parameter of type double that is named area. The parameter area gives the area occupied by the species, expressed in square miles. The method getDensity returns a value of type double that is equal to the number of individuals per square mile of the species. You can assume that the area is always greater than zero. (*Hint*: The definition is very short.)
- 11. Define a method called changePopulation that could be added to the definition of the class SpeciesSecondTry in Listing 5.6. This method has one parameter of type double that is named area. The parameter area gives the area occupied by the species, expressed in square miles. The method changePopulation changes the value of the instance variable population so that there will be two individuals per square mile.
- 12. Define a method called changePopulation that could be added to the definition of the class SpeciesSecondTry in Listing 5.6. This method has two parameters. One parameter, named area, is of type double and gives the area occupied by the species in square miles. The other parameter, named numberPerMile, is of type int and gives the desired number of individuals per square mile. The method changePopulation changes the value of the instance variable population so that the number of individuals per square mile is (approximately) equal to numberPerMile.

## **5.2** INFORMATION HIDING AND ENCAPSULATION

The cause is hidden, but the result is well known.

-OVID, METAMORPHOSES

Never tell people how to do things. Tell them what to do and they will surprise you with their ingenuity.

—GEORGE S. PATTON

Information hiding sounds as though it could be a bad thing to do. What advantage could hiding information have? As it turns out, in computer science hiding certain kinds of information is considered a good programming technique, one that makes the programmer's job simpler and the programmer's code easier to understand. It is basically a way to avoid "information overload."

## **Information Hiding**

A programmer who is using a method that you have defined does not need to know the details of the code in the body of the method definition to be able to use the method. If a method—or other piece of software—is well written, a programmer who uses the method need only know what the method accomplishes and not how the method accomplishes its task. For example, you can use the Scanner method nextInt without even looking at the definition of that method. It is not that the code contains some secret that is forbidden to you. The point is that viewing the code will not help you use the method, but it will give you more things to keep track of, which could distract you from your programming tasks.

Designing a method so that it can be used without any need to understand the fine detail of the code is called **information hiding**. The term emphasizes the fact that the programmer acts as though the body of the method were hidden from view. If the term *information hiding* sounds too negative to you, you can use the term **abstraction**. The two terms mean the same thing in this context. This use of the term *abstraction* should not be surprising. When you abstract something, you lose some of the details. For example, an abstract of a paper or a book is a brief description of the paper or book, as opposed to the entire document.

# PROGRAMMING TIP When You Design a Method, Separate What from How

Methods should be self-contained units that are designed separately from the incidental details of other methods and separately from any program that uses the method. A programmer who uses a method should need only know what the method does, not how it does it.

### **Precondition and Postcondition Comments**

An efficient and standard way to describe what a method does is by means of specific kinds of comments known as preconditions and postconditions. A method's **precondition** comment states the conditions that must be true before the method is invoked. The method should not be used, and cannot be expected to perform correctly, unless the precondition is satisfied.

Separate the what from the how

A precondition states a method's requirements

The **postcondition** comment describes all the effects produced by a method invocation. The postcondition tells what will be true after the method is executed in a situation in which the precondition holds. For a method that returns a value, the postcondition will include a description of the value returned by the method.

A postcondition states a method's effect

For example, the following shows some suitable precondition and postcondition comments for the method writeOutput shown in Listing 5.3:

```
/**
    Precondition: The instance variables of the calling
    object have values.
    Postcondition: The data stored in (the instance variables
    of) the receiving object have been written to the screen.
*/
public void writeOutput()
```

The comments for the method predictPopulation in Listing 5.6 can be expressed as follows:

```
/**
    Precondition: years is a nonnegative number.
    Postcondition: Returns the projected population of the
    receiving object
    after the specified number of years.
*/
public int predictPopulation(int years)
```

If the only postcondition is a description of the value returned, programmers usually omit the word *postcondition*. The previous comment would typically be written in the following alternative way:

```
/**
    Precondition: years is a nonnegative number.
    Returns the projected population of the receiving object
    after the specified number of years.
*/
public int predictPopulation(int years)
```

Some design specifications may require preconditions and postconditions for all methods. Others omit explicit preconditions and postconditions from certain methods whose names make their action obvious. Names such as readInput, writeOutput, and set are often considered self-explanatory. However, the sound rule to follow is to adhere to whatever guidelines your instructor or supervisor gives you, and when in doubt, add preconditions and postconditions.

Some programmers prefer not to use the words *precondition* and *postcondition* in their comments. However, you should always think in terms of preconditions and postconditions when writing method comments. The really important thing is not the words *precondition* and *postcondition*, but the concepts they name. Note that precondition and postcondition comments are examples of assertions.

## The public and private Modifiers

Any class can use a public class, method, or instance variable As you know, the modifier public, when applied to a class, method, or instance variable, means that any other class can directly use or access the class, method, or instance variable by name. For example, the program in Listing 5.7 contains the following three lines, which set the values of the public instance variables for the object speciesOfTheMonth:

```
speciesOfTheMonth.name = "Klingon ox";
speciesOfTheMonth.population = 10;
speciesOfTheMonth.growthRate = 15;
```

### LISTING 5.7 Using a Method That Has a Parameter

```
Demonstrates the use of a parameter
with the method predictPopulation.
*/
public class SpeciesSecondTryDemo
    public static void main(String[] args)
        SpeciesSecondTry speciesOfTheMonth = new
                                SpeciesSecondTry();
        System.out.println("Enter data on the Species of the " +
                            "Month:");
        speciesOfTheMonth.readInput();
        speciesOfTheMonth.writeOutput();
        int futurePopulation =
            speciesOfTheMonth.predictPopulation(10);
        System.out.println("In ten years the population will be " +
                           futurePopulation);
        //Change the species to show how to change
        //the values of instance variables:
        speciesOfTheMonth.name = "Klingon ox";
        speciesOfTheMonth.population = 10;
        speciesOfTheMonth.growthRate = 15;
        System.out.println("The new Species of the Month:");
        speciesOfTheMonth.writeOutput();
        System.out.println("In ten years the population will be " +
                           speciesOfTheMonth.predictPopulation(10));
    }
}
```

#### Sample Screen Output

The output is exactly the same as in Listing 5.4.

The object speciesOfTheMonth is an object of the class SpeciesSecondTry, whose definition appears in Listing 5.6. As you can see by looking at that class definition, the instance variables name, population, and growthRate all have the modifier public, and so the preceding three statements are perfectly valid.

While it is normal to have public classes and methods, it is *not* a good programming practice to make the instance variables of a class public. Typically, all instance variables should be private. You make an instance variable private by using the modifier private instead of the modifier public. The keywords public and private are examples of access modifiers.

Instance variables should be private

Suppose that we change the modifier that is before the instance variable name in the definition of the class SpeciesSecondTry in Listing 5.6 from public to private so that the class definition begins as follows:

```
public class SpeciesSecondTry
{
    private String name; //Private!
    public int population;
    public double growthRate;
```

With this change, the following Java statement in Listing 5.7 is invalid:

```
speciesOfTheMonth.name = "Klingon ox"; //Invalid when private.
```

The following two statements remain valid, because we left the modifiers of population and growthRate as public:

```
speciesOfTheMonth.population = 10;
speciesOfTheMonth.growthRate = 15;
```

When an instance variable is private, its *name* is not accessible *outside* of the class definition. Even so, you can still use its name in any way you wish within any method *inside* the class definition. In particular, you can directly change the value of the instance variable. Outside of the class definition, however, you cannot make any direct reference to the instance variable's name.

Private instance variables are accessible by name only within their own class

For example, let's make the three instance variables in the class SpeciesSecondTry private, but leave the method definitions unchanged. The result is shown in Listing 5.8 as the class SpeciesThirdTry. Because the instance variables are all private, the last three of the following statements would be invalid within any class other than the class SpeciesThirdTry:

## LISTING 5.8 A Class with Private Instance Variables

```
import java.util.Scanner;
public class SpeciesThirdTry

{
    private String name;
    private int population;
    private double growthRate;
    <The definitions of the methods readInput, writeOutput, and predictPopulation are the same as in Listing 5.3 and Listing 5.6.>
}
```

Notice, however, that the invocation of the method readInput is valid. So there is still a way to set the instance variables of an object, even though those instance variables are private. Within the definition of the method readInput (shown in Listing 5.3) are assignment statements such as

```
name = keyboard.nextLine();
and
population = keyboard.nextInt();
```

that set the value of instance variables. Thus, making an instance variable private does not mean that you cannot change it. It means only that you cannot use the instance variable's *name* to refer directly to the variable anywhere outside of the class definition.

Methods can also be private. If a method is marked private, it cannot be invoked outside of the class definition. However, a private method can still be invoked within the definition of any other method in that same class. Most methods are public, but if you have a method that will be used only within the definition of other methods of that class, it makes sense to make this "helping" method private. Using private methods is another way of hiding implementation details within the class.

Classes themselves can be private as well, but we will not discuss that until Chapter 12.

#### **RECAP The public and private Modifiers**

Within a class definition, each instance variable declaration and each method definition, as well as the class itself, can be preceded by either public or private. These access modifiers specify where a class, instance variable, or method can be used. If an instance variable is private, its name cannot be used to access it outside of the class definition. However, it can be used within the definitions of methods in its class. If an instance variable is public, there are no restrictions on where you can use its name.

(continued)

Private methods are called only within their own class. If a method definition is private, the method cannot be invoked outside of the class definition. However, it can be invoked within the definitions of methods in its class. If the method is public, you can invoke it anywhere without restriction.

Normally, all instance variables are private and most methods are public.

### ■ PROGRAMMING TIP Instance Variables Should Be Private

You should make all the instance variables in a class private. By doing so, you force the programmer who uses the class—whether that person is you or someone else—to access the instance variables only via the class's methods. This allows the class to control how a programmer looks at or changes the instance variables. The next programming example illustrates why making instance variables private is important.

## PROGRAMMING EXAMPLE

A Demonstration of Why Instance Variables Should Be Private

Listing 5.9 shows a simple class of rectangles. It has three private instance variables to represent a rectangle's width, height, and area The method setDimensions sets the width and height, and the method getArea returns the rectangle's area.

## LISTING 5.9 A Class of Rectangles

```
/**
Class that represents a rectangle.
*/
public class Rectangle
{
    private int width;
    private int height;
    private int area;

    public void setDimensions(int newWidth, int newHeight)
    {
        width = newWidth;
        height = newHeight;
        area = width * height;
    }
    public int getArea()
    {
        return area;
    }
}
```

You might use the class Rectangle in the following way:

```
Rectangle box = new Rectangle( );
box.setDimensions(10, 5);
System.out.println("The area of our rectangle is " +
box.getArea());
```

The output from these statements would be

The area of our rectangle is 50

Public instance variables can lead to the corruption of an object's data

Private instance variables enable the class to restrict how they are accessed or changed What would happen if the three instance variables in Rectangle were public instead of private? After creating a 10-by-5 rectangle box, you would be able to change the value of any or all of the instance variables. So while area is 50, you could change width, for example, to 6 by writing

```
box.width = 6; //You could do this if width were public.
```

If you then called getArea, you would still get 50 as the area, instead of the new area, 30. By making the instance variables in Rectangle public, we create the possibility that the instance variable area will be unequal to width \* height. Making the instance variables private enables you to restrict how they are accessed or changed.

# **GOTCHA** Public Instance Variables Can Lead to the Corruption of a Class's Data



The previous programming example shows how the ability to change an instance variable directly by name can cause inconsistent data within an object. Since public instance variables provide this ability, always make instance variables private.

## PROGRAMMING EXAMPLE

Another Implementation of a Class of Rectangles

Let's look at another class, Rectangle 2 in Listing 5.10, that has exactly the same methods as the previous class Rectangle, but implements them in a slightly different way. Our new class computes the area of the rectangle only when the method getArea is called. Additionally, the area is not saved in an instance variable.

Notice that you would use the class Rectangle2 in the same way that you would use Rectangle. The only change you would make to the three statements that we wrote in the previous programming example to demonstrate Rectangle would be to replace Rectangle with Rectangle2:

```
Rectangle2 box = new Rectangle2( );
box.setDimensons(10, 5);
System.out.println("The area of our rectangle is " +
box.getArea());
```

That is, you invoke the methods in the same way, and they have the same behavior, regardless of their class.

### **REMEMBER Implementation Should Not Affect Behavior**

Two classes can have the same behavior but different implementations.

We have two classes—Rectangle and Rectangle2—that behave in the same way. That is, what they do is the same, but how they perform their tasks differs. In Rectangle2, the method getArea computes and then returns the area without saving it. Rectangle, however, has an instance variable—area—for the rectangle's area. The method setDimensions in Rectangle computes the area and stores it in area. The method getArea then simply returns the value in the instance variable area.

Classes can define the same behaviors but have different implementations

Is one of these two classes "better" than the other? The answer depends on what we mean by "better" and how we use the class. We can make the following observations:

- Rectangle uses more memory than Rectangle2 because it has an additional instance variable.
- Rectangle always computes the area, even if it is not needed.

#### LISTING 5.10 Another Class of Rectangles

```
/**
Another class that represents a rectangle.
*/
public class Rectangle2
{
    private int width;
    private int height;
    public void setDimensions(int newWidth, int newHeight)
    {
        width = newWidth;
        height = newHeight;
    }
    public int getArea()
    {
        return width * height;
    }
}
```

The implication of our second observation is that using Rectangle could require more computer time than using Rectangle2. To appreciate this, you need to imagine that both classes have several more methods, so that not invoking getArea is a real possibility. If you rarely ask for the area of a particular rectangle, using Rectangle2 saves you both execution time and memory. However, if you repeatedly invoke getArea for a particular rectangle, using Rectangle will save you execution time because it computes the area only once.

#### REMEMBER Implementation Can Affect Efficiency

The way you implement a class can affect its execution time and memory requirements.

### **Accessor Methods and Mutator Methods**

An accessor method retrieves data in an object

A mutator method changes data in an object Making all instance variables private does control access to them, but what if you have a legitimate reason to access an instance variable? For these cases, you should provide accessor methods. An **accessor method** or **get method**, or **getter**, is simply a method that allows you to look at data contained in an instance variable. In Listing 5.11, we have rewritten the class for a species yet another time. This version has accessor methods for obtaining the value of each instance variable. The names of these methods start with the word get, as in getName.

Accessor methods allow you to look at the data in a private instance variable. Other methods, known as **mutator methods**, or **set methods**, or **setters**, allow you to change the data stored in private instance variables. Our class definition has a mutator method, called setSpecies, for setting the instance variables to new values. The program in Listing 5.12 illustrates the use of the mutator method setSpecies. That program is similar to the one in Listing 5.7, but because this version of our species class has private instance variables, we must use the mutator method setSpecies to reset the values of the instance variables.

Defining accessor methods and mutator methods might appear to defeat the purpose of making instance variables private, but that is not true. A mutator method can check that any change is appropriate and warn the user of a problem. For example, the mutator method setSpecies checks to see whether the program inadvertently tries to set population equal to a negative number.

## LISTING 5.11 A Class with Accessor and Mutator Methods

```
import java.util.Scanner;
                                                Yes, we will define an even better
public class SpeciesFourthTry
                                                version of this class later.
    private String name;
    private int population;
    private double growthRate;
    <The definitions of the methods readInput, writeOutput, and</p>
     predictPopulation go here. They are the same as in Listing
     5.3 and Listing 5.6.>
     public void setSpecies(String newName, int newPopulation,
                               double newGrowthRate)
    {
         name = newName;
         if (newPopulation >= 0)
             population = newPopulation;
         else
         {
                  System.out.println(
                              "ERROR: using a negative population.");
                  System.exit(0);
         growthRate = newGrowthRate;
    public String getName()
    {
         return name;
                                                   A mutator method can check
                                                   to make sure that instance
    public int getPopulation()
                                                   variables are set to proper
                                                   values.
         return population;
    public double getGrowthRate()
         return growthRate;
}
```

The names of these methods need not involve get and set; you can use any method name that is convenient. For example, you might prefer to give them names such as retrieveValue, reset, or giveNewValues. However, it is traditional to begin the names of accessor methods with get and mutator methods with set.

### LISTING 5.12 Using a Mutator Method

```
import java.util.Scanner;
Demonstrates the use of the mutator method setSpecies.
public class SpeciesFourthTryDemo
    public static void main(String[] args)
    {
        SpeciesFourthTry speciesOfTheMonth =
                                  new SpeciesFourthTry();
        System.out.println("Enter number of years to project:");
        Scanner keyboard = new Scanner(System.in);
        int numberOfYears = keyboard.nextInt();
        System.out.println(
                     "Enter data on the Species of the Month:");
        speciesOfTheMonth.readInput();
        speciesOfTheMonth.writeOutput();
        int futurePopulation =
        speciesOfTheMonth.predictPopulation(numberOfYears);
        System.out.println("In " + numberOfYears +
                           " years the population will be " +
                           futurePopulation);
        //Change the species to show how to change
        //the values of instance variables:
        speciesOfTheMonth.setSpecies("Klingon ox", 10, 15);
        System.out.println("The new Species of the Month:");
        speciesOfTheMonth.writeOutput();
        futurePopulation =
              speciesOfTheMonth.predictPopulation(numberOfYears);
        System.out.println("In " + numberOfYears +
                           " years the population will be " +
                           futurePopulation);
    }
}
```

#### Sample Screen Output

```
Enter number of years to project:
10
Enter data on the Species of the Month:
What is the species' name?
Ferengie fur ball
```

## LISTING 5.12 Using a Mutator Method

```
What is the population of the species?

1000

Enter growth rate (% increase per year):
-20.5

Name = Ferengie fur ball
Population = 1000

Growth rate = -20.5%

In 10 years the population will be 100

The new Species of the Month:

Name = Klingon ox

Population = 10

Growth rate = 15.0%

In 10 years the population will be 40
```

#### **RECAP** Accessor and Mutator Methods

A public method that returns data from a private instance variable is called an accessor method, a get method, or a getter. The names of accessor methods typically begin with get. A public method that changes the data stored in one or more private instance variables is called a mutator method, a set method, or a setter. The names of mutator methods typically begin with set.



## **SELF-TEST QUESTIONS**

13. In Listing 5.12, we set the data for the object speciesOfTheMonth as follows:

```
speciesOfTheMonth.setSpecies("Klingon ox", 10, 15);
```

Could we have used the following code instead?

```
speciesOfTheMonth.name = "Klingon ox";
speciesOfTheMonth.population = 10;
speciesOfTheMonth.growthRate = 15;
```

If we could have used this alternative code, why didn't we? If we could not have used this alternative code, explain why we could not use it.

14. Give preconditions and postconditions for the following method, assuming that it is in the class SpeciesFourthTry in Listing 5.11:

```
public void updatePopulation()
    population = (int)(population + (growthRate / 100) *
              population);
}
```

- 15. What is an accessor method? What is a mutator method?
- 16. Give the complete definition of a class called Person that has two instance variables, one for the person's name and the other for the person's age. Include accessor methods and mutator methods for each instance variable. Also, include a method that sets both the name and age of a person. There are no other methods.

## PROGRAMMING EXAMPLE A Purchase Class

Listing 5.13 contains a class for a single purchase of multiple identical items, such as 12 apples or 2 quarts of milk. It is designed to be part of a program used at the checkout stand of a supermarket. Recall that supermarkets often give prices for a group of items, such as 5 for \$1.25 or 3 for \$1.00, instead of the price for one item. They hope that if they price apples at 5 for \$1.25, you will buy 5 apples instead of 2. But 5 for \$1.25 is really \$0.25 each, and if you buy 2 apples, they charge you only \$0.50.

The instance variables are as follows:

```
private String name;
private int groupCount; //Part of a price, like the 2
                       // in 2 for $1.99.
private double groupPrice; //Part of a price, like the $1.99
                          //in 2 for $1.99.
private int numberBought;//Number of items bought.
```

Let's explain the meaning of these instance variables by giving an example. If you buy 12 apples at 5 for \$1.25, name has the value "apples", groupCount has the value 5, groupPrice has the value 1.25, and numberBought has the value 12. Note that the price of 5 for \$1.25 is stored in the two instance variables groupCount—for the 5—and groupPrice—for the \$1.25.

Consider the method getTotalCost, for example. The total cost of the purchase is calculated as

```
(groupPrice / groupCount) * numberBought
```

#### LISTING 5.13 The Purchase Class (part 1 of 3)

```
import java.util.Scanner;
Class for the purchase of one kind of item, such as 3 oranges.
Prices are set supermarket style, such as 5 for $1.25.
*/
public class Purchase
    private String name;
    private int groupCount;
                                    //Part of a price, like the 2 in //2 for $1.99.
                                    //Part of a price, like the $1.99
    private double groupPrice;
                                    // in 2 for $1.99.
    private int numberBought;
                                    //Number of items bought.
    public void setName(String newName)
        name = newName;
    Sets price to count pieces for $costForCount.
    For example, 2 for $1.99.
    public void setPrice(int count, double costForCount)
        if ((count <= 0) || (costForCount <= 0))</pre>
        {
            System.out.println("Error: Bad parameter in " +
                                "setPrice.");
            System.exit(0);
        }
        else
        {
            groupCount = count;
            groupPrice = costForCount;
        }
    }
    public void setNumberBought(int number)
        if (number <= 0)</pre>
        {
            System.out.println("Error: Bad parameter in " +
                                "setNumberBought.");
            System.exit(0);
        }
        else
            numberBought = number;
    }
```

### LISTING 5.13 The Purchase Class (part 2 of 3)

```
/ * *
Reads from keyboard the price and number of a purchase.
* /
public void readInput()
{
    Scanner keyboard = new Scanner(System.in);
    System.out.println("Enter name of item you are purchasing:");
    name = keyboard.nextLine();
    System.out.println("Enter price of item as two numbers.");
    System.out.println("For example, 3 for $2.99 is entered as");
    System.out.println("3 2.99");
    System.out.println("Enter price of item as two numbers, " +
                        "now:");
    groupCount = keyboard.nextInt();
    groupPrice = keyboard.nextDouble();
    while ((groupCount <= 0) || (groupPrice <= 0))</pre>
    { //Try again:
        System.out.println("Both numbers must " +
                            "be positive. Try again.");
        System.out.println("Enter price of " +
                            "item as two numbers.");
        System.out.println("For example, 3 for " +
                            "$2.99 is entered as");
        System.out.println("3 2.99");
        System.out.println(
                         "Enter price of item as two numbers, now:");
        groupCount = keyboard.nextInt();
        groupPrice = keyboard.nextDouble();
    System.out.println("Enter number of items purchased:");
    numberBought = keyboard.nextInt();
    while (numberBought <= 0)</pre>
    { //Try again:
        System.out.println("Number must be positive. " +
                       "Try again.");
        System.out.println("Enter number of items purchased:");
        numberBought = keyboard.nextInt();
    }
}
```

(continued)

### LISTING 5.13 The Purchase Class (part 3 of 3)

```
/ * *
    Displays price and number being purchased.
    public void writeOutput()
        System.out.println(numberBought + " " + name);
        System.out.println("at " + groupCount +
                            " for $" + groupPrice);
    public String getName()
        return name;
    public double getTotalCost()
        return (groupPrice / groupCount) * numberBought;
    public double getUnitCost()
        return groupPrice / groupCount;
    public int getNumberBought()
        return numberBought;
    }
}
```

If this purchase is 12 apples at 5 for \$1.25, the total cost is

```
(1.25 / 5) * 12
```

Also notice the methods readInput, setPrice, and setNumberBought. All of these methods check for negative numbers when it does not make sense to have a negative number, such as when the user enters the number purchased. A simple demonstration program that uses this class is given in Listing 5.14.

## LISTING 5.14 Use of the Purchase Class (part 1 of 2)

```
public class PurchaseDemo
{
    public static void main(String[] args)
    {
        Purchase oneSale = new Purchase();
        oneSale.readInput();
        (continued)
```

### LISTING 5.14 Use of the Purchase Class (part 2 of 2)

#### Sample Screen Output

```
Enter name of item you are purchasing:

pink grapefruit

Enter price of item as two numbers.

For example, 3 for $2.99 is entered as 3 2.99

Enter price of item as two numbers, now:

4 5.00

Enter number of items purchased:

0

Number must be positive. Try again.

Enter number of items purchased:

3

3 pink grapefruit

at 4 for $5.0

Cost each $1.25

Total cost $3.75
```

## **Methods Calling Methods**

A method body can contain an invocation of another method. The situation for this sort of method call is exactly the same as it would be if the method call had occurred in the main method of a program. However, if the called method is in the same class, it is typically invoked without writing any receiving object. This is true regardless of whether the called method is public or private.

Listing 5.15 contains the definition of a class called Oracle. The method chat of this class conducts a dialogue with the user that answers a series of one-line questions that the user asks. Notice that the definition of the method chat contains a call to the method answer, which is also a method in the class Oracle. If you look at the definition of the method answer, you will see that it in turn includes calls to two other methods, seekAdvice and update, both of which are also in the class Oracle.

### LISTING 5.15 Methods Calling Other Methods

```
import java.util.Scanner;
public class Oracle
    private String oldAnswer = "The answer is in your heart.";
    private String newAnswer;
    private String question;
    public void chat()
    {
        System.out.print("I am the oracle. ");
        System.out.println("I will answer any one-line question.");
        Scanner keyboard = new Scanner(System.in);
        String response:
        do
        {
             answer();
             System.out.println("Do you wish to ask " +
                 "another question?");
             response = keyboard.next();
        } while (response.equalsIgnoreCase("yes"));
        System.out.println("The oracle will now rest.");
    }
    private void answer()
        System.out.println("What is your question?");
        Scanner keyboard = new Scanner(System.in);
        question = keyboard.nextLine();
        seekAdvice();
        System.out.println("You asked the question:");
        System.out.println(" " + question);
        System.out.println("Now, here is my answer:");
        System.out.println(" " + oldAnswer);
        update();
    }
    private void seekAdvice()
    {
        System.out.println("Hmm, I need some help on that.");
        System.out.println("Please give me one line of advice.");
        Scanner keyboard = new Scanner(System.in);
        newAnswer = keyboard.nextLine();
        System.out.println("Thank you. That helped a lot.");
    }
    private void update()
        oldAnswer = newAnswer;
}
```

Let's first consider the invocation of the method answer within the definition of the method chat. Note that the method named answer is not preceded by an object and a dot. The receiving object is understood to be the receiving object of the method chat. The demonstration program in Listing 5.16 creates an object named delphi of the class Oracle and then uses this object to invoke the method chat, as follows:

```
delphi.chat();
So when chat calls answer, the invocation
    answer();
in the definition of is understood to mean
    delphi.answer();

LISTING 5.16 Oracle Demonstration Program (part 1 of 2)

public class OracleDemo
{
    public static void main(String[] args)
    {
        Oracle delphi = new Oracle();
        delphi.chat();
    }
}
```

#### Sample Screen Output

```
I am the oracle. I will answer any one-line question.
What is your question?
What time is it?
Hmm, I need some help on that.
Please give me one line of advice.
Seek and ye shall find the answer.
Thank you. That helped a lot.
You asked the question:
What time is it?
Now, here is my answer:
The answer is in your heart.
Do you wish to ask another question?
yes
What is your question?
What is the meaning of life?
Hmm, I need some help on that.
```

(continued)

### LISTING 5.16 Oracle Demonstration Program (part 2 of 2)

```
Please give me one line of advice.

Ask the car guys.

Thank you. That helped a lot.

You asked the question:

What is the meaning of life?

Now, here is my answer:

Seek and ye shall find the answer.

Do you wish to ask another question?

no

The oracle will now rest.
```

When you write the definition of a method like chat, you do not know what the name of the receiving object will be. It could be different at different times. Because you do not—in fact, cannot—know the name of the receiving object, you omit it. Therefore, in the definition of the class Oracle in Listing 5.15, when you write

```
answer();
```

within the definition of the method, it means

```
Receiving_Object. answer();
```

Because the keyword this means the receiving object, you can also write the call as

```
this.answer();
```

Omitting the keyword this and a dot when you invoke a method in the same class is not really new. We have already been doing this with instance variables. But it works only with methods in the same class. If you call a method of one class within the definition of a method of another class, you must include an object and a dot.<sup>2</sup> Note also that omitting the receiving object is possible only if the receiving object can be expressed as this. If the receiving object is some object that is declared and created within a method definition, you must include the object name and dot within that method definition.

Let's continue with our discussion of method definitions in the class Oracle. You can have methods that call other methods that in turn call yet

You typically omit this when calling a method from another method in the same class

<sup>&</sup>lt;sup>2</sup> This rule about calling a method of one class within the definition of another class does not apply to static methods, which we discuss in the next chapter. However, the rule does apply to all the kinds of methods we have discussed thus far.

Methods calling methods calling other methods other methods. In the class Oracle, the definition of the method answer includes calls to the two methods seekAdvice and update, both of which are also in the class Oracle. As we just discussed, these calls are not preceded by an object and a dot.

Let's consider the following invocation from the program in Listing 5.16:

```
delphi.chat();
```

The definition of includes the invocation

```
answer();
```

which is equivalent to

```
this.answer();
```

Because the receiving object is delphi, this statement is also equivalent to the invocation

```
delphi.answer();
```

The definition of answer includes the invocations

```
seekAdvice();
and
```

which are equivalent to

update();

```
this.seekAdvice();
```

and

```
this.update();
```

Because the receiving object again is delphi, these are also equivalent to

```
delphi.seekAdvice();
```

and

```
delphi.update();
```

You can have methods calling methods calling methods for any number of method calls. The details are always handled just as we've described here.

#### **REMEMBER Omitting the Receiving Object**

When the receiving object in a method invocation is represented as the keyword this, you can omit the this and the dot. For example, the method

(continued)

# ■ PROGRAMMING TIP Make Helping Methods Private

Look again at Listing 5.15. The methods answer, seekAdvice, and update are labeled private rather than public. Recall that if a method is labeled private, it can be called only from within the definitions of other methods of the same class. Thus, in some other class or program, the following invocation of the private method answer would be invalid and would produce a compiler error message:

```
Oracle myOracle = new Oracle();
myOracle.answer(); //Invalid: answer is private.
```

whereas the following call to the public method would be perfectly valid:

```
myOracle.chat(); //Valid.
```

We made the methods answer, seekAdvice, and update private because they are just helping methods. A programmer using the class Oracle is not expected to invoke these methods. They are used only within the definition of the method chat. This means that the methods answer, seekAdvice, and update are part of the class's implementation and should not be available to a user of the class. As we emphasize in the next section, entitled "Encapsulation," it is good programming practice to keep the implementation portion of a class private.

## **SELF-TEST QUESTIONS**

17. Can you invoke a method inside the definition of another method in the same class?

18. In the definition of the method in Listing 5.15, what is the effect of changing the statement

```
seekAdvice();
to
this.seekAdvice();
```

# **Encapsulation**

Encapsulation groups instance variables and methods into a class In Chapter 1, we said that encapsulation involves hiding the details of how a piece of software works. Now that you have more knowledge of Java and information hiding, we can expand upon this basic definition, to say that encapsulation is the process of hiding all the details of a class definition that are not necessary to understanding how objects of the class are used. Let's look at an example.

Suppose you want to drive an automobile. Given this task, what is the most useful way to describe an automobile? It clearly is not to list the number of cylinders and explain how they go through a cycle of taking in air and gasoline, igniting the gasoline–air mixture, and expelling exhaust. Such details won't help you learn how to drive.

To a person who wants to learn to drive an automobile, the most useful description consists of information such as the following:

- If you press your foot on the accelerator pedal, the automobile will move faster.
- If you press your foot on the brake pedal, the automobile will slow down and eventually stop.
- If you turn the steering wheel to the left or right, the automobile will turn in the same direction.

Although we can describe other details, these are perhaps the main ones and are enough to illustrate the concept of encapsulation.

The principle of encapsulation says that, when describing an automobile to somebody who wants to learn to drive, you should provide something like the previous list. In the context of programming, encapsulation means the same thing. To use a piece of software, a programmer does not need all the details of its definition. In particular, if your piece of software is ten pages long, the description given to another programmer who will use the software should be much shorter than ten pages, perhaps only a half page. Of course, that is possible only if you write your software in such a way that it lends itself to this sort of short description.

Another analogy that may help is that an automobile has certain things that are visible, such as the pedals and steering wheel, while other things are hidden under the hood. The automobile is encapsulated: Only the controls needed to drive the automobile are visible, and the details are hidden.

Encapsulation hides implementation details Similarly, a piece of software should be encapsulated so that only the necessary controls are visible and its details are hidden. The programmer who uses the software is thus spared the bother of worrying about its internal details. Encapsulation is important because it simplifies the job of the programmer who uses the encapsulated software to write more software.

We have already discussed some of the techniques of encapsulation earlier in this chapter, under the topic of information hiding. Encapsulation is a form of information hiding. For encapsulation to be useful, a class definition must be given in such a way that a programmer can use the class without seeing the hidden details. Encapsulation, when done correctly, neatly divides a class definition into two parts, which we will call the interface and the implementation. The class interface<sup>3</sup> tells programmers all they need to know to use the class in their programs. The class interface consists of the headings for the public methods and public named constants of the class, along with comments that tell a programmer how to use these public methods and constants.

A class interface describes the class's public view

The **implementation** of a class consists of all of the private elements of the class definition, principally the private instance variables of the class, along with the definitions of both the public methods and private methods. Note that the class interface and the implementation of a class definition are not separate in your Java code, but are mixed together. For example, the class interface for the class Purchase in Listing 5.13 is highlighted. Although you need a class's implementation when you run a program that uses the class, you should not need to know anything about the implementation to write the program itself.

A class's implementation is hidden from public view

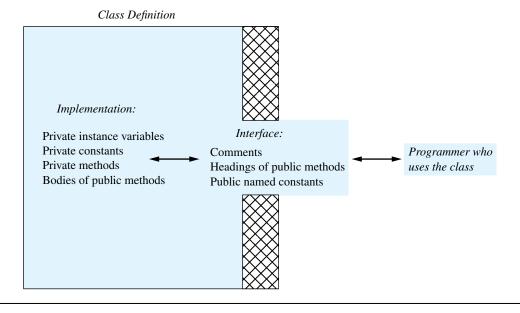
When defining a class using the principle of encapsulation, you must neatly separate the class interface from the implementation conceptually so that the interface is a simplified and safe description of the class. One way to think of this separation is to imagine a wall between the implementation and the interface, with well-regulated communication across the wall. This wall is illustrated graphically in Figure 5.3. When you use encapsulation to define a class in this way, we say that the class is well encapsulated.

Here are some of the most important guidelines for defining a well-encapsulated class:

Place a comment before the class definition that describes how the
programmer should think about the class data and methods. If the class
describes an amount of money, for example, the programmer should think
in terms of dollars and cents and not in terms of how the class represents
money. The comment in this case should be written to help the programmer
think in this way.

<sup>&</sup>lt;sup>3</sup> The word *interface* also has a technical meaning in the Java language, as you will see in Chapter 8. We are using the word somewhat differently when we say *class interface*, although in spirit, the two uses of the word *interface* are the same.

### FIGURE 5.3 A Well-Encapsulated Class Definition



- Declare all the instance variables in the class as private.
- Provide public accessor methods to retrieve the data in an object. Also
  provide public methods for any other basic needs that a programmer will
  have for manipulating the data in the class. Such methods could include
  public mutator methods.
- Place a comment before each public method heading that fully specifies how to use the method.
- Make any helping methods private.
- Write comments within the class definition to describe implementation details.

The comments in a class definition that describe how to use both the class and each public method are part of the class interface. As we indicated, these comments are usually placed before the class definition and before each method definition. Other comments clarify the implementation. A good rule to follow is to use the /\*\* \*/ style for class-interface comments and the // style for implementation comments.

When you use encapsulation to define your class, you should be able to go back and change the implementation details of the class definition without requiring changes in any program that uses the class. This is a good way to test whether you have written a well-encapsulated class definition. Often, you will have very good reasons for changing the implementation details of a class definition. For example, you may come up with a more efficient way to implement a method so that the method invocations run faster. You might

# Encapsulation guidelines

even decide to change some details of what the implementation does without changing the way the methods are invoked and the basic things they do. For example, if you have a class for bank account objects, you might change the rules for charging a penalty to an overdrawn account.

# FAQ Is a class interface related to an application programming interface?

We encountered the term *API*, or application programming interface, in Chapter 1 when we introduced the Java API. The API for a class is essentially the same thing as the class interface for the class. You will often see the term *API* when reading the documentation for class libraries.

#### FAQ What is an ADT?

The term ADT is short for abstract data type. It is a specification for a set of data and the operations on that data. These specifications describe what the operations do but do not indicate how to store the data or how to implement the operations. Thus, an ADT uses good information-hiding techniques.

#### **RECAP** Encapsulation

Encapsulation is a term often heard when describing modern programming techniques. Encapsulation is the process of hiding (encapsulating) all the details of how a piece of software works and describing only enough about the software to enable a programmer to use it. Encapsulation means that data and actions are combined into a single item—in our case, a class object—that hides the details of the implementation. Thus, the terms information hiding, ADT, and encapsulation all involve the same general idea. In very operational terms, the idea is to spare the programmer who uses your class from having to know the details of how your class is implemented.

# Automatic Documentation with javadoc

Java systems—including the one from Oracle Inc.—usually provide a program named javadoc that will automatically generate documentation for the class interfaces of your classes. This documentation tells other programmers what they need to know to use your class. To get a more useful javadoc document, you must write your comments in a particular way. The classes in this book are

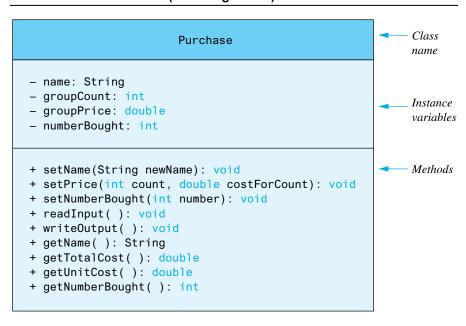
javadoc comments result in neat HTML documentation commented for use with javadoc, although because of space constraints, the comments are sparser than would be ideal. If you comment your class definition correctly, javadoc will take it as input and produce a nicely formatted display of its class interface. For example, if javadoc is run on the class definition in Listing 5.13, the output will consist only of the /\*\*\*/comments and the headings of public methods, after adjusting line breaks, spacing, and such. To read the documents produced by javadoc, you must use a Web browser or other HTML viewer.

You do not need to use javadoc to understand this book. Nor do you do need to use javadoc to be able to write Java programs. However, you are likely to find javadoc both easy to use and very useful. Appendix 5 will get you started in using javadoc and shows an example of its output.

# **UML Class Diagrams**

We gave an example of a class diagram in Figure 5.2 at the start of the chapter. You now know enough to understand all the notation in that diagram. However, rather than looking at that class diagram, let's look at a new one. Figure 5.4 contains a UML class diagram for the class Purchase from Listing 5.13. The

FIGURE 5.4 A UML Class Diagram for the Class Purchase (Listing 5.13)



A minus sign (-) means the member is private. A plus sign (+) means the member is public. details are pretty much self-explanatory, except for the plus and minus signs. A plus sign (+) before an instance variable or method means the variable or method is public. A minus sign (-), on the other hand, means it is private.

Notice that the class diagram contains more than the interface for the class and less than a full implementation. Often, you write a class diagram well before you define the class in Java. A class diagram is an outline of both the class interface and the implementation. It is primarily for the programmer defining the class. A class interface is for the programmer who will use the class when producing additional software.

UML is useful for designing and building a class



# **SELF-TEST QUESTIONS**

- 19. What is a well-encapsulated class definition?
- 20. When should an instance variable in a class definition be private, and when should it be public?
- 21. Under what circumstances would you define a private method?
- 22. In a class definition, is anything private ever part of the class interface?
- 23. In a class definition, is the body of any method definition ever part of the class interface?

#### **5.3** OBJECTS AND REFERENCES

"You are sad," the Knight said in an anxious tone: "let me sing you a song to comfort you."

"Is it very long?" Alice asked, for she had heard a good deal of poetry that day.

"It's long," said the Knight, "but it's very, very beautiful. Everybody that hears me sing it—either it brings the tears into their eyes, or else—"

"Or else what?" said Alice, for the Knight had made a sudden pause.

"Or else it doesn't, you know. The name of the song is called 'Haddocks' Eyes.' "

"Oh, that's the name of the song, is it?" Alice asked, trying to feel interested.

"No, you don't understand," the Knight said, looking a little vexed. "That's what the name is called. The name really is 'The Aged Aged Man.' "

"Then I ought to have said 'That's what the song is called'?" Alice corrected herself.

"No, you oughtn't: that's quite another thing! The song is called 'Ways and Means': but that's only what it's called, you know!"

"Well, what is the song, then?" said Alice, who was by this time completely bewildered.

"I was coming to that," the knight said. "The song really is 'A-sitting on a Gate': and the tune's my own invention."

—LEWIS CARROLL, Through the Looking-Glass

Variables of a class type, such as the variable oneSale in Listing 5.14, behave very differently from variables of a primitive type. Variables of a class type are names for objects of their class, but the objects are not the values of the variables in the same way that, say, the number 6 can be the value of a variable of type int. A variable of a class type can name an object, but the naming process is a bit subtle. In this section, we discuss how a variable of a class type names objects, and we also discuss the related topic of how method parameters of a class type behave in Java.

# Variables of a Class Type

Variables of a class type name objects in a way that is different from how variables of a primitive type store their values. Every variable, whether of a primitive type or a class type, is implemented as a memory location. If the variable has a primitive type, a data value is stored in the memory location assigned to the variable. However, a variable of a class type contains the memory address of the object named by the variable. The object itself is not stored in the variable, but rather in some other location in memory. The address of this other memory location is called a **reference** to the object. For this reason, class types are often called reference types. A **reference type** is just a type whose variables hold references—that is, memory addresses—as opposed to actual values of objects.

Class types are reference types

There is a reason why variables of a primitive type and variables of a class type name behave in different ways. Every value of a given primitive type, such as the type int, always requires the same amount of memory. Java has a maximum value of type int, and so values of type int cannot exceed a certain size in memory. However, an object, such as an object of the class String, might be any size, making it difficult for the system to set aside a fixed amount of space for variables that name objects. On the other hand, it can easily store the address of any string in a variable, since a computer's memory, and thus the size of a memory address, is finite.

Since variables of a class type contain references and behave very differently from variables of a primitive type, we can get some surprising results. Consider the following lines of code that might begin the main part of a program:

```
SpeciesFourthTry klingonSpecies = new SpeciesFourthTry();
SpeciesFourthTry earthSpecies = new SpeciesFourthTry();
int n = 42;
int m = n;
```

We have two variables of type int: n and m. Both have a value of 42, but if you change one, the other still has a value of 42. For example, if the program continues with

```
n = 99;
System.out.println(n + " and " + m);
the output produced will be
```

99 and 42

No surprises so far, but let's suppose the program continues as follows:

Assignments to variables of a class type

```
klingonSpecies.setSpecies("Klingon ox", 10, 15);
earthSpecies.setSpecies("Black rhino", 11, 2);
earthSpecies = klingonSpecies;
earthSpecies.setSpecies("Elephant", 100, 12);
System.out.println("earthSpecies:");
earthSpecies.writeOutput();
System.out.println("klingonSpecies:");
klingonSpecies.writeOutput();
```

You might think that the klingonSpecies is the Klingon ox and the earthSpecies is the elephant, but that is not so, as the following output indicates:

```
earthSpecies:
Name = Elephant
Population = 100
Growth rate = 12%
klingonSpecies:
Name = Elephant
Population = 100
Growth rate = 12%
```

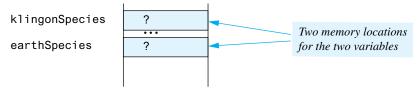
What has happened? You have two variables, klingonSpecies and earthSpecies. At first, the two variables reference different objects. Each object is stored in the computer's memory in some location, and that location has an address. Because variables of a class type store memory addresses for objects, not the objects themselves, the assignment statement

```
earthSpecies = klingonSpecies;
```

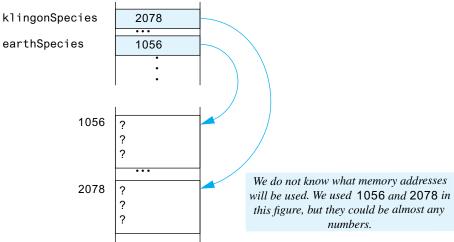
copies the memory address in klingonSpecies into the variable earthSpecies so that both variables contain the same memory address and therefore both variables name the same object. Regardless of which variable you use to invoke setSpecies, the same object actually receives the method call, and so the same object is changed. What happens to the second object we had before? It is no longer accessible to the program. Figure 5.5 illustrates this behavior.

FIGURE 5.5 Behavior of Class Variables

SpeciesFourthTry klingonSpecies, earthSpecies;



klingonSpecies = new SpeciesFourthTry();
earthSpecies = new SpeciesFourthTry();



klingonSpecies.setSpecies("Klingon ox", 10, 15);
earthSpecies.setSpecies("Black rhino", 11, 2);

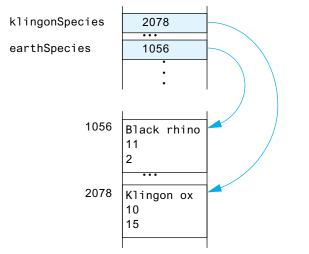
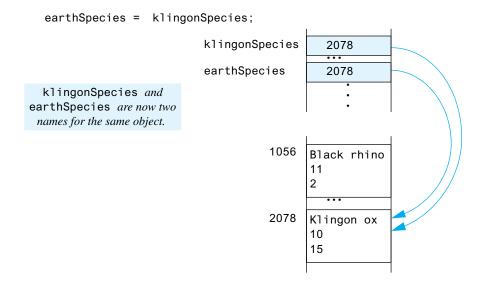
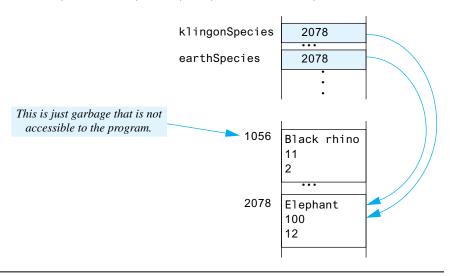


FIGURE 5.5 Behavior of Class Variables (continued)



earthSpecies.setSpecies("Elephant", 100, 12);



One word of warning about memory addresses: A memory address is a number, but it is not the same kind of number as an int value. So do not try to treat it as an ordinary integer.

# REMEMBER Variables of a Class Type Contain Memory Addresses

A variable of a primitive type contains a value of that type. A variable of a class type does not contain an object of that class. Instead, a variable of a class type contains the memory address of the object's location in the computer's memory. This scheme allows a variable of a class type to be used as a name for an object of that class. However, some operations, such as = and ==, behave quite differently for variables of a class type than they do for variables of a primitive type.

## **REMEMBER Memory Addresses Are and Are Not Numbers**

A variable of a class type contains a memory address. Although a memory address is a number, a variable of a class type cannot be used like a variable that stores a number. The important property of a memory address is that it identifies a memory location. The fact that addresses are numbers, rather than letters or colors or something else, is an accidental property. Java prevents you from using this accidental property. It does so to keep you from doing things you should not do, such as obtaining access to restricted memory or otherwise screwing up the computer. It also makes your code easier to understand.



#### **RECAP** Class Types and Reference Types

A variable of a class type holds the address in memory of an object of that class. This memory address is often called a reference to the object in memory. Thus, class types are reference types. Variables of a reference type hold references—that is, memory addresses—as opposed to actual values of objects. However, some reference types are not class types, so we will use the term *class type* when referring to the name of a class. All class types are reference types, but as you will see in Chapter 7, not all reference types are class types.

# **GOTCHA** Use of == with Variables of a Class Type

In the previous section, you saw some of the surprises you can get when using the assignment operator with variables of a class type. The test for equality also behaves in a way that may seem peculiar. Suppose the class SpeciesFourthTry

is defined as shown in Listing 5.11, and suppose you have the following in a program:

```
SpeciesFourthTry klingonSpecies = new SpeciesFourthTry();
SpeciesFourthTry earthSpecies = new SpeciesFourthTry();
klingonSpecies.setSpecies("Klingon ox", 10, 15);
earthSpecies.setSpecies("Klingon ox", 10, 15);
if (klingonSpecies == earthSpecies)
    System.out.println("They are EQUAL.");
else
    System.out.println("They are NOT equal.");
```

This will produce the output.

```
They are NOT equal.
```

Figure 5.6 illustrates the execution of this code.

Two objects of type SpeciesFourthTry are in memory. Both of them represent the same species in the real world, but they have different memory addresses. The problem is that, although the two objects are equal in an intuitive sense, a variable of a class type really contains only a memory address. The == operator checks only to see whether the memory addresses are equal. It tests for a kind of equality, but not the kind of equality you usually care about. When defining a class, you should normally define a method for the class that is called equals and that tests objects to see whether they are equal. The next section will show you how.

# Defining an equals Method for a Class

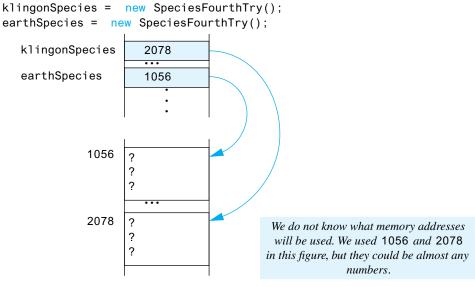
When you compare two objects using the == operator, you are checking to see whether they have the same address in memory. You are not testing for what you would intuitively call equality. To test for your intuitive notion of equality, you should define a method called equals. In Listing 5.17, we have revised our definition of a class for a species one last time to include an equals method.

You use the equals method of any class in exactly the same way that we used String's method equals with objects of type String. The program in Listing 5.18 demonstrates the use of the method equals defined in our revised class Species.

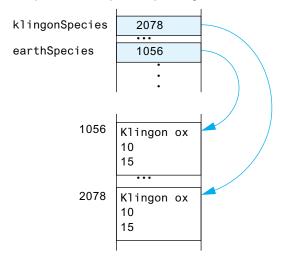
Our definition of the method equals in the class Species considers two Species objects equal if they have the same name—ignoring any differences in case—the same population, and the same growth rate. To compare the names, we use the method equals IgnoreCase of the class String. It compares two strings, treating uppercase letters as equal to their lowercase counterparts. As we pointed out in Chapter 2, this method is automatically provided as part of the Java language. We use the == operator to compare the populations and growth rates, since they are primitive values.

Test objects for equality by using an equals method

FIGURE 5.6 The Dangers of Using == with Objects



klingonSpecies.setSpecies("Klingon ox", 10, 15);
earthSpecies.setSpecies("Klingon ox", 10, 15);



```
if (klingonSpecies == earthSpecies)
    System.out.println("They are EQUAL.");
else
    System.out.println("They are NOT equal.");
```

The output is They are Not equal, because 2078 is not equal to 1056.

## LISTING 5.17 Defining an equals Method

```
import java.util.Scanner;
public class Species
    private String name;
    private int population;
    private double growthRate;
    <The definition of the methods readInput, writeOutput, and</pre>
     predictPopulation go here. They are the same as in
     Listing 5.3 and Listing 5.6.>
    <The definition of the methods setSpecies, getName,</pre>
     getPopulation, and getGrowthRate go here. They are the
     same as in Listing 5.11.>
    public boolean equals(Species otherObject)
        return (this.name.equalsIgnoreCase(otherObject.name)) &&
                (this.population == otherObject.population) &&
                (this.growthRate == otherObject.growthRate);
}
                        equalsIgnoreCase is a method of the class String.
```

Notice that the method equals in Listing 5.17 always returns a true or false value, and so the method's return type is boolean. The return statement may seem a bit strange, but it is nothing other than a boolean expression of the kind you might use in an if-else statement. It may help you to understand this method if you note that the definition of equals in Listing 5.17 can be expressed by the following pseudocode:

A method can return a boolean value

```
if ((this.name.equalsIgnoreCase(otherObject.name)) &&
     (this.population == otherObject.population) &&
     (this.growthRate == otherObject.growthRate))
then return true
otherwise return false
```

This change would make the following statement from the program in Listing 5.18:

### equivalent to

We will say more about methods that return a value of type boolean in the section "Boolean-Valued Methods" a little later in this chapter.

There is no unique definition of equals that has been handed down by the gods for all time. The definition of equals that you write will depend on how you intend to use the class. The definition in Listing 5.17 says that two objects of the class Species are equal if they represent the same species name, the same population size, and the same growth rate. In some other context, you might want to define equality to mean that two objects have the same species name but possibly different populations or different growth rates. This would correspond to considering two objects to be equal if they are records for the same species but reflect data taken at different times.

# LISTING 5.18 Demonstrating an equals Method (part 1 of 2)

```
public class SpeciesEqualsDemo
{
   public static void main(String[] args)
        Species s1 = new Species(), s2 = new Species();
        s1.setSpecies("Klingon ox", 10, 15);
        s2.setSpecies("Klingon ox", 10, 15);
        if (s1 == s2)
            System.out.println("Match with ==.");
        else
            System.out.println("Do Not match with ==.");
        if (s1.equals(s2))
            System.out.println("Match with the method " +
                               "equals.");
        else
            System.out.println("Do Not match with the method " +
                               "equals.");
        System.out.println("Now change one Klingon ox to " +
                           "lowercase.");
```

(continued)

#### LISTING 5.18 Demonstrating an equals Method (part 2 of 2)

```
s2.setSpecies("klingon ox", 10, 15); //Use lowercase
        if (s1.equals(s2))
            System.out.println("Match with the method equals.");
        else
            System.out.println("Do Not match with the method " +
                                "equals.");
    }
}
```

#### Screen Output

```
Do Not match with ==.
Match with the method equals.
Now change one Klingon ox to lowercase.
Match with the method equals.
```

You should always use the identifier equals for the name of any method you create to test whether two objects are equal. Do not use some other identifier, such as same; do not even use equal without an s. Certain software that is part of Java depends on your using the exact name equals to test for equality of objects. This software invokes a method named equals, so your method had better have that name.

If you do not define an equals method for your class, Java will automatically create a default definition of equals, but it is unlikely to behave the way you want it to. Thus, it is best to define your own equals method.

# PROGRAMMING EXAMPLE A Species Class

The final version of our class for species objects, as given in Listing 5.17, is repeated in Listing 5.19, but this time we have included all of the details so that you can see a complete example. We have also written the definition of the method equals without using the keyword this, since that is the form most programmers use. The definition of equals in Listing 5.19 is completely equivalent to the definition in Listing 5.17. Figure 5.7 contains the class diagram for this class Species.

# LISTING 5.19 The Complete Species Class (part 1 of 2)

```
This is the same class definition
import java.util.Scanner;
                                            as in Listing 5.17, but with all the
                                           details shown.
Class for data on endangered species.
public class Species
    private String name;
    private int population;
    private double growthRate;
    public void readInput()
        Scanner keyboard = new Scanner(System.in);
        System.out.println("What is the species' name?");
        name = keyboard.nextLine();
        System.out.println(
                         "What is the population of the species?");
        population = keyboard.nextInt();
        while (population < 0)</pre>
        {
            System.out.println("Population cannot be negative.");
            System.out.println("Reenter population:");
            population = keyboard.nextInt();
        System.out.println(
                       "Enter growth rate (% increase per year):");
        growthRate = keyboard.nextDouble();
    }
    public void writeOutput()
    {
        System.out.println("Name = " + name);
        System.out.println("Population = " + population);
        System.out.println("Growth rate = " + growthRate + "%");
    }
    / * *
    Precondition: years is a nonnegative number.
    Returns the projected population of the receiving object
    after the specified number of years.
    public int predictPopulation(int years)
    {
        int result = 0;
        double populationAmount = population;
                                                          (continued)
```

## LISTING 5.19 The Complete Species Class (part 2 of 2)

```
int count = years;
    while ((count > 0) && (populationAmount > 0))
        populationAmount = (populationAmount +
                             (growthRate / 100) *
                             populationAmount);
        count--:
    }
    if (populationAmount > 0)
        result = (int)populationAmount;
    return result;
public void setSpecies(String newName, int newPopulation,
                        double newGrowthRate)
{
    name = newName;
    if (newPopulation >= 0)
        population = newPopulation;
    else
    {
        System.out.println("ERROR: using a negative " +
                             "population.");
        System.exit(0);
    growthRate = newGrowthRate;
}
public String getName()
{
    return name;
public int getPopulation()
{
    return population;
public double getGrowthRate()
{
    return growthRate;
public boolean equals(Species otherObject)
{
    return (name.equalsIgnoreCase(otherObject.name)) &&
           (population == otherObject.population) &&
           (growthRate == otherObject.growthRate);
}
          This version of equals is equivalent to the version in Listing 5.17.
          Here, the keyword this is understood to be there implicitly.
```

}

FIGURE 5.7 Class Diagram for the Class Species in Listing 5.19

```
species

- name: String
- population: int
- growthRate: double

+ readInput(): void
+ writeOutput(): void
+ predictPopulation(int years): int
+ setSpecies(String newName, int newPopulation, double newGrowthRate): void
+ getName(): String
+ getPopulation(): int
+ getGrowthRate(): double
+ equals(Species otherObject): boolean
```

#### **Boolean-Valued Methods**

Methods can return a value of type boolean. There is really nothing new about this: You just specify a return type of boolean and use a boolean expression in the return statement. You have already seen one such method, namely the equals method for the class Species in Listing 5.19. This method simply evaluates the boolean expression in the return statement, yielding a value of true or false. The method then returns this value.

As you have already seen, you can use an invocation of the method equals in an if statement, a while statement, or another statement that requires a boolean expression. You can also store the value returned by the method equals, or any other boolean-valued method, in a variable of type boolean. For example,

```
Species s1 = new Species(), s2 = new Species();
<Some code to set the values of s1 and s2.>
boolean areEqual = s1.equals(s2);
<Some more code.>
if (areEqual)
    System.out.println("They are equal.");
else
    System.out.println("They are not equal.");
```

As another example of a boolean-valued method, the following is a method you might add to the definition of the class Species in Listing 5.19:

```
/**
    Precondition: This object and the argument otherSpecies
both have values for their population. Returns true if the
population of this object is greater than the population of
otherSpecies; otherwise, returns false.

*/
public boolean isPopulationLargerThan(Species otherSpecies)
{
    return population > otherSpecies.population;
}
```

You can then use the method isPopulationLargerThan in the same sorts of ways that you use the method equals. For example, the following might appear in a program:

```
Species s1 = new Species(), s2 = new Species();
<Some code to set the values of s1 and s2.>
String nameOfLarger = s1.getName();
if (s2.isPopulationLargerThan(s1))
    nameOfLarger = s2.getName();
System.out.println(nameOfLarger + " has the larger population.");
```

The following method is another you might add to the definition of the class Species in Listing 5.19:

```
/**
    Precondition: This object has a value for its population.
    Returns true if the population of this object is zero;
    otherwise, returns false.
*/
public Boolean isExtinct()
{
    return population == 0;
}
```

The following sample code might then appear in a program:

```
Species s1 = new Species();
<Some code to set the value of s1.>
if (s1.isExtinct())
    System.out.println(s1.getName() + " is extinct.");
else
    System.out.println(s1.getName() + " is still with us.")
```

# ■ PROGRAMMING TIP Naming Boolean-Valued Methods

When our boolean-valued method is Extinct is invoked within an if statement, we can understand its meaning simply by reading the statement in English. For example,

```
if (s1.isExtinct())
```

means "if s1 is extinct." Beginning the name of a boolean-valued method with a word such as *is* or *has* clarifies the meaning of your program. Not only will others benefit from this naming convention, you likely will make fewer errors while writing the program.

# **SELF-TEST QUESTIONS**

- 24. What is a reference type? Are class types reference types? Are primitive types, such as int, reference types?
- 25. When comparing two quantities of a class type to see whether they are "equal," should you use == or the method equals?
- 26. When comparing two quantities of type int to see whether they are "equal," should you use == or the method equals?
- 27. Write a method definition for a method called isGrowthRateLargerThan that could be added to the class Species in Listing 5.19. This method has one argument of type Species. The method returns true if the receiving object has a larger growth rate than the growth rate of the argument; otherwise, it returns false.

# **CASE STUDY** Unit Testing

So far we've tested our programs by running them, typing in some input, and visually checking the results to see if the output is what we expected. This is fine for small programs but is generally insufficient for large programs. In a large program there are usually so many combinations of interacting inputs that it would take too much time to manually verify the correct result for all inputs. Additionally, it is possible that code changes result in unintended side effects. For example, a fix for one error might introduce a different error. One way to attack this problem is to write **unit tests**. Unit testing is a methodology in which the programmer tests the correctness of individual units of code. A unit is often a method but it could be a class or other group of code.

The collection of unit tests becomes the **test suite**. Each test is generally automated so that human input is not required. Automation is important because it is desirable to have tests that run often and quickly. This makes it possible to run the tests repeatedly, perhaps once a day or every time code is changed, to make sure that everything is still working. The process of running tests repeatedly is called **regression testing**.

Let's start with a simple test case for the Species class in Listing 5.19. Our first test might be to verify that the name, initial population, and growth rate is correctly set in the setSpecies method. We can accomplish this by creating

Unit testing verifies if individual units of code are working correctly an object of type Species, invoking setSpecies, and verifying if all the values match.

```
Species testSpecies = new Species();
// Test the setSpecies method
testSpecies.setSpecies("Tribbles", 100, 50);
                                                           Since
if (testSpecies.getName().equals("Tribbles") &&
    (testSpecies.getPopulation() == 100) &&
                                                           getGrowthRate
                                                           returns a double we
    (testSpecies.getGrowthRate() >= 49.99) &&
                                                           should not attempt
    (testSpecies.getGrowthRate() <= 50.01))</pre>
                                                           testSpecies.
{
                                                           getGrowthRate()
    System.out.println("Pass: setSpecies test.");
                                                           ==50.
}
else
{
    System.out.println("FAIL: setSpecies test.");
}
```

In this simple example we came up with inputs for the test case, invoked the code, and checked to see if the results matched our expectations. If there was an error, such as forgetting to copy the growth rate into an instance variable in the setSpecies method, then the test case would find the problem.

Often the design of the test case is more complicated. Consider testing the predictPopulation method. Once again we must determine appropriate inputs and see if the unit to be tested produces the expected outputs. One type of test we might try is a **negative test**. This is a test to confirm that the system doesn't crash when given unexpected inputs. For example, if the number of years passed to predictPopulation is negative, then we might expect the method to return the initial population. In addition, we might test the method with inputs of 1 and 5 years into the future. Such a test case using the testSpecies object is shown in Listing 5.20.

A common practice is to write tests using the assert statement. For example, instead of the if-else statement we could write:

```
assert (testSpecies.getPopulation() == 100);
```

Don't be fooled into thinking that the program is guaranteed to work if all tests pass. It is possible that there is an untested combination of input values that will cause the program to fail. There may also be bugs at the level where working units are integrated. However, a successful test run gives us some confidence that basic functionality is working.

Ideally, the test cases should be kept separate from the implementation of the class. In our simple example we created a separate class with a main method to test the Species class. For larger projects you might consider a test framework such as JUnit that is designed to help organize and run test suites.

### LISTING 5.20 Sample Tests for the Species Class

```
public class SpeciesTest
    public static void main(String[] args)
        Species testSpecies = new Species();
        // Test the setSpecies method
        testSpecies.setSpecies("Tribbles", 100, 50);
        if (testSpecies.getName().equals("Tribbles") &&
           (testSpecies.getPopulation() == 100) &&
           (testSpecies.getGrowthRate() >= 49.99) &&
           (testSpecies.getGrowthRate() <= 50.01))</pre>
        {
            System.out.println("Pass: setSpecies test.");
        }
        else
        {
            System.out.println("FAIL: setSpecies test.");
        }
        // Test the predictPopulation method
        if ((testSpecies.predictPopulation(-1) == 100) &&
            (testSpecies.predictPopulation(1) == 150) &&
            (testSpecies.predictPopulation(5) == 759))
        {
             System.out.println("Pass: predictPopulation test.");
        }
        else
        {
             System.out.println("FAIL: predictPopulation test.");
        }
    }
}
```

## Sample Screen Output

```
Pass: setSpecies test.
Pass: predictPopulation test.
```

# Parameters of a Class Type

Parameters of a class type

A method's parameters of a class type are treated differently than its parameters of a primitive type. We touched upon this difference when we discussed using

the assignment operator with objects. The following two points from that discussion will help us describe how parameters of a class type work:

 First, recall how the assignment operator works with objects. Suppose that Species is the class defined in Listing 5.19, and consider the following code:

```
Species species1 = new Species();
species1.readInput();
Species species2 = species1;
```

When you use an assignment operator with objects of a class type, you are actually copying a memory address. Thus, as we discussed in the previous section, species1 and species2 are now two names for the same object.

• Now recall how parameters of a primitive type work. For example, the definition of the method predictPopulation in Listing 5.19 begins as follows:

Parameters of a primitive type

```
public int predictPopulation(int years)
{
   int result = 0;
   double populationAmount = population;
   int count = years;
```

We said previously that the formal parameter years is actually a local variable. When we invoke the method predictPopulation, this local variable years is initialized to the value of the argument given in the method call. So, for example, when we use the following call in Listing 5.12:

```
int futurePopulation =
    speciesOfTheMonth.predictPopulation(numberOfYears);
```

the parameter years is initialized to numberOfYears. The effect is like temporarily inserting the assignment statement

```
years = numberOfYears;
```

into the method definition. In other words, it is as if the definition of the method predictPopulation were, for the duration of this method invocation, changed as follows:

Wow—that's a long preamble, but if you understand these two points, it will be very easy to understand how parameters of a class type work. Parameters of a class type work like parameters of a primitive type, but because the assignment operator means something different for variables of a class type, the effect is very different!

Let's go through that explanation again with slightly different words, but with the same message. Consider the following call to the method equals that was used in Listing 5.18:

In this call, s2 is an argument of the class type Species defined in Listing 5.19. We reproduce here the definition for the method equals given in Listing 5.19:

When the method equals is called in s1.equals(s2), it is as if the following assignment statement were temporarily inserted at the start of the method definition:

```
otherObject = s2;
```

In other words, the method definition, for the duration of this call to equals, is equivalent to

Recall, however, that this assignment statement merely copies the memory address of s2 into the variable otherObject, so otherObject becomes just another name for the object named by s2. Thus, anything done with the object named otherObject will in fact be done with the object named s2. It is as if the method performed the following action:

Notice that any action taken with a formal parameter of a class type—in this example, otherObject—is actually taken with the argument used in the method call—in this case, s2. So the argument used in the method call is actually acted upon and can be changed by the method call.

In the case of the method equals, the effect of this parameter-passing mechanism for parameters of a class type is not so different from what happens with parameters of a primitive type. With some other methods, however, the difference is more striking. The next section gives a more dramatic example of how parameters of a class type differ from parameters of a primitive type.

#### **ASIDE** Call by Reference

Some programmers refer to the parameter mechanism for parameters of a class type as call-by-reference parameter passing. Others say that this terminology is incorrect. The problem is that there is more than one commonly used definition of call by reference. In addition, parameters of a class type in Java behave a bit differently than call-by-reference parameters in other languages. Therefore, we will not use the term *call by reference* here. The important thing is to understand how parameters of a class type work, regardless of what you call them.

# **RECAP** Parameters of a Class Type

Formal parameters are given in parentheses after the method name at the beginning of a method definition. A formal parameter of a class type is a local variable that holds the memory address of an object of that class type. When the method is invoked, the parameter is initialized to the address of the corresponding argument in the method invocation. In less technical terms, this means that the formal parameter will serve as an alternative name for the object given as the corresponding argument in a method invocation.

# REMEMBER A Method Can Change an Object Passed as an Argument

An object that is an argument in a method invocation is actually acted upon and can be altered by the method call. However, the object cannot be replaced by another object. The next programming example will demonstrate these points.

## PROGRAMMING EXAMPLE

Class-Type Parameters Versus Primitive-Type Parameters

A method cannot change the value of an argument of a primitive type Suppose we add three methods to the class Species to form a new class called DemoSpecies, as shown in Listing 5.21. This class is only for our demonstration, so do not worry about the rest of the class definition. Let's play with this toy class.

### LISTING 5.21 A Demonstration Class (part 1 of 2)

```
import java.util.Scanner;
/**
This version of the class Species is only a toy example designed
to demonstrate the difference between parameters of a class type
and parameters of a primitive type.
public class DemoSpecies
{
    private String name;
    private int population;
    private double growthRate;
    Tries to set intVariable equal to the population of this
    object. But arguments of a primitive type cannot be
    changed.
    */
    public void tryToChange(int intVariable)
        intVariable = this.population;
    / * *
    Tries to make otherObject reference this object.
    But arguments of a class type cannot be replaced.
    */
    public void tryToReplace(DemoSpecies otherObject)
        otherObject = this;
    }
    / * *
    Changes the data in otherObject to the data in this object,
    which is unchanged.
    */
```

(continued)

### LISTING 5.21 A Demonstration Class (part 2 of 2)

```
public void change(DemoSpecies otherObject)
{
    otherObject.name = this.name;
    otherObject.population = this.population;
    otherObject.growthRate = this.growthRate;
}
<The rest of the class definition is the same as that of the class
Species in Listing 5.19.>
}
```

Look at the method tryToChange within our new class DemoSpecies. This method has a formal parameter of the primitive type int. Within the method's body is an assignment to that parameter. The program in Listing 5.21 calls tryToChange, passing it the argument aPopulation of type int. However, the assignment performed in the method body has no effect on the argument aPopulation. Since variables of a primitive type hold actual values, not memory addresses, Java's call-by-value parameter mechanism copies the value of the argument to the parameter, which really is a local variable. Thus, any changes the method makes to the parameter are made to this local variable and not to the argument.

The method tryToReplace has a parameter whose type is DemoSpecies, so it is of a class type. Once again, Java's call-by-value parameter mechanism copies the value of the argument to the parameter. But since both the argument and the parameter are of a class type, the memory address of the object argument is copied to the parameter. The assignment statement within the body of the method then assigns a new value to the parameter. (In fact, this new value is the address of the receiving object—indicated by the keyword this—but the value is irrelevant.) Just as in the previous method tryToChange, this assignment to the parameter does not affect the argument. Thus, s2, an object of DemoSpecies that the program in Listing 5.22 passes to tryToReplace, is unaffected.

Finally, the data type of the parameter of the method change is the class type DemoSpecies. The program in Listing 5.22 calls change, passing it the argument s2. The assignment statements within the body of the method actually change the values of the instance variables of the object argument s2. A method can change the state of an argument of a class type.

As you can see, parameters of a class type are more versatile than parameters of a primitive type. Parameters of a primitive type pass values to a method, but a method cannot change the value of any primitive-type variable that is given to it as an argument. On the other hand, not only can parameters of a class type be used to give information to a method, but the method can also change the state of the object named by an argument of a class type. The method, however, cannot replace the object passed to it as an argument with another object.

A method cannot replace an argument object with another object

A method can change the state of an argument object

## LISTING 5.22 Parameters of a Class Type Versus Parameters of a Primitive Type

```
public class ParametersDemo
    public static void main(String[] args)
    {
        DemoSpecies s1 = new DemoSpecies(),
                    s2 = new DemoSpecies();
        s1.setSpecies("Klingon ox", 10, 15);
        int aPopulation = 42;
        System.out.println("aPopulation BEFORE calling " +
                            "tryToChange: " + aPopulation);
        s1.tryToChange(aPopulation);
        System.out.println("aPopulation AFTER calling " +
                            "tryToChange: aPopulation);
        s2.setSpecies("Ferengie Fur Ball", 90, 56);
        System.out.println("s2 BEFORE calling tryToReplace: ");
        s2.writeOutput();
        s1.tryToReplace(s2);
        System.out.println("s2 AFTER calling tryToReplace: ");
        s2.writeOutput();
        s1.change(s2);
        System.out.println("s2 AFTER calling change: ");
        s2.writeOutput();
    }
}
```

#### Screen Output

```
aPopulation BEFORE calling tryToChange: 42 An argument of a primitive
                                              type cannot change in value.
aPopulation AFTER calling tryToChange: 42
s2 BEFORE calling tryToReplace:
Name = Ferengie Fur Ball
Population = 90
Growth Rate = 56.0%
s2 AFTER calling tryToReplace:
                                     An argument of a class
Name = Ferengie Fur Ball
                                     type can change in state.
Population = 90
Growth Rate = 56.0%
s2 AFTER calling change:
Name = K1ingon ox
                               An argument of a class
Population = 10
                               type cannot be replaced.
Growth Rate = 15.0%
```

# REMEMBER Differences Between Primitive-Type and Class-Type Parameters

VideoNote
Exploring parameters of class types

A method cannot change the value of an argument of a primitive type that is passed to it. In addition, a method cannot replace an object passed to it as an argument with another object. On the other hand, a method can change the values of the instance variables of an argument of a class type.

# **SELF-TEST QUESTIONS**

28. Given the class Species as defined in Listing 5.19, why does the following program cause an error message?

```
public class SpeciesEqualsDemo
{
  public static void main(String[] args)
  {
     Species s1, s2; s1.
     setSpecies("Klingon ox", 10, 15);
     s2.setSpecies("Klingon ox", 10, 15);
     if (s1 == s2)
          System.out.println("Match with ==.");
     else
          System.out.println("Do Not match with ==.")
  }
}
```

- 29. After correcting the program in the previous question, what output does the program produce?
- 30. What is the biggest difference between a parameter of a primitive type and a parameter of a class type?
- 31. Given the class Species, as defined in Listing 5.19, and the class

```
public class ExerciseClass
{
    public void mystery(Species s, int m)
    {
        s.setSpecies("Klingon ox", 10, 15);
        m = 42;
    }
}
```

what output is produced by the following program?

```
public class ExerciseProgram
{
    public static void main(String[] args)
    {
        Species s1 = new Species();
        ExerciseClass mysteryMaker = new ExerciseClass();
        int n = 0;
        s1.setSpecies("Hobbit", 100, 2);
        mysteryMaker.mystery(s1, n);
        s1.writeOutput();
        System.out.println("n = " + n);
    }
}
```

32. Write an equals method for the class Person described in Self-Test Question 16.

### **5.4** GRAPHICS SUPPLEMENT

The whole is more than the sum of its parts.

```
-PROVERB
```

Now that we have explained methods and parameters more completely, we will revisit material from the previous graphics supplements to give more detailed explanations. We will

- Explain the GraphicsContext class and the structure of a JavaFX application more completely.
- Use methods to rewrite one of our previous graphics applications in a cleaner way.
- Introduce some additional drawing methods.

# The GraphicsContext Class

A JavaFX application uses the metaphor of a stage and scenes, just like the stage and scene of a theater. The Stage class is a top-level JavaFX container and in our examples will correspond to a window. Every Stage has an associated Scene object. The Scene object contains a set of nodes called a **scene graph**. These nodes, represented by the **Node** class, describe a scene of the application, just like the script, actors, and props describe a scene in a play or movie. In JavaFX, the scene graph is a hierarchical set of nodes where the *root* node is at the top of the tree. Underneath the root node, we can create sub-trees consisting of layout components, such as panels, buttons, text, or shapes that could be drawn in the scene. Nodes have properties that include items such as the text, size, position, color, or visual effects.

In our simple JavaFX programs, we create a special type of Node called a Group. A Group can contain other Nodes and can "auto-size" based on the nodes

that are added to it. In our programs, we have added only one item, a Canvas, so it expands to fill the window. The class GraphicsContext associated with the Canvas object allows us to issue drawing calls that produce displays in the scene.

At this point, it is sufficient to know that GraphicsContext is a class that has methods that allow us to draw figures and write text in the area of the screen it represents. A summary of some of these methods is given in Figure 5.8.

FIGURE 5.8 Some Methods in the Class GraphicsContext

```
gc.strokeOval(X, Y, Width, Height)
 Draws the outline of an oval having the specified width and height at the point (X, Y).
gc.filloval(X, Y, Width, Height)
 Same as strokeOval, but the oval is filled in.
gc.strokeArc(X, Y, Width, Height, StartAngle, ArcAngle, ArcType)
 Draws an arc—that is, draws part of an oval. See the graphics supplement section of
 Chapter 1 for details.
gc.fillArc(X, Y, Width, Height, StartAngle, ArcAngle, ArcType)
 Same as strokeArc, but the visible portion of the oval is filled in.
gc.strokeRect(X, Y, Width, Height)
 Draws the outline of a rectangle having the specified width and height at the point
 (X, Y).
gc.fillRect(X, Y, Width, Height)
 Same as strokeRect, but the rectangle is filled in.
gc.strokeLine(X1, Y1, X2, Y2)
 Draws a line between points (X1, Y1) and (X2, Y2).
gc.fillText(String, X, Y)
 Draws the specified string at point (X, Y).
gc.setLineWidth(Width)
 Sets the current line width.
gc.setFill(Attribute)
 Sets the current fill paint attribute. We have been using color as the fill attribute to
 set the current color, but gradients or image patterns are other attributes.
gc.setFont(Font)
 Sets the current font.
gc.drawImage(Image, X, Y)
 Draws the specified image at point (X, Y).
gc.setEffect(Effect)
 Sets the effect to be applied to the next drawing call.
```

You have already seen most of these methods used within previous JavaFX examples.

Although we have limited our discussion to relatively simple shapes at this point, the GraphicsContext class supports a wider range of geometric shapes, can fill them with different textures and gradients, allows control over font and shape properties, and supports visual effects such as blurs, transparency, transformations, and other functionality one would need to create a rich media application or video game.

In Listing 5.23, we give you a taste of this functionality by loading an image and displaying it in three ways. First, the image is displayed in its normal 1:1 ratio. Next, the image is displayed at twice the height and twice the width.

LISTING 5.23 Drawing Images and Applying Effects (part 1 of 2)

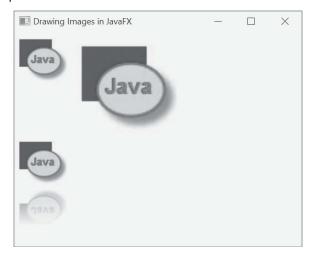
```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.shape.ArcType;
import javafx.scene.paint.Color;
import javafx.scene.image.Image;
import javafx.scene.effect.Reflection;
public class ImageExample extends Application
   public static void main(String[] args)
      launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
   {
       Group root = new Group():
       Scene scene = new Scene(root);
       // Java looks for "java.jpg" in the default folder
       Image img = new Image("java.jpg");
       Canvas canvas = new Canvas (400, 400);
       GraphicsContext gc = canvas.getGraphicsContext2D();
       // Draw image in normal scaling at (1,1)
       gc.drawImage(img, 1, 1);
       // Draw image twice as large to the right of
       // previous image
       gc.drawImage(img, img.getWidth() + 10, 1,
                    img.getWidth() * 2, img.getHeight() * 2);
                                                         (continued)
```

# LISTING 5.23 Drawing Images and Applying Effects (part 2 of 2)

```
// Draw image below the first with a reflection effect
gc.setEffect(new Reflection());
gc.drawImage(img, 1, img.getHeight() *2);

root.getChildren().add(canvas);
primaryStage.setTitle("Drawing Images in JavaFX");
primaryStage.setScene(scene);
primaryStage.show();
}
```

#### Program Output



JavaFX will scale the image to fit the specified dimensions. Finally, a visual effect is applied before the image is displayed. In this case, we apply a reflection effect so that a reflection of the image is seen below the image. In our example, we used a JPEG image with the word "Java" in it along with some shapes, but you could use any image. JavaFX is capable of reading in common image formats such as GIF, JPEG, or PNG.

#### **RECAP The GraphicsContext Class**

Objects of the class GraphicsContext represent an area of the screen and have methods for drawing figures, images, text, and applying visual effects. The GraphicsContext is associated with a Canvas that in turn is part of a hierarchy of Nodes in a Scene displayed in the Stage (window).

# **PROGRAMMING EXAMPLE**

Multiple Faces, but with a Helping Method

In Listing 5.24 we have revised the JavaFX shown in Listing 4.9. In this new version, we have extracted the code for drawing all of a face except the mouth and skin color and placed it into the body of a method named drawFaceSansMouth. In our older version of this application (Listing 4.9), the code for the face was repeated three times: once in the body of the for loop and twice after the for loop. In Listing 5.24, this code is written only once—in the body of the method drawFaceSansMouth. This saves some typing, but more importantly, it makes the code easier to read and to maintain. The method drawFaceSansMouth packages the complex task of drawing most of the face. Instead of writing several lines of code each time you want to draw a face, you write one method call to drawFaceSansMouth. It is much easier to understand.

A helping method simplifies code

# LISTING 5.24 Using a Method for a Recurrent Subtask (part 1 of 4)

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.shape.ArcType;
import javafx.scene.paint.Color;
import javafx.scene.text.Font;
(continued)
```

#### LISTING 5.24 Using a Method for a Recurrent Subtask (part 2 of 4)

```
public class MultipleFaces extends Application
   public static final int WINDOW_WIDTH = 450;
   public static final int WINDOW_HEIGHT = 300;
   public static final int FACE_DIAMETER = 50;
   public static final int X_FACE0 = 10;
   public static final int Y FACE0 = 5;
   public static final int EYE_WIDTH = 5;
   public static final int EYE_HEIGHT = 10;
   public static final int X RIGHT EYE0 = 20;
   public static final int Y_RIGHT_EYE0 = 15;
   public static final int X LEFT EYE0 = 45;
   public static final int Y_LEFT_EYE0 = Y_RIGHT_EYE0;
   public static final int NOSE_DIAMETER = 5;
   public static final int X_NOSE0 = 32;
   public static final int Y_NOSE0 = 25;
   public static final int MOUTH_WIDTH = 30;
   public static final int MOUTH HEIGHTO = 0;
   public static final int X_MOUTHO = 20;
   public static final int Y_MOUTHO = 35;
   public static final int MOUTH_START_ANGLE = 180;
   public static final int MOUTH EXTENT ANGLE = 180;
   public static void main(String[] args)
      launch(args);
   gc is the drawing area. pos indicates the position of the
   face. As pos increases, the face is drawn lower and further
   to the right.
   * /
   private void drawFaceSansMouth(GraphicsContext gc, int pos)
      // Draw face oval
      gc.setFill(Color.BLACK);
      gc.stroke0val(X_FACE0 + 50 * pos, Y_FACE0 + 30 * pos,
                      FACE_DIAMETER, FACE_DIAMETER);
      // Draw eyes
      qc.setFill(Color.BLUE);
```

#### LISTING 5.24 Using a Method for a Recurrent Subtask (part 3 of 4)

```
gc.fillOval(X_RIGHT_EYEO + 50 * pos, Y_RIGHT_EYEO + 30 * pos,
                EYE_WIDTH, EYE_HEIGHT);
   gc.fillOval(X_LEFT_EYEO + 50 * pos, Y_LEFT_EYEO + 30 * pos,
                 EYE_WIDTH, EYE_HEIGHT);
   //Draw nose
   gc.setFill(Color.BLACK);
   gc.filloval(X_NOSEO + 50 * pos, Y_NOSEO + 30 * pos,
                 NOSE_DIAMETER, NOSE_DIAMETER);
@Override
public void start(Stage primaryStage) throws Exception
    Group root = new Group();
    Scene scene = new Scene(root);
    Canvas canvas = new Canvas(WINDOW_WIDTH, WINDOW_HEIGHT);
    GraphicsContext gc = canvas.getGraphicsContext2D();
    int i:
            //Want i to exist after the loop ends
    for (i = 0; i <= 4; i++)
    {//Draw one face:
       if (i \% 2 == 0) // if i is even
       {//Make face yellow
           gc.setFill(Color.YELLOW);
           gc.filloval(X_FACEO + 50 * i, Y_FACEO + 30 * i,
                                 FACE_DIAMETER, FACE_DIAMETER);
       drawFaceSansMouth(gc, i);
       //Draw mouth:
       gc.setFill(Color.RED);
       gc.strokeArc(X_MOUTHO + 50 * i, Y_MOUTHO + 30 * i,
                    MOUTH_WIDTH, MOUTH_HEIGHTO + 3 * i + 1,
                    MOUTH_START_ANGLE, MOUTH_EXTENT_ANGLE,
                    ArcType.OPEN);
    //i is 5 when the previous loop ends
    //Draw kissing face:
    drawFaceSansMouth(gc, i);
    //Draw mouth in shape of a kiss:
    gc.setFill(Color.RED);
    gc.filloval(X_MOUTHO + 50 * i + 10, Y_MOUTHO + 30 * i,
                  MOUTH WIDTH - 20, MOUTH WIDTH - 20);
    //Add text in Times New Roman, 12 point:
    gc.setFont(Font.font("Times New Roman", 12));
```

## LISTING 5.24 Using a Method for a Recurrent Subtask (part 4 of 4)

```
gc.setFill(Color.BLACK);
       gc.fillText("Kiss, Kiss.",
              X FACEO + 50 * i + FACE DIAMETER, Y FACEO + 30 * i);
       //Draw blushing face:
       i++:
       //Draw face circle:
       gc.setFill(Color.PINK);
       gc.filloval(X_FACEO + 50*i, Y_FACEO + 30*i,
                      FACE_DIAMETER, FACE_DIAMETER);
       drawFaceSansMouth(gc, i);
       gc.setFill(Color.RED);
       //Draw mouth:
       gc.setFill(Color.BLACK);
       gc.strokeArc(X_MOUTHO + 50*i, Y_MOUTHO + 30*i, MOUTH_WIDTH,
                     MOUTH_HEIGHTO + 3 * (i - 2),
                     MOUTH_START_ANGLE, MOUTH_EXTENT_ANGLE, ArcType.OPEN);
       //Add text in Courier New Font, 16 point:
       gc.setFont(Font.font("Courier New ", 16));
       gc.fillText("Tee Hee.",
             X_FACEO + 50*i + FACE_DIAMETER, Y_FACEO + 30*i);
     root.getChildren().add(canvas);
     primaryStage.setTitle("MultipleFaces in JavaFX");
     primaryStage.setScene(scene);
     primaryStage.show();
   }
Program Output
                  The drawing produced is identical to the one show in Listing 4.9
                  except for some of the colors used to draw the faces.
```

Of course, you must still understand how to design and write the helping method, but you do not have to write it three times, as you did in the older version in Listing 4.9.

Notice that since the method drawFaceSansMouth is only a helping method for the method start, we have made drawFaceSansMouth a private method.

# **SELF-TEST QUESTION**

33. Rewrite the method drawFaceSansMouth in Listing 5.24 so that it colors the eyes according to the color specified by one additional parameter.

# Adding Labels to a JavaFX Application

A label in a JavaFX application is little more than a quoted string, but it is handled in the same way that many other components, such as buttons, are handled. Thus, labels provide another way to add text to a JavaFX application, but serve as an introduction to expand to other types of components. We will add other components in the same way that we add labels.

Listing 5.25 contains a JavaFX application that displays the text Hello Out there!, but this program does not use fillText to create the displayed text; it uses labels instead. To access the label class we import javafx.scene. control.Label. In our program, we add two labels to the program. We could have added only one label containing all the text, but we wanted an example of adding more than one component to the program.

Typically, you will add multiple items to a JavaFX application. When you do so, you need to specify how the components should be arranged visually in the window. In Listing 5.25, we did this using a vertical box layout. We access this class by importing javafx.scene.layout.VBox. Then in the code we use:

```
VBox root = new VBox();
```

## LISTING 5.25 Adding Labels to a JavaFX Application (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.text.Font;
import javafx.scene.layout.VBox;
import javafx.scene.control.Label;
public class LabelDemo extends Application
{
  public static void main(String[] args)
       launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
       VBox root = new VBox();
       Label label1, label2;
       label1 = new Label("Hello");
       label1.setFont(Font.font("Times New Roman", 24));
       label2 = new Label("Out there!");
       label2.setFont(Font.font("Courier New", 36));
       root.getChildren().add(label1);
       root.getChildren().add(label2);
```

(continued)

## LISTING 5.25 Adding Labels to a JavaFX Application (part 2 of 2)

```
Scene scene = new Scene(root, 300, 100);
    primaryStage.setTitle("Label Demo");
    primaryStage.setScene(scene);
    primaryStage.show();
    }
}
Program Output
```



This statement says to create a vertical box layout to arrange our components vertically, one on top of the other. The first component we add to the layout will be displayed at the top. The second component will be displayed beneath it, and so on. There are other layouts that we will discuss later in the text, but this is a simple layout to begin with.

Labels are created and added to the scene in two separate steps. You create a label as an object of the class Label, as illustrated in these lines:

```
Label label1, label2;
label1 = new Label("Hello");
```

We can optionally set the font or other properties for the individual label, as in:

```
label1.setFont(Font.font("Times New Roman", 24));
```

Finally, the label is added to the layout with:

```
root.getChildren().add(label1);
```

#### FAQ Why bother with labels? Why not just use fillText?

Using labels in a JavaFX application seems like a lot of work when you could get the same result simply by calling the method fillText. So far, that is true, but you will soon see that we can do some special things with labels. Moreover, you will see that once you learn how to include labels, you can easily include lots of other kinds of components, such as buttons, because they are added to an application in the same way that you add labels. You will start to see all this in the graphics supplement in the next chapter.

#### **CHAPTER SUMMARY**

- Classes have instance variables to store data and method definitions that perform actions.
- Each class, instance variable, and method definition can be either public or private. Those that are public can be used or accessed anywhere. A private instance variable cannot be accessed by name outside of its class definition. However, it can be used within the definitions of methods in its class. A private method definition cannot be invoked outside of its class definition. However, it can be invoked within the definitions of methods in its class.
- Instance variables should be private, even though as a result, they cannot be referenced by name except within the definition of a method of the same class.
- Accessor methods return the value of an instance variable. Mutator methods set the value of one or more instance variables.
- Every method belongs to some class and is available to objects created from that class.
- There are two kinds of methods: methods that return a value and void methods, which do not return a value.
- You can use the invocation of a method that returns a single quantity anyplace that you can use a value of the method's return type.
- You follow the invocation of a void method with a semicolon to form a statement that performs an action.
- The keyword this, when used within a method definition, represents the object that receives the invocation of the method.
- A local variable is a variable declared within a method definition. The variable does not exist outside of its method.
- Arguments in a method invocation must match the formal parameters in the method heading with respect to their number, their order, and their data types.
- The formal parameters of a method behave like local variables. Each is initialized to the value of the corresponding argument when the method is called. This mechanism of substituting arguments for formal parameters is known as the call-by-value mechanism.
- Methods can have parameters of a primitive type and/or parameters of a class type, but the two types of parameters behave differently. A parameter

- of a primitive type is initialized to the primitive value of its corresponding argument. A parameter of a class type is initialized to the memory address, or reference, of the corresponding argument object.
- Any change made to a parameter of a primitive type is *not* made to the corresponding argument.
- A parameter of a class type becomes another name for the corresponding argument in a method invocation. Thus, any change that is made to the state of the parameter will be made to the corresponding argument. However, if a parameter is replaced by another object within the method definition, the original argument is not affected.
- A method definition can include a call to another method that is in either the same class or a different class.
- A block is a compound statement that declares a local variable.
- Encapsulation means that data and actions are combined into a single item—a class object—and that the details of the implementation are hidden. Making all instance variables private is part of the encapsulation process.
- A method's precondition comment states the conditions that must be true before the method is invoked. Its postcondition comment tells what will be true after the method is executed. That is, the postcondition describes all the effects produced by an invocation of the method if the precondition holds. Preconditions and postconditions are kinds of assertions.
- The utility program j avadoc creates documentation from a class's comments that are written in a certain form.
- Class designers use a notation called UML to represent classes.
- Unit testing is a methodology in which the programmer writes a suite of tests to determine if individual units of code are operating properly.
- The operators = and ==, when used on objects of a class, do not behave the same as they do when used on primitive types.
- You usually want to provide an equals method for the classes you define.
- The GraphicsContext object in a JavaFX application lets you draw graphics, text, or images.
- You add a label to a JavaFX application by choosing a layout and adding the label to the layout.

#### **Exercises**

- 1. Design a class to represent a credit card. Think about the attributes of a credit card; that is, what data is on the card? What behaviors might be reasonable for a credit card? Use the answers to these questions to write a UML class diagram for a credit card class. Then give three examples of instances of this class.
- 2. Repeat Exercise 1 for a credit card account instead of a credit card. An account represents the charges and payments made using a credit card.
- 3. Repeat Exercise 1 for a cheque instead of a credit card.
- 4. Repeat Exercise 1 for an online payment on Apple Pay instead of a credit card.
- 5. Consider a Java class that you could use to get an acceptable integer value from the user. An object of this class will have the attributes
  - Minimum accepted value
  - Maximum accepted value
  - Prompt string

and the following method:

- getValue displays the prompt and reads a value using the class Scanner. If the value read is not within the allowed range, the method should display an error message and ask the user for a new value, repeating these actions until an acceptable value is entered. The method then returns the value read.
- a. Write preconditions and postconditions for the method getValue.
- b. Implement the class in Java.
- c. Write some Java statements that test the class.
- 6. Consider a class that keeps track of the students in a session. An object of this class will have the attributes
  - Total number of students
  - Total number of scholarships awarded
  - Scholarships per student
  - Total scholarship amount
  - Donations received for scholarships
  - Unutilized balance of donations

and the following methods:

- registerScholarships (n) records the scholarship amount to *n* percent of the total number of students. If *n* is larger than 10%, the scholarship amount per student will be reduced.
- displayUnutilizedDonations displays the amount of donations received and the amount that remains unutilized.

- a. Implement the class in Java.
- b. Write some Java statements that test the class.
- 7. Consider a class MotorBoat that represents motorboats. A motorboat has attributes for
  - The capacity of the fuel tank
  - The amount of fuel in the tank
  - The maximum speed of the boat
  - The current speed of the boat
  - The efficiency of the boat's motor
  - The distance traveled

#### The class has methods to

- Change the speed of the boat
- Operate the boat for an amount of time at the current speed
- Refuel the boat with some amount of fuel
- Return the amount of fuel in the tank
- Return the distance traveled so far

If the boat has efficiency e, the amount of fuel used when traveling at a speed s for time t is  $e \times s^2 \times t$ . The distance traveled in that time is  $s \times t$ .

- a. Write a method heading for each method.
- b. Write preconditions and postconditions for each method.
- c. Write some Java statements that test the class.
- d. Implement the class.
- 8. Consider a class PersonAddress that represents an entry in an address book. Its attributes are
  - The first name of the person
  - The last name of the person
  - The e-mail address of the person
  - The telephone number of the person

#### It will have methods to

- · Access each attribute
- Change the e-mail address
- Change the telephone number
- Test whether two instances are equal based solely on name
- a. Write a method heading for each method.
- b. Write preconditions and postconditions for each method.
- c. Write some Java statements that test the class.
- d. Implement the class.

- 9. Consider a class RatingScore that represents a numeric rating for something such as a movie. Its attributes are
  - A description of what is being rated
  - The maximum possible rating
  - The rating

#### It will have methods to

- Get the rating from a user
- Return the maximum rating possible
- Return the rating
- Return a string showing the rating in a format suitable for display
- a. Write a method heading for each method.
- b. Write preconditions and postconditions for each method.
- c. Write some Java statements that test the class.
- d. Implement the class.
- 10. Consider a class ScienceFairProjectRating that will be used to help judge a science fair project. It will use the class RatingScore described in the previous exercise. The attributes for the new class are
  - The name of the project
  - A unique identification string for the project
  - The name of the person
  - A rating for the creative ability (max. 30)
  - A rating for the scientific thought (max. 30)
  - A rating for thoroughness (max. 15)
  - A rating for technical skills (max. 15)
  - A rating for clarity (max. 10)

#### It will have methods to

- Get the number of judges
- Get all the ratings for a particular project
- Return the total of the ratings for a particular project
- Return the maximum total rating possible
- Return a string showing a project's rating in a format suitable for display
- a. Write a method heading for each method.
- b. Write preconditions and postconditions for each method.
- c. Write some Java statements that test the class.
- d. Implement the class.

#### **PRACTICE PROGRAMS**

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

1. Write a program to answer questions like the following: Suppose the species Klingon ox has a population of 100 and a growth rate of

15 percent, and the species elephant has a population of 10 and a growth rate of 35 percent. How many years will it take for the elephant population to exceed the Klingon ox population? Use the class Species in Listing 5.19. Your program will ask for the data on both species and will respond by telling you how many years it will take for the species that starts with the lower population to outnumber the species that starts with the higher population. The two species may be entered in any order. It is possible that the species with the smaller population will never outnumber the other species. In this case, your program should display a suitable message stating this fact.

- 2. Define a class called Salary. An object of this class is used to calculate salaries, so it calculates a salary that is a whole number greater than basic salary. Include methods to set the basic salary to 5000, to increase the salary by 10%, and to decrease the salary by 10%. Be sure that no method allows the value of the counter to become less than the basic salary. Also include an accessor method that returns the current salary value, as well as a method that displays the salary on the screen. Do not define an input method. The only method that can set the basic salary is the one that sets it to 5000. Write a program to test your class definition. (*Hint*: You need only one instance variable.)
- 3. Redo or do Practice Program 8 from Chapter 4, except write a class for the Magic 8 Ball. Write a program that simulates the Magic 8 Ball game. The class should have a method that returns an answer at random. Test your class by outputting the answer several times.
- 4. Define a Trivia class that contains information about a single trivia question. The question and answer should be defined as instance variables of type String. Create accessor and mutator methods. In your main method create two Trivia objects with questions and answers of your choice. Then for each Trivia object have your program ask the question, input an answer, compare the typed answer to the actual answer, and output if the user's answer was correct or incorrect.
- 5. Define a Beer class that contains the following instance variables with accessors/mutators:

```
String name; // The name of the beer

double alcohol; // The percent alcohol of the beer, e.g.

// 0.05 for 5%

Add the following method:

// This method returns the number of drinks that a person

// of (weight) pounds can drink using the alcohol percentage

// in the beer, assuming a drink of 12 ounces. This is an

// estimate. The method assumed that the legal limit is 0.08 blood

// alcohol.

public double intoxicated(double weight)
```

Write code in a main method that creates two Beer objects with different alcohol percentages. Invoke the intoxicated method for a light individual and a heavy individual and output the estimated number of drinks to become legally intoxicated.

#### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

- 1. Write a grading program for an instructor whose course has the following policies:
  - Two quizzes, each graded on the basis of 10 points, are given.
  - One midterm exam and one final exam, each graded on the basis of 100 points, are given.
  - The final exam counts for 50 percent of the grade, the midterm counts for 25 percent, and the two quizzes together count for a total of 25 percent. (Do not forget to normalize the quiz scores. They should be converted to percentages before they are averaged in.)

Any grade of 90 percent or more is an A, any grade between 80 and 89 percent is a B, any grade between 70 and 79 percent is a C, any grade between 60 and 69 percent is a D, and any grade below 60 percent is an F.

The program should read in the student's scores and display the student's record, which consists of two quiz scores, two exam scores, the student's total score for the entire course, and the final letter grade. The total score is a number in the range 0 to 100, which represents the weighted average of the student's work.

Define and use a class for the student record. The class should have instance variables for the quizzes, midterm, final, total score for the course, and final letter grade. The class should have input and output methods. The input method should not ask for the final numeric grade, nor should it ask for the final letter grade. The class should have methods

to compute the overall numeric grade and the final letter grade. These last two methods will be void methods that set the appropriate instance variables. Remember, one method can call another method. If you prefer, you can define a single method that sets both the overall numeric score and the final letter grade, but if you do this, use a helping method. Your program should use all the methods described here. Your class should have a reasonable set of accessor and mutator methods, whether or not your program uses them. You may add other methods if you wish.

- 2. Add methods to the Person class from Self-Test Question 16 to perform the following tasks:
  - Set the name attribute of a Person object.
  - Set the age attribute of a Person object.
  - Test whether two Person objects are equal (have the same name and age).
  - Test whether two Person objects have the same name.
  - Test whether two Person objects are the same age.
  - Test whether one Person object is older than another.
  - Test whether one Person object is younger than another.

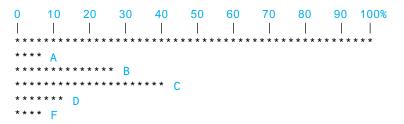
Write a driver (test) program that demonstrates each method, with at least one true and one false case for each of the methods tested.

- 3. Create a class that represents a grade distribution for a given course. Write methods to perform the following tasks:
  - Set the number of each of the letter grades A, B, C, D, and F.
  - Read the number of each of the letter grades A, B, C, D, and F.
  - Return the total number of grades.
  - Return the percentage of each letter grade as a whole number between 0 and 100, inclusive.
  - Draw a bar graph of the grade distribution.

The graph will have five bars, one per grade. Each bar can be a horizontal row of asterisks, such that the number of asterisks in a row is proportionate to the percentage of grades in each category. Let one asterisk represent 2 percent, so 50 asterisks correspond to 100 percent. Mark the horizontal axis at 10 percent increments from 0 to 100 percent, and label each line with its letter grade.

For example, if the grades are 1 A, 4 Bs, 6 Cs, 2 Ds, and 1 F, the total number of grades is 14, the percentage of As is 7, the percentage of Bs is 29, the percentage of Cs is 43, the percentage of Ds is 14, and the percentage of Fs is 7. The A row would contain 4 asterisks (7 percent of 50 rounded to

the nearest integer), the B row 14, the C row 21, the D row 7, and the F row 4. The graph would look like this:



4. Write a program that uses the Purchase class in Listing 5.13 to set the following prices:

Oranges: 10 for \$2.99 Eggs: 12 for \$1.69 Apples: 3 for \$1.00 Watermelons: \$4.39 each Bagels: 6 for \$3.50

bageis. 6 101 \$3.30

Then calculate the cost of each of the following five items and the total bill:

- 2 dozen oranges
- 3 dozen eggs
- 20 apples
- 2 watermelons
- 1 dozen bagels
- 5. Write a program to answer questions like the following: Suppose the species Klingon ox has a population of 100 and a growth rate of 15 percent, and it lives in an area of 1500 square miles. How long would it take for the population density to exceed 1 per square mile? Use the class Species in Listing 5.19 with the addition of the getDensity method from Self-Test Question 10.
- 6. Consider a class that could be used to play a game of hangman. The class has the following attributes:
  - The secret word.
  - The disguised word, in which each unknown letter in the secret word is replaced with a question mark (?). For example, if the secret word is *abracadabra* and the letters *a*, *b*, and *e* have been guessed, the disguised word would be *ab?a?a?ab?a*.
  - The number of guesses made.
  - The number of incorrect guesses.



#### It will have the following methods:

- makeGuess(c) guesses that character c is in the word.
- getDisguisedWord returns a string containing correctly guessed letters in their correct positions and unknown letters replaced with?
- getSecretWord returns the secret word.
- getGuessCount returns the number of guesses made.
- isFound returns true if the hidden word has been discovered.
- a. Write a method heading for each method.
- b. Write preconditions and postconditions for each method.
- c. Write some Java statements that test the class.
- d. Implement the class.
- e. List any additional methods and attributes needed in the implementation that were not listed in the original design. List any other changes made to the original design.
- f. Write a program that implements the game of hangman using the class you wrote for Part *d*.
- 7. Consider a class BasketballGame that represents the state of a basketball game. Its attributes are
  - The name of the first team
  - The name of the second team
  - The score of the first team
  - The score of the second team
  - The status of the game (finished or in progress)

#### BasketballGame has methods to

- Record one point scored for a team
- Record two points scored for a team
- Record three points scored for a team
- Change the status of the game to finished
- Return the score of a team
- Return the name of the team that is currently winning
- a. Write a method heading for each method.
- b. Write preconditions and postconditions for each method.
- c. Write some Java statements that test the class.
- d. Implement the class.
- e. List any additional methods and attributes needed in the implementation that were not listed in the original design. List any other changes made to the original design.
- f. Write a program that uses the class BasketballGame to keep track of the score of a basketball game. Use a loop that reads input each time a basket is scored. (You will need to indicate the scoring team and the

number of points scored for each basket: 1, 2, or 3.) After each input is read, display the current score of the game. For example, a portion of the interaction with the program might be as follows:

```
Enter a score:
a 1
Cats 1, Dogs 0; Cats are winning.
Enter a score:
a 2
Cats 3, Dogs 0; Cats are winning.
Enter a score:
b 2
Cats 3, Dogs 2; Cats are winning.
Enter a score:
b 3
Cats 3, Dogs 5; Dogs are winning.
```

- 8. Consider a class ConcertPromoter that records the tickets sold for a performance. Before the day of the concert, tickets are sold only over the phone. Sales on the day of the performance are made only in person at the concert venue. The class has the following attributes:
  - The name of the band
  - The capacity of the venue
  - The number of tickets sold
  - The price of a ticket sold by phone
  - The price of a ticket sold at the concert venue
  - The total sales amount

#### It has methods to

- Record the sale of one or more tickets
- Change from phone sales to sales at the concert venue
- Return the number of tickets sold
- Return the number of tickets remaining
- Return the total sales for the concert
- a. Write a method heading for each method.
- b. Write preconditions and postconditions for each method.
- c. Write some Java statements that test the class.
- d. Implement the class.
- e. List any additional methods and attributes needed in the implementation that were not listed in the original design. List any other changes made to the original design.

- f. Write a program using the class you wrote for Part *d* that will be used to record sales for a concert. Your program should record phone sales, then sales at the venue. As tickets are sold, the number of seats remaining should be displayed. At the end of the program, display the number of tickets sold and the total sales amount for the concert.
- 9. Rewrite the Dog class given in Listing 5.1 by utilizing the information and encapsulation principles described in Section 5.2. The new version should include accessor and mutator methods. Also define an equals method for the class that returns true if the dog's name, age, and breed match the same variables for the other object that is being compared. Include a main method to test the functionality of the new Dog class.
- 10. Consider a class Movie that contains information about a movie. The class has the following attributes:



- The movie name
- The MPAA rating (e.g., G, PG, PG-13, R)
- The number of people who have rated this movie as a 1 (Terrible)
- The number of people who have rated this movie as a 2 (Bad)
- The number of people who have rated this movie as a 3 (OK)
- The number of people who have rated this movie as a 4 (Good)
- The number of people who have rated this movie as a 5 (Great)

Implement the class with accessors and mutators for the movie name and MPAA rating. Write a method addRating that takes an integer as an input parameter. The method should verify that the parameter is a number between 1 and 5, and if so, increment by one the number of people rating the movie that matches the input parameter. For example, if 3 is the input parameter, then the number of people who rated the movie as a 3 should be incremented by one. Write another method, getAverage, that returns the average value for all of the movie ratings.

Test the class by writing a main method that creates at least two movie objects, adds at least five ratings for each movie, and outputs the movie name, MPAA rating, and average rating for each movie object.

11. Repeat Programming Project 18 from Chapter 4, but use a method that displays a circular disk as a subtask.

**Graphics** 

12. Create a JavaFX application that displays something like the following picture. You should have methods for drawing a monkey face and a hand.







See no evil



Speak no evil

- 13. Do Programming Project 17 from Chapter 4, the Edoc calculator, except write a method that takes the number of candy, Edoc, and Margorp as input parameters and returns the amount of experience that can be earned. Modify your program to give advice to the player using the following rules:
  - Catching an additional Edoc gives you three Edoc candy.
  - If you can't get any experience points with the provided inputs then output "You can't evolve any Edoc, catch more."
  - If catching one or two additional Edoc will give you more experience points compared to evolving right now then output "Catch more Edoc before evolving."
  - Otherwise output "You should evolve now."

#### **Answers to Self-Test Questions**

```
1. SpeciesFirstTry speciesOfTheYear = new SpeciesFirstTry();
  System.out.println("Enter data for Species of the Year:");
  speciesOfTheYear.readInput();
dilbert.readInput();
import java.util.Scanner;
  public class SpeciesFirstTry
      public String name;
      public int number;
      public int population;
      public double growthRate;
      public void readInput()
          Scanner keyboard = new Scanner(System.in);
          System.out.println("What is the species name?");
          name = keyboard.nextLine();
          System.out.println("What is the species number?");
          number = keyboard.nextInt();
          System.out.println("What is the population of the " +
                      "species?");
          population = keyboard.nextInt();
          System.out.println("Enter growth rate (% increase " +
                              "per year):");
          growthRate = keyboard.nextDouble();
  }
      public void writeOutput()
          System.out.println("Name = " + name);
          System.out.println("Number = " + number);
          System.out.println("Population = " + population);
          System.out.println("Growth rate = " + growthRate + "%");
  }
```

Graphics

```
public int getPopulationIn10()
  <This method does not change.>
4. public int getFemalePopulation()
      return population / 2 + population % 2;
  public int getMalePopulation()
      return population / 2;
  }
5. public void writeOutput()
      System.out.println("Name = " + this.name);
      System.out.println("Population = " + this.population);
      System.out.println("Growth rate = " + this.growthRate + "%");
  }
6. public void readInput()
      Scanner keyboard = new Scanner(System.in); System.out.
      println("What is the species name?");
      this.name = keyboard.nextLine();
      System.out.println(
           "What is the population of the species?");
      this.population =
                           keyboard.nextInt();
      System.out.println(
           "Enter growth rate (% increase per year):");
      this.growthRate = keyboard.nextDouble();
  }
7. public int getPopulationIn10()
      int result = 0;
      double populationAmount = this.population;
      int count = 10;
      while ((count > 0) && (populationAmount > 0))
      {
          populationAmount = (populationAmount +
               (this.growthRate / 100) * populationAmount);
         count - - - ;
      if (populationAmount > 0)
           result = (int)populationAmount;
      return result;
  }
```

- 8. The expression (int) is a type cast. It is needed because the method heading specifies that the type of the returned value is int, and so the value of populationAmount must be changed from double to int before it is returned.
- 9. In this book the terms *parameter* and *formal parameter* mean exactly the same thing.

```
10. public double getDensity(double area)
{
    return population / area;
}
11. public void changePopulation(double area)
{
    population = (int)(2 * area);
}
12. public void changePopulation(double area, int numberPerMile)
{
    population = (int)(numberPerMile * area);
}
```

- 13. We cannot use the alternative code, because the instance variables are labeled private in the class definition and so cannot be accessed by name except within a method definition of the class SpeciesFourthTry.
- 14. /\*\*
   Precondition: This object's population and growth rate have been given values.
   Postcondition: This object population was updated to reflect one year's change. Other data values are unchanged.
   \*/
- 15. An accessor method is a public method that returns the data from a private instance variable. The name of an accessor method typically begins with get. A mutator method is a public method that changes the data stored in one or more private instance variables. The name of a mutator method typically begins with set.

```
16. import java.util.Scanner;
   public class Person
   {
      private String name;
      private int age;
      public void setName(String newName)
      {
            name = newName;
      }
      public void setAge(int newAge)
```

```
{
          if (newAge >= 0)
                age = newAge;
          else
          {
                System.out.println("ERROR: Age is " +
                   "negative.");
                System.exit(0);
          }
    public void setPerson(String newName, int newAge)
          setName(newName);
          setAge(newAge)
    public String getName()
           return name;
    public int getAge()
           return age;
}
```

- 17. Yes. See Listing 5.15 for an example.
- 18. No effect at all. The two statements are equivalent in this context.
- 19. A well-encapsulated class definition logically separates into class interface and implementation. A programmer should be able to use the class knowing only the information given in the class interface and should need to know nothing about the implementation.
- 20. Instance variables should always be private.
- 21. If a method is a helping method that is used only within the definitions of other methods, it should be private.
- 22. No, it is part of the implementation.
- 23. No, it is part of the implementation.
- 24. A reference type is a type whose variables hold references—that is, memory addresses—as opposed to actual values of objects. Class types are reference types. Not all reference types are class types, but we will not see any examples of this until later in the book. Primitive types are not reference types.
- 25. Normally, you use the method equals when testing two objects to see whether they are "equal." The only time you would use = = is if you wanted to see whether the objects were in the same place in memory, that is, were identical.

26. You use == when comparing two quantities of a primitive type (like int) to see whether they are "equal." Primitive types have no equals method.

# 27. /\*\* Precondition: This object and the argument otherSpecies both have values for their growth rates. Returns true if the growth rate of this object is greater than the growth rate of otherSpecies; otherwise, returns false. \*/ public boolean isGrowthRateLargerThan(Species otherSpecies) { return growthRate > otherSpecies.growthRate; }

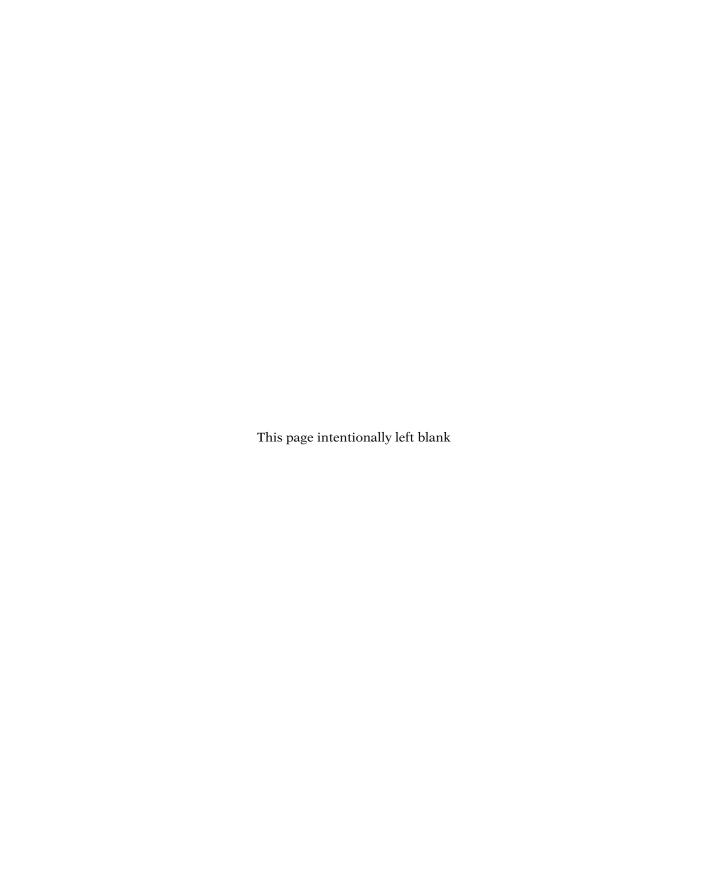
28. The variables s1 and s2 are names for objects of type Species, but this program does not create any objects for them to name. They are just names, not yet objects. The program should begin as follows:

```
public class SpeciesEqualsDemo
{
    public static void main(String[] args)
    {
        Species s1 = new Species(), s2 = new Species();
        <The rest of the code is OK.>
```

- 29. Do Not match with ==.
- 30. The biggest difference is in how a method handles arguments that correspond to the different kinds of parameters. A method cannot change the value of a variable of a primitive type that is an argument to the method, nor can it replace an argument of a class type with another object. On the other hand, a method can change the values of the instance variables of an object of a class type whose name is an argument to the method.
- 31. Name = Klingon ox
  Population = 10
  Growth rate = 15.0%
  n = 0
- 32. Here are two possible definitions of equals. The first definition considers two Person objects equal if they have the same name, regardless of their ages. The second one considers two Person objects equal if they have both the same name and the same age.

```
public boolean equals(Person otherObject)
{
    return this.name.equalsIgnoreCase(otherObject.name);
}
public boolean equals(Person otherObject)
```

```
{
       return this.name.equalsIgnoreCase(otherObject.name) &&
               (this.age == otherObject.age);
   }
   You can omit all the occurrences of this and the dot that follows.
33. private void drawFaceSansMouth(GraphicsContext gc, int pos,
                                   Color eyeColor)
   {
          // Draw face oval
          gc.setFill(Color.BLACK);
          gc.strokeOval(X_FACEO + 50 * pos, Y_FACEO + 30 * pos,
                          FACE_DIAMETER, FACE_DIAMETER);
          // Draw eyes
          gc.setFill(eyeColor);
          gc.fillOval(X_RIGHT_EYEO + 50 * pos, Y_RIGHT_EYEO + 30 * pos,
                          EYE_WIDTH, EYE_HEIGHT);
          gc.filloval(X_LEFT_EYEO + 50 * pos, Y_LEFT_EYEO + 30 * pos,
                     EYE_WIDTH, EYE_HEIGHT);
          //Draw nose
          gc.setFill(Color.BLACK);
         gc.fillOval(X_NOSE0 + 50 * pos, Y_NOSE0 + 30 * pos,
                      NOSE_DIAMETER, NOSE_DIAMETER);
   }
   The method would be invoked as:
   drawFaceSansMouth(gc, i, Color.GREEN);
```



# More About Objects and Methods

#### **6.1 CONSTRUCTORS** 421

Defining Constructors 421
Calling Methods from Constructors 430
Calling a Constructor from Other Constructors
(Optional) 433

# 6.2 STATIC VARIABLES AND STATIC METHODS 435

Static Variables 435
Static Methods 436
Dividing the Task of a main Method into Subtasks 443
Adding a main Method to a Class 444
The Math Class 446
Wrapper Classes 449

#### **6.3 WRITING METHODS** 455

Case Study: Formatting Output 455
Decomposition 461
Addressing Compiler Concerns 462
Testing Methods 464

#### **6.4 OVERLOADING** 466

Overloading Basics 466
Overloading and Automatic Type Conversion 469
Overloading and the Return Type 472
Programming Example: A Class for Money 474

## **6.5 INFORMATION HIDING REVISITED** 481

Privacy Leaks 481

#### **6.6 ENUMERATION AS A CLASS** 485

#### **6.7 PACKAGES** 487

Packages and Importing 488
Package Names and Directories 489
Name Clashes 492

#### **6.8 GRAPHICS SUPPLEMENT** 493

Adding Buttons 493 Adding Icons 493 A tourist stopped an elderly gentleman on the streets of New York City and asked him, "Please sir, could you tell me how I can get to Carnegie Hall?" "Practice, practice, practice," the old gentleman replied.

—A VERY OLD JOKE

In this chapter, we continue our discussion of how to define and use classes and their methods. As part of that discussion, we introduce constructors, which are methods used to create a new object. You have already used a constructor when you used the operator new. Java supplied that constructor, but we will show you how to write your own constructors.

In addition, we examine static methods. The method main is static, so our discussion will help you understand it. But you can also write other static methods that can be invoked using the class name, rather than an object name.

You will also learn about overloading, which allows you to give two or more methods the same name within the same class. We also discuss packages, which are libraries of classes that you can use in other class definitions. Again, you have used packages when you used classes in the Java Class Library. Along the way, we cover a number of program design techniques that will help you write better method definitions.

Finally, in the graphics supplement, you will see how to add buttons and icons—which are small pictures—to your applications. We also discuss an important programming technique—event-driven programming—that is often used for graphics programs.

#### **OBJECTIVES**

After studying this chapter, you should be able to

- Define and use a class's constructors
- Write and use static variables and static methods
- Use methods in the predefined Math class
- Use the predefined wrapper classes
- Use stubs, drivers, and other techniques to test your classes and programs
- Write and use overloaded methods
- Define and use enumeration methods
- Define and use packages and import statements
- Add buttons and icons to your JavaFX applications
- Use basic event-driven programming in a JavaFX application

#### **PREREQUISITES**

You must cover the material in Chapter 5 before reading this chapter. As we describe next, certain sections of this chapter can be postponed until after you've read some of the subsequent chapters.

Section 6.5 discusses some subtle points about using instance variables of a class type. Strictly speaking, this section is not required for the rest of the material in this book and so can be postponed. However, Section 6.5 does discuss fundamental issues that you should read at some point.

The material on writing packages in Section 6.7 requires a knowledge of folders (directories) and path variables. Folders and path variables are not Java topics; they are operating system topics, and the details depend on what operating system you are using. Section 6.7 is not required for any other material in this book, so you need not cover this section until you are ready to do so.

### **6.1** CONSTRUCTORS

First things first.

—COMMON SAYING

When you create an object of a class using the new operator, you invoke a special kind of method called a constructor. At that time, you often want certain initializing actions to occur, such as giving specific values to the instance variables. A constructor will perform such initializations. In this section, we tell you how to define and use constructors.

Constructors create and initialize new objects

## **Defining Constructors**

A **constructor** is a special method that is called when you use the new operator to create a new object. Until now, Java has supplied a constructor for us. For example, given the class Species in Listing 5.19 of the previous chapter, we can create a new Species object by writing

Using new calls a constructor

```
Species earthSpecies = new Species();
```

The first part of this statement, Species earthSpecies, declares the variable earthSpecies to be a name for an object of the class Species. The second part, newSpecies(), creates and initializes a new object, whose address is then assigned to earthSpecies. Here Species() is a call to the constructor that Java provided for the class. The parentheses are empty because this particular constructor takes no arguments.

For the classes you've seen thus far, the constructors create objects and give their instance variables default initial values. These values might not be what you want, however. Instead, you may wish to have some or all instance variables initialized to your specifications at the time an object is created. You can do this by writing your own constructors.

A constructor can perform any action you write into its definition, but a constructor is meant to perform initializing actions, such as initializing the values of instance variables. Constructors serve essentially the same purpose as set methods. But unlike set methods, constructors create an object as well as initializing it. Like set methods, constructors can have parameters.

A constructor supplied by Java uses default initial values A class diagram does not include constructors

Instance variables that you do not initialize are given default initial values by Java Let's consider a simple class to represent our pets. Suppose that we describe a pet by its name, its age, and its weight. We could give basic behaviors to a pet object that simply set or get these three attributes. Now imagine that we draw a class diagram like the one in Figure 6.1 for a class named Pet. Notice the four methods that set different instance variables. One sets all three of the instance variables name, age, and weight. The other three methods set only one instance variable each. This class diagram does not include constructors, as is typical.

One property of constructors that may seem strange at first is that each constructor has the same name as its class. So if the class is named Species, its constructors are named Species. If the class is named Pet, the constructors are named Pet.

Constructors often have multiple definitions, each with different numbers or types of parameters, and they sometimes parallel a class's set methods. As an example, Listing 6.1 contains a definition of our class Pet that includes several constructors. Note that the headings of these constructors do not have the word void. When you define a constructor, you do not specify any return type, not even void. These constructors look very much like our set methods, which *are* void methods. In fact, we have grouped each constructor with its similar set method, just for this example. Unlike some of the set methods, however, the constructors give values to *all* the instance variables, even though they might not have a parameter for each instance variable. If you do not initialize a particular instance variable, Java will do so by giving it a default value. However, it is normal programming practice to explicitly give values to all the instance variables when defining a constructor.

FIGURE 6.1 Class Diagram for a Class Pet

```
Pet

- name: String
- age: int
- weight: double

+ writeOutput(): void
+ setPet(String newName,int newAge,double newWeight): void
+ setName(String newName): void
+ setAge(int newAge): void
+ setWeight(double newWeight): void
+ getName(): String
+ getAge(): int
+ getWeight(): double
```

# LISTING 6.1 The Class Pet: An Example of Constructors and Set Methods (part 1 of 3)

```
/**
Class for basic pet data: name, age, and weight.
public class Pet
    private String name;
    private int age; //in years
    private double weight;//in pounds
    public Pet() ← Default constructor
    {
        name = "No name yet.";
        age = 0;
        weight = 0;
   public Pet(String initialName, int initialAge,
               double initialWeight)
   {
        name = initialName;
        if ((initialAge < 0) || (initialWeight < 0))</pre>
             System.out.println("Error: Negative age or weight.");
             System.exit(0);
        }
        else
        {
             age = initialAge;
             weight = initialWeight;
        }
   public void setPet(String newName, int newAge,
                        double newWeight)
        name = newName;
        if ((\text{newAge} < 0) \mid | (\text{newWeight} < 0))
        {
             System.out.println("Error: Negative age or weight.");
             System.exit(0);
        }
        else
        {
             age = newAge;
             weight = newWeight;
   1}
                                                            (continued)
```

LISTING 6.1 The Class Pet: An Example of Constructors and Set Methods (part 2 of 3)

```
ipublic Pet(String initialName)
    name = initialName;
    age = 0;
    weight = 0;
public void setName(String newName)
{
    name = newName; //age and weight are unchanged.
public Pet(int initialAge)
    name = "No name yet.";
    weight = 0;
    if (initialAge < 0)</pre>
    {
        System.out.println("Error: Negative age.");
        System.exit(0);
    }
    else
        age = initialAge;
public void setAge(int newAge)
: {
    if (newAge < 0)
        System.out.println("Error: Negative age.");
        System.exit(0);
    }
    else
        age = newAge;
    //name and weight are unchanged.
1 }
public Pet(double initialWeight)
    name = "No name yet";
    age = 0;
    if (initialWeight < 0)</pre>
        System.out.println("Error: Negative weight.");
        System.exit(0);
```

(continued)

# LISTING 6.1 The Class Pet: An Example of Constructors and Set Methods (part 3 of 3)

```
else weight = initialWeight;
   }
   public void setWeight(double newWeight)
        if (newWeight < 0)</pre>
             System.out.println("Error: Negative weight.");
             System.exit(0);
        }
        else
             weight = newWeight; //name and age are unchanged.
    public String getName()
        return name;
    public int getAge()
        return age;
    public double getWeight()
        return weight;
    public void writeOutput()
         System.out.println("Name: " + name);
         System.out.println("Age: " + age + " years");
         System.out.println("Weight: " + weight + " pounds");
    }
}
```

# REMEMBER Constructors and Set Methods Are Used in Related but Different Ways

Constructors are called only when you create an object. To change the state of an existing object, you need one or more set methods.

A default constructor has no parameters

Java defines a constructor if you do not

Constructors can require arguments

Listing 6.1 includes a constructor named Pet that has no parameters. Such a constructor is called a **default constructor**. Typically, whenever you define at least one constructor, you should also include a constructor without parameters. If you look at the definition of the class Species in the previous chapter, you will not find any constructor definitions at all. Whenever a class definition does not have a constructor definition, Java automatically defines a default constructor, that is, one without parameters. This automatically defined constructor creates an object of the class and initializes the instance variables to default values. If, however, you define at least one constructor in a class, no constructors are created for you automatically. Thus, for the class Pet in Listing 6.1, since we defined constructors, we were careful to include a constructor without parameters, that is, a default constructor.

When you create a new object by using the operator new, you must always include a call to a constructor. As with any method invocation, you list any arguments in parentheses after the constructor's name—which, remember, is the same as the class name. For example suppose you want to use new to create a new object of our class Pet. You might do so as follows:

```
Pet fish = new Pet("Wanda", 2, 0.25);
```

The part Pet ("Wanda", 2, 0.25) is a call to the constructor in Pet that takes three arguments: one of type String, one of type int, and the last of type double. This statement creates a new object to represent a pet named Wanda who is 2 years old and weighs 0.25 pound.

You can think of a constructor invocation as returning a reference to—that is, the memory address of—an object of the class Pet. The previous example assigns this reference to the variable fish. Figure 6.2 illustrates how this works.

Let's look at another example. The statement

```
Pet myPet = new Pet();
```

creates a new object of the class Pet by calling the default constructor—that is, the constructor without parameters. If you look at the definition of the class Pet in Listing 6.1, you will see that the default constructor gives the object the name No name yet and sets the instance variables age and weight to zero. (A newborn pet does not weigh zero, of course. The value of zero is just a place holder until the actual weight can be determined.)

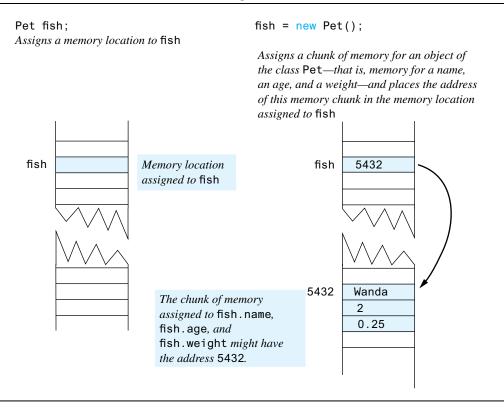
You cannot use an existing object to call a constructor, so the following invocation involving the object myPet of the class Pet is invalid:

```
myPet.Pet("Fang", 1, 150.0); //Invalid!
```

You need some other way to change the values of the instance variables of an object, once it has been created. That way involves calling one or more set

You cannot use an existing object to call a constructor

FIGURE 6.2 A Constructor Returning a Reference



methods. Thus, given the class defined in Listing 6.1, instead of the preceding invalid invocation of the constructor Pet, we could call setPet as follows:

A set method can change the state of an existing object

A sample program illustrating the use of a constructor and several set methods is given in Listing 6.2.

# ■ PROGRAMMING TIP Group the Constructor Definitions

In Listing 6.1, we have written an analogous set method after each constructor definition. We did this to emphasize the similarities and differences between these two kinds of methods. However, programmers usually group the definitions of constructors, often placing them before all the other methods in the class.

#### LISTING 6.2 Using a Constructor and Set Methods

```
import java.util.Scanner;
public class PetDemo
    public static void main(String[] args)
    {
        Pet yourPet = new Pet("Jane Doe");
        System.out.println("My records on your pet are inaccurate.");
        System.out.println("Here is what they currently say:");
        yourPet.writeOutput();
        Scanner keyboard = new Scanner(System.in);
        System.out.println("Please enter the correct pet name:");
        String correctName = keyboard.nextLine();
        yourPet.setName(correctName);
        System.out.println("Please enter the correct pet age:");
        int correctAge = keyboard.nextInt();
        yourPet.setAge(correctAge);
        System.out.println("Please enter the correct pet weight:");
        double correctWeight = keyboard.nextDouble();
        yourPet.setWeight(correctWeight);
        System.out.println("My updated records now say:");
        yourPet.writeOutput();
    }
}
```

#### Sample Screen Output

```
My records on your pet are inaccurate.
Here is what they currently say:
Name: Jane Doe
Age: 0
Weight: 0.0 pounds
Please enter the correct pet name:
Moon Child
Please enter the correct pet age:
5
Please enter the correct pet weight:
24.5
My updated records now say:
Name: Moon Child
Age: 5
Weight: 24.5 pounds
```

#### **RECAP** Constructor

A constructor is a method that is called when an object of the class is created by using the new operator. A constructor provides initial values for the instance variables of the newly created object.

Constructors must have the same name as the class to which they belong. A constructor is defined like any other method except that it does not have a return type—not even void—in the method heading.

#### **EXAMPLES**

See Listing 6.1 for examples of constructor definitions. The following are examples of invoking these constructors:

```
Pet myDog = new Pet("Fido", 2, 4.5);
Pet yourDog = new Pet("Cha Cha");
Pet ourDog = new Pet();
```

#### **RECAP Default Constructor**

A constructor without parameters is called the default constructor. Most of the classes you define should include a default constructor.

#### **REMEMBER** Java Can Define a Constructor for You

If you do not define any constructor for a class, Java will define one for you. This supplied constructor will be a default constructor—that is, one without parameters—and will give default values to the instance variables. However, once you define any constructor for a class, Java will not define any for you. In this case, if you do not explicitly define a default constructor, your class will not have one.

# **GOTCHA** Omitting the Default Constructor

Suppose we were to omit the definition of the default constructor from the class Pet in Listing 6.1. The statement

```
Pet heinz57 = new Pet();
```

would then be invalid and would produce an error message. Since Java automatically provides a default constructor if none is defined, you might think that this statement should be valid. But since this class definition contains at least one constructor definition, Java does not provide any constructors.

Classes are often reused again and again, and sooner or later you might want to create a new object by using a constructor without arguments. You should carefully consider a decision to omit a default constructor definition from the classes you write.

#### FAQ Should I include constructors in a class diagram?

A class diagram does not have to include all the methods in a class. Because a class diagram is a design tool, it need be only as complete as is required for the design task at hand. Normally, constructors are not listed in a class diagram, because they are always needed and always serve the same basic purpose.

# **Calling Methods from Constructors**

You saw in the previous chapter that a method can call other methods within its class. Likewise, a constructor can call methods within its class. For example, all of the constructors in the definition of the class Pet in Listing 6.1 can be revised to call one of the set methods. In particular, the definition of the first constructor in Pet is quite similar to the definition of the method setPet. We can avoid repeating this code by defining the constructor as follows:

A constructor that calls a public method can cause a problem

A constructor and a set method can call the same private method Although it is generally a good practice to have a method call another to avoid repeating code, you need to be careful when constructors call public methods of their class. The problem has to do with inheritance, which we will cover in Chapter 8. As you will see, it is possible for another class to alter the behavior of the public method and thereby adversely alter the behavior of the constructor. Chapter 8 will show you one way to prevent this problem, but we can offer another solution right now: Make the method that a constructor calls private. For our Pet example, making setPet private isn't an option because we want it to be public. However, we can define a private

method that both setPet and the constructor can call, as the following code demonstrates:

```
public Pet(String initialName, int initialAge,
           double initialWeight)
{
    set(initialName, initialAge, initialWeight);
public void setPet(String newName, int newAge,
        double newWeight)
{
    set(newName, newAge, newWeight);
private void set(String newName, int newAge, double newWeight)
    name = newName;
    if ((\text{newAge} < 0) \mid | (\text{newWeight} < 0))
        System.out.println("Error: Negative age or weight.");
        System.exit(0);
    }
    else
    {
        age = newAge;
        weight = newWeight;
    }
}
```

The other constructors and set methods in Pet can also be revised to invoke the private method set, as Listing 6.3 shows.

# LISTING 6.3 Constructors and Set Methods That Call a Private Method (part 1 of 3)

# LISTING 6.3 Constructors and Set Methods That Call a Private Method (part 2 of 3)

```
public Pet2(String initialName)
{
    set(initialName, 0, 0);
public Pet2(int initialAge)
    set("No name yet.", initialAge, 0);
public Pet2(double initialWeight)
    set("No name yet.", 0, initialWeight);
public Pet2( )
    set("No name yet.", 0, 0);
public void setPet(String newName, int newAge,
                   double newWeight)
{
    set(newName, newAge, newWeight);
}
public void setName(String newName)
    set(newName, age, weight);//age and weight unchanged
public void setAge(int newAge)
    set(name, newAge, weight);//name and weight unchanged
public void setWeight(double newWeight)
{
    set(name, age, newWeight);//name and age unchanged
private void set(String newName, int newAge,
                 double newWeight)
{
    name = newName;
    if ((newAge < 0) || (newWeight < 0))</pre>
         System.out.println("Error: Negative age or weight.");
         System.exit(0);
    }
                                                      (continued)
```

# LISTING 6.3 Constructors and Set Methods That Call a Private Method (part 3 of 3)

```
else
{
      age = newAge;
      weight = newWeight;
    }

      che methods getName, getAge, getWeight, and writeOutput
      are the same as in Listing 6.1.>
}
```



## **SELF-TEST QUESTIONS**

- 1. If a class is named Student, what name can you use for a constructor for this class?
- 2. When defining a constructor, what do you specify for the type of the value returned? A primitive type? A class type? void?
- 3. What is a default constructor?
- 4. Does every class in Java automatically have a default constructor? If not, when is a default constructor provided automatically by Java and when is it not provided?
- 5. In the program PetDemo shown in Listing 6.2, you can replace the calls to the three set methods with one call to setPet. Write this invocation.

# Calling a Constructor from Other Constructors (Optional)

Let's again consider Pet2 in Listing 6.3. Once we have defined the first constructor—the one having three parameters—and the private method set, we could make the other constructors invoke this first constructor. To do so, we use the keyword this as if it were the name of a method in an invocation. For example, the statement

A constructor can call another constructor by using the keyword this

```
this(initialName, 0, 0);
```

would invoke the three-parameter constructor from within the body of another constructor in our class. The invocation must be the first action taken within the body of the constructor. Listing 6.4 shows how we could revise the constructors in Listing 6.3 in this way. Note that the set methods do not use this statement; they invoke the private method set, as they did in Pet2. Using the keyword this to invoke a constructor can occur only within the body of another constructor within the same class.

# LISTING 6.4 Constructors That Call Another Constructor

```
/**
Revised class for basic pet data: name, age, and weight.
public class Pet3
    private String name;
    private int age;
                          //in years
    private double weight;//in pounds
    public Pet3(String initialName, int initialAge,
                double initialWeight)
    {
         set(initialName, initialAge, initialWeight);
    public Pet3(String initialName)
         this(initialName, 0, 0);
    public Pet3(int initialAge)
         this("No name yet.", initialAge, 0);
    public Pet3(double initialWeight)
         this("No name yet.", 0, initialWeight);
    public Pet3( )
         this("No name yet.", 0, 0);
    <The rest of the class is like Pet2 in Listing 6.3.>
}
```

# **RECAP** Constructors Calling Other Constructors in the Same Class

When defining a constructor for a class, you can use this as a name for another constructor in the same class. Any call to this must be the first action taken by the constructor.

(continued)

```
public Pet3(String initialName)
{
    this(initialName, 0, 0);
}
```

## ■ PROGRAMMING TIP Write Interdependent Constructors

When writing multiple constructors for a class, identify one that the others can call by using this. Writing constructors in this way places the actual initialization in one place, making the class easier to maintain and less prone to error. Chapter 8 will talk more about this way of writing constructors.

### **6.2** STATIC VARIABLES AND STATIC METHODS

One Universe made up of all that is; and one God in it all, and one principle of Being, and one Law, the Reason, shared by all thinking creatures, and one Truth.

—MARCUS AURELIUS, reported in Bartlett's Familiar Quotations, 10th ed. (1919)

A class can have variables that are static as well as methods that are static. Static variables and static methods belong to a class as a whole and not to an individual object. In this section, we show you how to define static variables and static methods.

#### **Static Variables**

We have already used **static variables** in one special case, namely, in the definition of named constant values such as the following:

Static variables are shared by all objects of a class

```
public static final double FEET_PER_YARD = 3;
```

Only one copy of FEET\_PER\_YARD exists. It belongs to the class, so individual objects of the class that contains this definition do not have their own versions of this constant. Instead, they have access to and share this one constant.

This particular static variable cannot change in value—it is a constant—because its definition includes the keyword final. However, we can have static variables that can change in value. They are declared like instance variables, but with the keyword static. For example, the following static variable can change in value:

```
private static int numberOfInvocations;
```

A static variable can be public or private; however, like instance variables, static variables that are not constants should normally be private and should be accessed or changed only via accessor and mutator methods.

Static variables that are not constants should be private

#### **ASIDE** System.out Is a Static Object

Chapter 2 mentioned that out is an object of the class System. But it is actually a static constant that has the following declaration:

#### public static final

#### PrintStream out;

Since out is public, we can access it by name outside of the class System. However, when we do so we must precede its name with System and a dot, as in System.out. The statement just shown creates out as an object of the class PrintStream, which is in the Java Class Library. The methods print and println are methods in this class. To invoke these methods, you write the name of an object of PrintStream, a dot, and the name of the method. So when we write System.out.println(), for example, we are invoking the method println of the object out.

There is only one variable named numberOfInvocations, and it can be accessed by every object of its class. This means that the static variable could allow objects to communicate with one another or perform some joint action. For example, each method in its class could increment numberOfInvocations and so track how many method calls are made by all objects of the class. The next section gives an example of a static variable in use. You can initialize a static variable in the same way that you initialize a named constant, except that you omit the keyword final:

#### private static int

numberOfInvocations = 0;

Static variables are also called **class variables**. Do not confuse the term *class variable*—which simply means a static variable within a class—with the notion of a variable of a class type—which means a variable whose type is a class, that is, a variable that is used to name objects of a class. Both static variables and instance variables are sometimes called **fields** or **data members**.

#### **RECAP Static, or Class, Variables**

The declaration of a static variable contains the keyword static. A static variable is shared by all the objects of its class.

#### **REMEMBER Three Kinds of Variables**

Java has three kinds of variables: local variables, instance variables, and static (class) variables.

#### Static Methods

Sometimes you need a method that has no relation to an object of any kind. For example, you might need a method to compute the maximum of two integers, or a method to compute the square root of a number, or a method to convert a letter character from lowercase to uppercase. None of these methods

#### LISTING 6.5 Static Methods

```
/**
Class of static methods to perform dimension conversions.

*/
public class DimensionConverter
{
    public static final int INCHES_PER_FOOT = 12;
    public static double convertFeetToInches(double feet)
    {
        return feet * INCHES_PER_FOOT;
    }
    public static double convertInchesToFeet(double inches)
    {
        return inches / INCHES_PER_FOOT;
    }
}
```

has any obvious object to which it should belong. In these cases, you can define the method as static. When you define a **static method**, the method is still a member of a class, since you define it in a class, but the method can be invoked without using any object. You normally invoke a static method by using the class name instead of an object name.

Invoke a static method using the class name, not an object name

For example, Listing 6.5 contains a class named DimensionConverter, which defines two static methods for converting between measurements in feet and measurements in inches. You define a static method in the same way that you would define any other method, but you add the keyword static to the method's heading.

The following examples show how these methods are called:

```
double feet = DimensionConverter.convertInchesToFeet(53.7);
double inches = DimensionConverter.convertFeetToInches(2.6);
```

Calling a static method

When you call a static method, you write the class name instead of an object name. Listing 6.6 shows these methods in use in a complete program. Although you could create an object of the class DimensionConverter and use it to invoke either static method in the class, doing so can be confusing to programmers reading your code.

#### **REMEMBER A Class of Static Methods**

You can create a collection of static methods to perform computations that are somehow related and group them within a single class.

### LISTING 6.6 Using Static Methods

```
import java.util.Scanner;
Demonstration of using the class DimensionConverter.
public class DimensionConverterDemo
    public static void main(String[] args)
    {
        Scanner keyboard = new Scanner(System.in);
        System.out.println("Enter a measurement in inches: ");
        double inches = keyboard.nextDouble();
        double feet =
               DimensionConverter.convertInchesToFeet(inches);
        System.out.println(inches + " inches = " +
                           feet + " feet.");
        System.out.print("Enter a measurement in feet: ");
        feet = keyboard.nextDouble();
        inches = DimensionConverter.convertFeetToInches(feet);
        System.out.println(feet + " feet = " +
                           inches + " inches.");
    }
}
```

#### Sample Screen Output

```
Enter a measurement in inches: 18
18.0 inches = 1.5 feet.
Enter a measurement in feet: 1.5
1.5 feet = 18.0 inches.
```

In the class DimensionConverter in Listing 6.5, both the named constant and the two methods are static and public. (We could have declared the named constant INCHES\_PER\_F00T as private if we did not want it to be accessible outside of this class.) Although this class declares no instance variables, a class can have instance variables, static variables, static constants, static methods, and non-static methods. While such a combination is possible, you do need to be a bit careful.

Let's study the interaction among various static and non-static members of a class by examining the class SavingsAccount in Listing 6.7. This class maintains the balance of individual savings accounts, and so it declares an instance variable balance. All accounts can earn the same rate of interest, so the class has a static variable interestRate. The class also counts the number of accounts opened by using the static variable numberOfAccounts.

# LISTING 6.7 Mixing Static and Non-static Members in a Class (part 1 of 2)

```
import java.util.Scanner;
Class with static and nonstatic members.
public class SavingsAccount
                                          - An instance variable (nonstatic)
     private double balance;
     public static double interestRate = 0;
                                                       Static variables
     public static int numberOfAccounts = 0;
     public SavingsAccount()
        balance = 0;
                                              A nonstatic method can
        numberOfAccounts++;
                                              reference a static variable.
    }
    public static void setInterestRate(double newRate)
    {
                                               A static method can
        interestRate = newRate;
                                               reference a static variable
    }
                                               but not an instance variable.
    public static double getInterestRate()
        return interestRate;
    }
    public static int getNumberOfAccounts()
        return numberOfAccounts;
    }
    public void deposit(double amount)
    {
        balance = balance + amount;
    }
    public double withdraw(double amount)
        if (balance >= amount)
            balance = balance - amount;
        else
            amount = 0;
            return amount;
    }
```

LISTING 6.7 Mixing Static and Non-static Members in a Class (part 2 of 2)

```
A nonstatic method can
    public void addInterest()
                                                      reference a static variable
    {
                                                      or call a static method.
        double interest = balance * interestRate:
         // you can replace interestRate with getInterestRate()
        balance = balance + interest;
    }
    public double getBalance()
        return balance;
    public static void showBalance(SavingsAccount account)
        System.out.print(account.getBalance());
    }
                                  A static method cannot call a nonstatic method
}
                                  unless it has an object to do so.
```

The class has static set and get methods for the interest rate, a static get method for the number of accounts, and non-static methods for making deposits, making withdrawals, adding interest, and getting an account balance. Lastly, the class has a static method that displays the balance of any given savings account.

Within the definition of a static method, you cannot reference an instance variable. Because a static method can be invoked without using any object name, there is no instance variable to refer to. For example, the static method setInterestRate can reference the static variable interestRate but not the instance variable balance, which is not static.

A static method—and remember that main is a static method—cannot call a non-static without having an instance of a class to use in the invocation. For example, the static method showBalance has an object of SavingsAccount as its parameter. It uses this object to invoke the non-static method getBalance. The only way showBalance can get data for the balance of an account is from an object that represents that account.

The non-static addInterest can reference the static variable interestRate or call the static method getInterestRate. Preceding the method name in the invocation of getInterestRate with the name of the class and a dot is optional, since the methods are all within SavingsAccount. Notice that the constructor also is not static. It increments the static variable numberOfAccounts to count the number of times it is called, thus counting the number of new account objects.

Listing 6.8 shows a sample program that demonstrates the class SavingsAccount. Because we use a double variable to represent an account's

A static method cannot reference an instance variable

A static method can call only a static method

main is a static method

A non-static method can reference any variable or call any method within its class balance, one of the dollar amounts shown in the screen output isn't as neat as it could be. Somewhat later in this chapter, we will present one remedy for this situation.

### LISTING 6.8 Using Static and Non-static Methods

```
public class SavingsAccountDemo
    public static void main(String[] args)
    {
        SavingsAccount.setInterestRate(0.01);
        SavingsAccount mySavings = new SavingsAccount();
        SavingsAccount yourSavings = new SavingsAccount( );
        System.out.println("I deposited $10.75.");
        mySavings.deposit(10.75);
        System.out.println("You deposited $75.");
        yourSavings.deposit(75.00);
        System.out.println("You deposited $55.");
        yourSavings.deposit(55.00);
        double cash = yourSavings.withdraw(15.75);
        System.out.println("You withdrew $" + cash + ".");
        if (yourSavings.getBalance() > 100.00)
            System.out.println("You received interest.");
            yourSavings.addInterest();
        }
        System.out.println("Your savings is $" +
                            yourSavings.getBalance());
        System.out.print("My savings is $");
        SavingsAccount.showBalance(mySavings);
        System.out.println();
        int count = SavingsAccount.getNumberOfAccounts();
        System.out.println("We opened " + count +
                           " savings accounts today.");
    }
}
```

# Screen Output

```
I deposited $10.75.
You deposited $75.
You deposited $55.
You withdrew $15.75.
You received interest.
Your savings is $115.3925
My savings is $10.75
We opened 2 savings accounts today.
```

# **GOTCHA** Invoking a Non-Static Method from Within a Static Method

You will often hear people say, "You cannot invoke a non-static method within the definition of a static method." This is not quite true, however. A more precise, and correct, statement is, "You cannot invoke a non-static method within a static method unless you have an object to use in the call of the non-static method." Put another way, in the definition of a static method—such as main—you cannot use an instance variable or method that has an implicit or explicit this as its calling object. Since a static method can be invoked without any calling object, it can be invoked when there is no meaning for this. To paraphrase Gertrude Stein, in a static method, "there is no this there."

#### **RECAP Static Methods**

If you place the keyword static in the heading of the definition of a method, the method can be invoked using the class name in place of an object name. Since it does not need an object in its invocation, a static method cannot reference an instance variable of the class. It also cannot invoke a non-static method of the class, unless it has an object of the class and uses this object in the invocation. In other words, the definition of a static method cannot use an instance variable or a non-static method that has an implicit or explicit this as its calling object.



### **SELF-TEST QUESTIONS**

- 6. What is the difference between a static variable and an instance variable?
- 7. Can a class contain both instance variables and static methods?
- 8. Can you reference a static variable by name within the definition of a static method without using a class name and a dot?
- 9. Can you reference an instance variable by name within the definition of a static method without using a class name or an object name and a dot?
- 10. Can you reference a static variable by name within the definition of a non-static method without using a class name and a dot?
- 11. Can you reference an instance variable by name within the definition of a non-static method without using a class name or an object name and a dot?

12. Is the following valid, given the class DimensionConverter in Listing 6.5?

```
DimensionConverter dc = new DimensionConverter(); double
inches = dc.convertFeetToInches(2.5);
```

- 13. Can a class contain both static and non-static methods?
- 14. Can you invoke a non-static method within a static method?
- 15. Can you invoke a static method within a non-static method?
- 16. Is the following valid, given the class SavingsAccount in Listing 6.7?
  SavingsAccount.addInterest();

# Dividing the Task of a main Method into Subtasks

When a program's logic is involved or its code is repetitive, you can create static methods to accomplish various subtasks and invoke these methods from your main method. Recall from the previous chapter the program in Listing 5.18 that we used to test the equals methods in the class Species. Listing 6.9 reproduces that program here. We have highlighted two sections of code that are identical. Rather than repeat this code, we could place it into a static method and invoke it twice within the main method. We have made this revision in Listing 6.10 and have also created an additional method from the code within the unfilled colored rectangle in Listing 6.9. Our two new helping methods are static as well as private.

The method main can invoke other static methods

# PROGRAMMING TIP Helping Methods for a main Method

Simplify the logic of a main method within an application program by having it call helping methods. These methods should be static, since main is static. As helping methods, they likely should be private as well.

#### REMEMBER main Is a Static Method

Since the method main is static, you must adhere to the points made in the previous section about static methods. Generally, a static method can invoke only static methods and reference only static variables. It cannot invoke a non-static method of the same class unless you have an object of the class to use in the invocation.

#### LISTING 6.9 A main Method with Repetitive Code

```
public class SpeciesEqualsDemo
    public static void main(String[] args)
        Species s1 = new Species(), s2 = new Species();
        s1.setSpecies("Klingon 0x", 10, 15);
        s2.setSpecies("Klingon 0x", 10, 15);
        if (s1 == s2)
             System.out.println("Match with ==.");
        else
             System.out.println("Do Not match with ==.");
        if (s1.equals(s2))
            System.out.println("Match with the method equals.");
        else
            System.out.println("Do Not match with the method "+
                                "equals.");
        System.out.println("Now change one Klingon Ox to "+
                            "lowercase.");
        s2.setSpecies("klingon ox", 10, 15); //Use lowercase
        if (s1.equals(s2))
            System.out.println("Match with the method equals.");
        else
            System.out.println("Do Not match with the method "+
                                "equals.");
    }
}
```

# Adding a main Method to a Class

So far, whenever we have written a main method, it was by itself in its own class definition within a separate file. However, sometimes it makes sense to have a main method within a class definition. The class can then be used for two purposes: It can be used to create objects in other classes, or it can be run as a program. For example, you can write a main method inside the definition of the class Species, which is given in Listing 5.19 of the previous chapter. The result is shown in Listing 6.11.

After redefining the class Species in this way, running it as a program causes the main method to be invoked. When Species is used as an ordinary class to create objects, the main method is ignored.

Since a main method is static, it cannot contain an invocation of a non-static method of the same class unless it has an object of the class and uses it in the invocation of the non-static method. The main method in Listing 6.11

Any class can have a main method

#### LISTING 6.10 A main Method That Uses Helping Methods

```
On the Web, this class is
public class SpeciesEqualsDemo
                                                SpeciesEqualsDemo2.
    public static void main(String[] args)
        Species s1 = new Species(), s2 = new Species();
        s1.setSpecies("Klingon 0x", 10, 15);
        s2.setSpecies("Klingon 0x", 10, 15);
        testEqualsOperator(s1, s2);
        testEqualsMethod(s1, s2);
        System.out.println("Now change one Klingon Ox to "+
                            "lowercase.");
        s2.setSpecies("klingon ox", 10, 15); //Use lowercase
        testEqualsMethod(s1, s2);
    }
    private static void testEqualsOperator(Species s1, Species s2)
        if (s1 == s2)
            System.out.println("Match with ==.");
        else
            System.out.println("Do Not match with ==.");
    private static void testEqualsMethod(Species s1, Species s2)
        if (s1.equals(s2))
            System.out.println("Match with the method equals.");
        else
            System.out.println("Do Not match with the method "+
                                "equals.");
}
```

invokes the methods of the class Species by first creating an object of the class Species and then using it to invoke other methods. Doing so is necessary even though the main method is inside the definition of the class Species.

# PROGRAMMING TIP Add a main Method to a Class to Test It

You should not place just any main method in a class definition that is to be used as a regular class to create objects. However, placing a small diagnostic main method inside of your class definition provides a handy way to test it. Doing so also alerts other programmers about the tests you have done. We talk more about testing later in this chapter.

# LISTING 6.11 Placing a main Method in a Class Definition

```
import java.util.Scanner;
public class Species
    private String name;
    private int population;
    private double growthRate;
    <The methods readInput, writeOutput, predictPopulation, set-</pre>
     Species, getName, getPopulation, getGrowthRate, and equals go
     here. They are the same as in Listing 5.19.>
    public static void main(String[] args)
    {
        Species speciesToday = new Species( );
        System.out.println("Enter data on today's species:");
        speciesToday.readInput( );
        speciesToday.writeOutput( );
        System.out.println("Enter number of years to project:");
        Scanner keyboard = new Scanner(System.in);
        int numberOfYears = keyboard.nextInt( );
        int futurePopulation =
                  speciesToday.predictPopulation(numberOfYears);
        System.out.println("In " + numberOfYears +
                            " years the population will be " +
                            futurePopulation);
        speciesToday.setSpecies("Klingon ox", 10, 15);
        System.out.println("The new species is:");
        speciesToday.writeOutput( );
    }
}
```

#### The Math Class

The class Math contains a collection of mathematical methods and constants

The predefined class Math provides you with a number of standard mathematical methods. This class is automatically provided when you use the Java language; no import statement is needed. Some of the methods in the class Math are described in Figure 6.3. All of these methods are static, which means that you do not need—and in fact have no real use for—an object of the class Math. You normally call these methods by using the class name, Math, in place of an object name. For example, the following displays the maximum of the two numbers 2 and 3.

```
int ans = Math.max(2, 3);
System.out.println(ans);
```

You could also omit the variable and and simply write

```
System.out.println(Math.max(2, 3));
```

The class Math also defines two named constants, PI and E. The constant PI—often written as p in mathematical formulas—is used in calculations involving circles, spheres, and other geometric figures based on circles. PI is approximately 3.14159. The constant E is the base of the natural logarithm system—often written *e* in mathematical formulas. E is approximately 2.71828. The constants PI and E are static, so you reference them as Math.PI and Math.E. For example, the following computes the area of a circle, given its radius:

```
area = Math.PI * radius * radius;
```

You should use the constants Math.PI and Math.E in the definition of your classes instead of defining your own versions.

If you look at the methods in the table in Figure 6.3, you will find three similar, but not identical, methods named round, floor, and ceil. Some of these return a value of type double, but they all return a value that is intuitively a whole number that is close to the value of their arguments. The method round rounds a number to the nearest whole number. If the argument is a double, the method returns a value of type long. If you want that whole number as a value of type int, you must use a type cast, as in the following:

```
double start = 3.56;
int answer = (int)Math.round(start);
```

Here, answer is assigned the value 4.

The methods floor and ceil are similar to round, with slight differences. They both return a whole number as a value of type double, not of type int or long, that is close to their argument. The method floor returns the nearest whole number that is less than or equal to its argument. This action is called **rounding down**. So Math.floor(3.9) returns 3.0, not 4.0. Math.floor(3.3) also returns 3.0.

The method ceil—short for *ceiling*—returns the nearest whole number that is greater than or equal to its argument. This action is called **rounding up**. So Math.ceil(3.1) returns 4.0, not 3.0. Of course, Math.ceil(3.9) also returns 4.0.

If you want to store the value returned by either floor or ceil in a variable of type int, you must use a type cast, as in the following example:

```
double start = 3.56;
int lowAnswer = (int)Math.floor(start)
int highAnswer = (int)Math.ceil(start);
```

In this example, Math.floor(start) returns the double value 3.0, and the variable lowAnswer receives the int value 3. Math.ceil(start) returns the double value 4.0, and the variable highAnswer receives the int value 4.

<sup>&</sup>lt;sup>1</sup> You cannot store a long value in a variable of type int, even if it is a small value like 4 that would fit in an int variable.

FIGURE 6.3 Static Methods in the Class Math

Name	Description	Argument Type	Return Type	Example	Value Returned
pow	Power	double	double	Math.pow(2.0,3.0)	8.0
abs	Absolute value	int, long, float, <b>or</b> double	Same as the type of the argument	Math.abs(-7) Math.abs(7) Math.abs(-3.5)	7 7 3.5
max	Maximum	int, long, float, <b>or</b> double	Same as the type of the arguments	Math.max(5, 6) Math.max(5.5, 5.3)	6 5.5
min	Minimum	int, long, float, <b>or</b> double	Same as the type of the arguments	Math.min(5, 6) Math.min(5.5, 5.3)	5 5.3
random	Random number	none	double	Math.random()	Random number in the range $\geq 0$ and $< 1$
round	Rounding	float or double	int or long, respectively	Math.round(6.2) Math.round(6.8)	6 7
ceil	Ceiling	double	double	Math.ceil(3.2) Math.ceil(3.9)	4.0 4.0
floor	Floor	double	double	Math.floor(3.2) Math.floor(3.9)	3.0 3.0
sqrt	Square root	double	double	Math.sqrt(4.0)	2.0



Finally, the method random returns a random double that is  $\geq 0$  and < 1. Often a number between 0 and 1 is not what is desired, in which case the random number can be scaled to the desired range by multiplication and addition. If an integer is desired, then type casting is necessary. For example, to simulate rolling a six-sided die, we could use the following:

```
int die = (int)(6.0 * Math.random()) + 1;
```

Multiplying the random number by 6.0 gives us a value in the range  $\geq 0$  and < 6.0. Type casting this to an int truncates the result, which is an integer that is 0, 1, 2, 3, 4, or 5. Adding 1 results in a random integer that is in the range 1–6.

### **SELF-TEST QUESTIONS**

- 17. What values are returned by each of the following?
  - a. Math.round(2.3)
  - b. Math.round(2.7)
  - c. Math.floor(2.3)
  - d. Math.floor(2.7)
  - e. Math.ceil(2.3)
  - f. Math.ceil(2.7)
  - g. (int) (Math.random() \* 10.0) + 10;
- 18. Suppose that speed is a variable of type double and you want to assign Math.round(speed) to the variable approxSpeed, which is of type int. How do you write the assignment statement?
- 19. Repeat the previous question, but instead assign Math.round(speed) to the variable longSpeed, which is of type long.
- 20. Suppose that n1 is of type int and n2 is of type long. What is the type of the value returned by Math.min(n1, n2)?
- 21. Define a class CircleCalculator that has only two methods, getArea and getCircumference. These methods return the area and circumference, respectively, of a circle, given its radius. Both methods are static. Do not define your own value for pi.

# **Wrapper Classes**

Java makes a distinction between the primitive types, such as int, double, and char, and the class types, such as the class String and the programmer-defined classes. For example, you saw in Chapter 5 that an argument to a method is treated differently, depending on whether the argument is of a primitive type or a class type. If a method needs an argument of a class type, but we have a value of a primitive type, we need to convert the primitive value—such as the int value 42—to an "equivalent" value of some class type that corresponds to the primitive type int. To make this conversion, Java provides a wrapper class for each of the primitive types. Such classes define methods that can act on values of a primitive type.

Integer is a wrapper class for the primitive type int

For example, the wrapper class for the primitive type int is the predefined class Integer. If you want to convert an int value, such as 42, to an object of type Integer, you can do so as follows:

```
Integer n = new Integer(42);
```

After the preceding executes, n names an object of the class Integer that corresponds to the int value 42. In fact, the object n has an instance variable containing the int value 42. Conversely, the following statement converts an object of type Integer to an int value:

```
int i = n.intValue();//n names an object of the class Integer.
```

The method intValue recovers the equivalent int value from an object of type Integer.

Other wrapper classes

The wrapper classes for the primitive types long, float, double, and char are Long, Float, Double, and Character, respectively. And, of course, rather than the method intValue, the classes Long, Float, Double, and Character use the methods longValue, floatValue, doubleValue, and charValue, respectively.

Boxing converts from a primitive type to a wrapper class The conversion from a primitive type, such as int, to its corresponding wrapper class, such as Integer, is done automatically in Java. This type casting is called **boxing**. You can think of the object as a "box" into which you place the value of the primitive type as the value of a private instance variable. So the statements

```
Integer n = new Integer(42);
Double d = new Double(9.99);
Character c = new Character('Z');
```

can be written in the simpler form:

```
Integer n = 42;
Double d = 9.99;
Character c = 'Z';
```

**Boxing examples** 

These simple-looking assignments are really just abbreviations for the longer versions that include the new operator. The situation is analogous to what happens when a value of type int is assigned to a variable of type double; a type cast is made automatically.

Unboxing converts from a wrapper class to a primitive type

The reverse conversion from an object of a wrapper class to a value of its associated primitive type is called **unboxing**. Unboxing is also done automatically. So if n is an object of the class Integer, for example, the statement

```
int i = n.intValue();//n names an object of the class Integer.
```

can be written in the abbreviated form

```
int i = n;//n names an object of the class Integer.
```

The following are also examples of automatic unboxing:

**Unboxing** examples

```
int i = new Integer(42);
double f = new Double(9.99);
char s = new Character('Z');
```

What really takes place is that Java automatically applies the appropriate accessor method—intValue, doubleValue, or charValue in these examples—to obtain the value of the primitive type that is assigned to the variable.

Automatic boxing and unboxing applies to parameters as well as to the simple assignment statements we just discussed. You can plug in a value of a primitive type, such as a value of type int, for a parameter of the associated wrapper class, such as Integer. Similarly, you can plug in a wrapper class argument, such as an argument of type Integer, for a parameter of the associated primitive type, such as int.

At this point, the main importance of these wrapper classes is that they contain a number of useful constants and static methods. For example, you can use the associated wrapper class to find the largest and smallest values of any of the primitive number types. The largest and smallest values of type int are

Constants in wrapper classes

```
Integer.MAX_VALUE and Integer.MIN_VALUE
```

Largest and smallest values

The largest and smallest values of type double are

```
Double.MAX VALUE and Double.MIN VALUE
```

MAX\_VALUE and MIN\_VALUE are defined as static named constants in each of the wrapper classes Integer, Long, Float, Double, and Character. For example, the class Integer defines MAX\_VALUE as

```
public static final int MAX_VALUE = 2147483647;
```

Static methods in the wrapper classes can be used to convert a string to the corresponding number of type int, double, long, or float. For example, the static method parse Double of the wrapper class Double will convert a string to a value of type double. So

```
Double.parseDouble("199.98")
```

Methods in wrapper classes

returns the double value 199.98. Of course, you knew this by simply looking at the statement, and so it hardly seems worth all this effort. But the same technique can be used to change the value of a string variable. For example, suppose the String is a variable of type String whose value is the string representation of a number of type double. The following will return the double value corresponding to the string value of the String:

```
Double.parseDouble(theString)
```

If there is any possibility that the string named by the String has extra leading or trailing blanks, you should instead use

```
Double.parseDouble(theString.trim())
```

The method trim is in the class String and trims off leading and trailing whitespace, such as blanks. It is always safest to use trim when invoking a method like parseDouble. You never know when leading or trailing blanks might appear. If the string is not a correctly formed number, the invocation of Double.parseDouble will cause your program to end. The use of trim helps avoid this problem.

This conversion of a string to a number can be done with any of the wrapper classes Integer, Long, and Float, as well as with the wrapper class Double. Just use one of the static methods Integer.parseInt, Long. parseLong, or Float.parseFloat instead of Double.parseDouble.

Each of the numeric wrapper classes also has a static method called toString that will convert in the other direction—that is, it converts from a numeric value to a string representation of the numeric value. For example,

```
Integer.toString(42)
returns the string value "42". And
Double.toString(199.98)
returns the string value "199.98".
```

Character is the wrapper class for the primitive type char. The following piece of code illustrates some of the basic methods for this class:

This code displays

```
a is not the same as A
```

The equals method checks for equality of characters, so uppercase and lowercase letters are considered different.

The class Character also has other useful static methods. Some of these methods, which convert between uppercase and lowercase letters or test whether a character is a letter or a digit, are listed in Figure 6.4.

Java also has a wrapper class Boolean. It has names for the two constants of type boolean: Boolean.TRUE and Boolean.FALSE. However, the Java keywords true and false are much easier to use.

Character is the wrapper class for the type char

We will not use the wrapper class Boolean

FIGURE 6.4 Static Methods in the Class Character

Name	Description	Argument Type	Return Type	Examples	Return Value			
toUpperCase	Convert to uppercase	char	char	Character.toUpperCase('a') Character.toUpperCase('A')	'A' 'A'			
toLowerCase	Convert to lowercase	char	char	Character.toLowerCase('a') Character.toLowerCase('A')	'a' 'a'			
isUpperCase	Test for uppercase	char	boolean	Character.isUpperCase('A') Character.isUpperCase('a')	true false			
isLowerCase	Test for lowercase	char	boolean	Character.isLowerCase('A') Character.isLowerCase('a')	true false			
isLetter	Test for a letter	char	boolean	Character.isLetter('A') Character.isLetter('%')	true false			
isDigit	Test for a digit	char	boolean	Character.isDigit('5') Character.isDigit('A')	true false			
isWhitespace	Test for whitespace	char	boolean	Character.isWhitespace(' ') Character.isWhitespace('A')	true false			
Whitespace characters are those that print as white space, such as the blank, the tab character (' $\t^{\prime}$ ), and the line-break character (' $\t^{\prime}$ ).								

#### **RECAP** Wrapper Classes

Every primitive type has a wrapper class. Wrapper classes allow you to have a class object that corresponds to a value of a primitive type. Wrapper classes also contain a number of useful predefined constants and methods. Thus, each wrapper class has two related but distinct uses.

For example, you can create objects of the wrapper class Integer that correspond to values of type int, as in

```
Integer n = new Integer(42);
```

The wrapper class Integer also serves as a library of useful static methods, such as the method parseInt, as in

(continued)

```
String numeralString;
. . . .
int number = Integer.parseInt(numeralString);
Any one program can use both personalities of a wrapper class.
```

### **GOTCHA** Wrapper Classes Have No Default Constructor

The wrapper classes Boolean, Byte, Character, Double, Float, Integer, Long, and Short have no default constructors. Thus, a statement such as

```
Integer n = new Integer();//Invalid!
```

is incorrect. When you create a new object of one of these classes, you must provide an initializing value as an argument to the constructor, as in the following example:

```
Character myMark = new Character('Z');
```

Wrapper classes do not have set methods, so you cannot change the value of existing objects of these classes. The designers, therefore, decided not to allow the creation of objects that have default values, and so they did not define default constructors.



# **SELF-TEST QUESTIONS**

22. Which of the following statements are legal?

```
Integer n = new Integer(77);
int m = 77;
n = m;
m = n;
```

If any are illegal, tell how to write a valid Java statement that does what the illegal statement is trying to do.

- 23. Write a Java expression to convert the number in the double variable x to a string.
- 24. Consider the variable s of type String that contains a string, such as "123", that is the normal way of writing some integer. Write a Java expression to convert the string in s to the corresponding value of type int.
- 25. Repeat the previous question, but accommodate a string that might contain leading or trailing blanks, such as "123".
- 26. Write Java code to display the largest and smallest values of type double that you can have in Java.

### **6.3** WRITING METHODS

It is common sense to take a method and try it. If it fails, admit it frankly and try another. But above all, try something.

—FRANKLIN DELANO ROOSEVELT, Address at Oglethorpe University (MAY 22, 1932)

In this section we discuss some basic techniques that will help you to design, code, and test methods. We start with a case study.

# **CASE STUDY** Formatting Output

If you have a variable of type double that stores some amount of money, your programs should display the amount in a nice format. However, you are likely to get output that looks like this:

```
Your cost, including tax, is $19.98123576432
```

Instead, we would like the output to look like this:

```
Your cost, including tax, is $19.98
```

In this case study, we will define a class called DollarFormat containing two static methods named write and writeln that can be used to produce this kind of nicely formatted output.<sup>2</sup> For example, if the amount of money is in a variable of type double named amount, we could write the following to get such output:

Task specification

```
System.out.print("Your cost, including tax, is ");
DollarFormat.writeln(amount);
```

Note that write and writeln should add the dollar sign for you and should always display exactly two digits after the decimal point. So these methods would display \$2.10, not \$2.1.

When the amount has more than two digits after the decimal point, we must decide what to do with the extra digits. Suppose we decide to round the number. Then if the amount is 9.128, for example, we would get an output of \$9.13.

The difference between write and writeln will be the same as the difference between print and println. After writing its output, write does not advance to the next line, but writeln does. So the method writeln can simply call write and then use println to go the next line.

<sup>&</sup>lt;sup>2</sup> In addition to the printf method, Java has other classes that allow you to output numbers in any format that you wish. However, using these classes can get quite involved. It will be instructive, and perhaps even easier, to program the details ourselves. If you want to know more about such formatting classes, look at Appendix 4, which has a brief discussion of the class Decimal Format.

Pseudocode for the write method Now that we know what we want these methods to do, how do we implement them? To display an amount like 9.87, we have little choice but to break it into the pieces 9 and 87 and then display each piece separately. The following pseudocode outlines what the method write must do:

Algorithm to display a double amount as dollars and cents (The variable amount contains the amount to be displayed.)

- 1. dollars = the number of whole dollars in amount.
- 2. cents = the number of cents in amount. Round if there are more than two digits after the decimal point.
- 3. Display a dollar sign, dollars, and a decimal point.
- 4. Display cents as a two-digit integer.

We now need to convert our pseudocode to Java code. Let's assume that the variable amount already contains a double value. To obtain the number of whole dollars and the number of cents as two int values, we need to somehow get rid of the decimal point. One way to do this is to convert the amount to all cents. For example, to convert 10.95 dollars to all cents, we multiply by 100 to obtain 1095.0. If there is a fraction of a penny, such as when converting 10.9567 dollars to 1095.67 cents, we can use the round method: Math.round(1095.67) returns 1096 as a value of type long.

Note that we will want to store the result of this rounding in an int variable for holding the total amount expressed as all cents. However, Math. round returns a value of type long, and you cannot store a value of type long in a variable of type int, even if it is a small integer. So you need to perform a type cast to convert this long value to an int value as follows:

```
(int) (Math.round(1095.67))
```

This returns 1096 as an int value. Thus, our code will begin with something like

```
int allCents = (int)(Math.round(amount * 100));
```

Now we need to convert allCents to a dollar amount and a cents amount. For example, since 1096 cents is \$10.96, we need to convert 1096 to the integers 10 and 96. Since a dollar is 100 cents, we can use integer division to obtain the number of dollars:

```
int dollars = allCents / 100;
```

The amount left over after this division is the number of cents, so we can use the % operator to obtain it:

```
int cents = allCents % 100;
```

Thus, we have translated the first two steps of our pseudocode into the following Java code:

```
int allCents = (int)(Math.round(amount * 100));
int dollars = allCents / 100;
int cents = allCents % 100:
```

The third step in our pseudocode, when expressed in Java, is simply

```
System.out.print('$');
System.out.print(dollars);
System.out.print(.);
```

All that is left to do is to translate the last pseudocode instruction,

```
Display cents as a two-digit integer.
```

into Java code. This looks easy. Suppose we try the following:

```
System.out.println(cents);
```

Testing our code with amount equal to 10.9567 would result in the output

```
Early testing
```

```
$10.96
```

which looks pretty good. (By the way, a simple assignment statement to initialize amount provides a quick way to test our initial code.) When we try some more examples, however, we run into a problem. For example, if amount is 7.05, we get

```
$7.5
```

instead of

```
$7.05
```

This quick test makes us realize that we need to display a zero before the number of cents whenever it is less than 10. The following statement will fix the problem:

```
if (cents < 10)
{
    System.out.print(0);
    System.out.print(cents);
}
else
    System.out.print(cents);</pre>
```

Listing 6.12 shows our class. Now that we have a complete definition of the class, it is time for some serious testing. Listing 6.13 shows a program that tests the method write. These sorts of programs are often called **driver programs**, or simply **drivers**, because they do nothing but exercise, or "drive," the method. Any method can be tested in a program like this.

Use a driver program to test a class

### LISTING 6.12 The Class DollarFormatFirstTry

```
public class DollarFormatFirstTry
    Displays amount in dollars and cents notation.
    Rounds after two decimal places.
    Does not advance to the next line after output.
    public static void write(double amount)
        int allCents = (int)(Math.round(amount * 100));
        int dollars = allCents / 100;
        int cents = allCents % 100;
        System.out.print('$');
        System.out.print(dollars);
        System.out.print('.');
        if (cents < 10)
            System.out.print('0');
            System.out.print(cents);
        else
            System.out.print(cents);
    }
    Displays amount in dollars and cents notation.
    Rounds after two decimal places.
   Advances to the next line after output.
    public static void writeln(double amount)
        write(amount);
        System.out.println();
    }
}
```

The testing goes quite well until we decide to try a negative number. After all, a negative amount of money is feasible; it's called a debt. But the amount -1.20 produces the output \$-1.0 - 20. Something is wrong with the way our method handles negative amounts.

Examining our calculation when amount is negative indicates that both dollars and cents will contain negative numbers. A negative value in dollars is correct, and we display \$-1 for our test case. But now we need to display 20, not -20. We could fix this mistake in a number of ways, but here is a clean and simple one. Since our code works correctly for nonnegative numbers, we can

#### LISTING 6.13 A Driver That Tests DollarFormatFirstTry

```
This kind of testing
import java.util.Scanner;
                                                   program is often called
public class DollarFormatFirstTryDriver
                                                   a driver program.
    public static void main(String[] args)
    {
        double amount;
        String response:
        Scanner keyboard = new Scanner(System.in);
        System.out.println(
                         "Testing DollarFormatFirstTry.write:");
        do
        {
             System.out.println("Enter a value of type double:")
             amount = keyboard.nextDouble();
             DollarFormatFirstTry.write(amount);
             System.out.println();
             System.out.println("Test again?");
             response = keyboard.next();
        } while (response.equalsIgnoreCase("yes"));
        System.out.println("End of test.");
    }
}
```

#### Sample Screen Output

```
Testing DollarFormatFirstTry.write:
Enter a value of type double:
1.2345
$1.23
Test again?
yes
Enter a value of type double:
1.235
$1.24
Test again?
Enter a value of type double:
9.02
$9.02
Test again?
Enter a value of type double:
-1.20
                             Oops. There's
$-1.0-20
                             a problem here.
Test again?
no
```

{

convert any negative number to a positive number. We then display the minus sign followed by the positive number.

The revised version of our class is shown in Listing 6.14. Notice that the new method writePositive is almost the same as the old method write. The only difference is that writePositive does not display the dollar sign; a new version of the method write does that.

LISTING 6.14 The Corrected Class DollarFormat (part 1 of 2)

```
public class DollarFormat
    / * *
    Displays amount in dollars and cents notation.
    Rounds after two decimal places.
    Does not advance to the next line after output.
    */
    public static void write(double amount)
        if (amount >= 0)
        {
             System.out.print('$');
             writePositive(amount);
        }
        else
        {
             double positiveAmount = amount;
                                                  The case for negative
             System.out.print('$');
                                                  amounts of money
             System.out.print('-');
             writePositive(positiveAmount);
        }
    //Precondition: amount >= 0:
    //Displays amount in dollars and cents notation. Rounds
    //after two decimal places. Omits the dollar sign.
    private static void writePositive(double amount)
    {
        int allCents = (int)(Math.round(amount * 100));
        int dollars = allCents / 100;
        int cents = allCents % 100;
        System.out.print(dollars);
        System.out.print('.');
        if (cents < 10)
                                       We have simplified this logic,
            System.out.print('0');
                                       but it is equivalent to that
        System.out.print(cents);
                                       used in Listing 6.12.
    }
                                                           (continued)
```

# LISTING 6.14 The Corrected Class DollarFormat (part 2 of 2)

```
/**
  Displays amount in dollars and cents notation.
  Rounds after two decimal places.
  Advances to the next line after output.
*/
public static void writeln(double amount)
{
    write(amount);
    System.out.println();
}

DollarFormatDriver.java
    in the source code on the Web is a
    testing and demonstration program
    for this class.
```

Testing the class DollarFormat with a program similar to the one we used to test DollarFormatFirstTry is successful. Such a driver program is in the file DollarFormatDriver. java included with the source code for this book that is available on the Web.

Extra code on the Web

### PROGRAMMING TIP Retest

Every time you change the definition of a class or method, you should test it.

# **Decomposition**

In the previous case study, we used the following pseudocode for our first attempt to design a method that displays a double number that represents a monetary value:

- 1. dollars = the number of whole dollars in amount.
- 2. cents = the number of cents in amount. Round if there are more than two digits after the decimal point.
- 3. Display a dollar sign, dollars, and a decimal point.
- 4. Display cents as a two-digit integer.

What we have done with this pseudocode is to **decompose** the task for displaying an amount of money into a number of subtasks. For example, the first step of our pseudocode is shorthand for the task

Decompose a task into subtasks

Calculate the number of whole dollars in amount and store it in an int variable called dollars.

We then solved each of these subtasks separately and produced code for each subtask. After that, all we had to do to produce the final definition of the method was to combine the code for the subtasks.

As it turned out, we ended up using the code derived from the preceding pseudocode for the method writePositive rather than for the method write. But this was just a further illustration of using subtasks. The method writePositive solved a subtask that we used in the final definition of the method write.

Often, though not always, the solutions to subtasks are implemented as private helping methods. If a subtask is large, you divide it into smaller subsubtasks and solve the sub-subtasks separately. These sub-subtasks may be further decomposed into even smaller tasks, but eventually the tasks become small enough to be easy to design and code.

# **Addressing Compiler Concerns**

The compiler has a reason for giving an error message The compiler checks to make sure you have done certain necessary things, such as initializing variables or including a return statement in the definition of a method that returns a value. Sometimes you may find that the compiler is asking you to do one of these things, yet you are certain either that you have done it or that you do not need to do it. In such cases, it does no good to argue with the compiler. It most likely is correct. If you cannot find a mistake in your code, change it anyway, so that it is more obvious that you have done what the compiler is asking for.

For example, suppose that you have a method that returns a value of type int and the method definition ends as follows:

```
if (something > somethingElse)
    return something;
else if (something < somethingElse)
    return somethingElse;</pre>
```

Note that this statement does not address the possibility that something could be equal to somethingElse, and the compiler will complain that you need a return statement. Even if you think that you are correct, because you know that something will never equal somethingElse, you will have to change this last if-else statement to either

```
if (something > somethingElse)
    return something;
else if (something < somethingElse)
    return somethingElse;
else
    return 0;
or the equivalent
    int answer = 0;
    if (something > somethingElse)
        answer = something;
else if (something < somethingElse)
        answer = somethingElse;
    return answer;</pre>
```

In the previous chapter, we suggested that a method should contain no more than one return statement. If you adhere to that advice, the compiler is less likely to complain.

As another example, suppose that you declare a variable like this:

```
String line:
```

If the compiler insists that you must initialize the variable, you could change the declaration to

```
String line = null;
```

The constant value null is a special predefined constant that you can use to give a value to any variable of any class type. Because null is like an address, you use = = and != rather than the method equals when you test to see whether a variable contains null.

null is a predefined constant

Note that null is not an object but a sort of place holder for an object's address. Use null to initialize a variable of a class type only when you know that, before the variable is used in the invocation of some method, your code will assign an object to the class variable. This means that you should use null to initialize a variable of a class type only when it is conceptually necessary. However, the compiler will sometimes insist on an initialization even when it is not needed.

### **GOTCHA** Null Pointer Exception

Since null is not an object, you cannot use it to invoke a method. If you try, you will get an error message that says "Null Pointer Exception." For example, the statements

```
Pet myDog = null;
myDog.setPet("Spot", 2, 35.4);
```

will produce this error message no matter how the class Pet is defined. The way to correct the problem is to use new to create an object of type Pet, as follows:

```
Pet myDog = new Pet();
myDog.setPet("Spot", 2, 35.4);
```

As you do more programming, you will probably encounter other situations that produce a "Null Pointer Exception" message. In these cases, look for an uninitialized variable of a class type.

# ■ PROGRAMMING TIP The Compiler Is Always Right

Well, we hope it is. If you approach debugging with the thought that you didn't make a mistake, you are less likely to find the error that caused the compiler to complain.

# **Testing Methods**

Use a driver program to test a method

When you test a method, you can use a driver program like the one in Listing 6.13. These driver programs are just for your use, and so they can be quite simple. They need not have any fancy output or anything else very elaborate. All they have to do is give the method some arguments and invoke the method.

Every method you write for a class should be tested. Moreover, it should be tested in a program in which it is the only method that has not yet been fully tested. In that way, if you discover that something is wrong, you know which method contains the mistake. If you test more than one method in the same program, you can easily be fooled into thinking that the mistake is in one method when in fact it is in some other method.

# **PROGRAMMING TIP** Test Methods Separately

Test each method in a program in which it is the only untested method.

Test methods one at a time

One way to test each method separately is called **bottom-up testing**. If method A calls method B, bottom-up testing asks that method B be fully tested before you test method A. Bottom-up testing is a good and safe technique, but it can become tedious. Other ways of testing can find bugs faster and less painfully. And sometimes you want to test a method before all the methods it uses are tested. For example, you might want to test your general approach to the problem before even writing all the methods. However, you should still test each method in a program in which it is the only untested method. This presents a problem. If method A calls method B and method B is not yet tested, how can you test method A in a program in which it is the only untested method? The answer is to use a stub for method B.

A **stub** is a simplified version of a method that is not good enough for the final class definition but is good enough for testing and is simple enough for you to be sure—or as sure as possible—that it is correct. For example, suppose you are testing the class DollarFormat in Listing 6.14 and you want to test the method writeln before you test the method write. You can use a stub for the method write, as follows:

```
public static void write(double amount)
    System.out.print("$99.12"); //STUB
```

This is certainly not a correct definition of the method write. It always displays 99.12 no matter what it gets as an argument. However, it is good enough to use in testing the method writeln. If you test the method writeln using this stub for the method write, and writeln displays \$99.12 in the correct way, then writeln is almost certain to be correct. Note that using this stub for write will let you test the method writeln before you complete either of the methods write or writePositive.

A stub is a temporary definition of a method used in testing



### **SELF-TEST QUESTIONS**

- 27. Given the class DollarFormat in Listing 6.14, what is displayed by the invocation DollarFormat.writeln(7.0)?
- 28. Consider the variable allCents in the method writePositive in Listing 6.14. It holds an amount of money as if it were all cents. So for the amount \$12.95, the int variable allCents would be set to 1295. Using an int variable is somewhat limiting. The largest value of type int is 2147483647, meaning that the largest amount the method can handle is \$21,474,836.47. That is more than \$21 million, a nice large sum, but we often need to consider larger amounts, such as the national budget or even the salary for the CEO of a large company. How can you easily change the definitions of the methods in the class DollarFormat so that they handle larger amounts of money?
- 29. What is wrong with a program that starts as follows? (The class Species is defined in Listing 5.19 in Chapter 5.)

```
public class SpeciesDemo
{
    public static void main(String[] args)
{
    Species s1 = null;
    Species s2 = null;
    s1.setSpecies("Klingon 0x", 10, 15);
    s2.setSpecies("Naked Mole Rat", 10000, 25);
```

30. Design a class to display values of type double that are not necessarily for money amounts. Call the class OutputFormat. It should have two static methods, write and writeln, each of which takes two arguments. The first argument gives a double value to be written to the screen. The second argument is an int value telling how many digits to show after the decimal point. Have your methods round any extra digits. These methods are similar to the methods write and writeln in the class DollarFormat. Although you can use the class DollarFormat as a model, the methods in these two classes have some differences. As you would expect, any output occurring after write executes will be on the same line, and output occurring after writeln executes will be on the following line; otherwise, write and writeln do the same thing.

For example, the statements

```
OutputFormat.writeln(9.1234667, 4);
OutputFormat.writeln(9.9999, 2);
OutputFormat.writeln(7.01234, 4);
```

should produce the following output:

9.1235 10.00 7.0123

Do not forget to test your methods with numbers that have zeros after the decimal point, like 1.023 and 1.0023. [Hint: You may find the static method Math.pow (Figure 6.3) helpful as part of an expression to move a decimal point.] This is a fairly difficult exercise, so allow yourself some time to complete it. If you do not succeed in writing this class, be sure that you at least understand the answer given at the end of the chapter. This is a very useful class.

31. In your definition of the class OutputFormat in the previous question, would it be valid to use the names print and println, rather than write and writeln, or would this produce a name conflict with System.out. println?

### **6.4** OVERLOADING

A good name is better than precious ointment ...

-ECCLESIASTES 7:1

You have seen that two or more different classes can define methods having the same name. For example, many classes have a method named readInput. This is not so surprising. The type of the calling object allows Java to decide which definition of the method readInput to use. You may be more surprised to hear that you can also have two or more methods *in the same class* that have the same method name. How is this possible? Read on.

# **Overloading Basics**

When you give two or more methods the same name within the same class, you are **overloading** the method name. To do this, you must ensure that the different method definitions have something different about their parameter lists.

For example, Listing 6.15 contains a very simple example of overloading. The class Overload in this listing defines three different static methods, all named getAverage. When Overload.getAverage is invoked, how does Java know which definition of getAverage to use? If all the arguments are of type double, Java can tell which definition of getAverage to use by the number of arguments: If there are two arguments of type double, it uses the first definition of getAverage. If there are three arguments, it uses the second definition.

Overloading a method name means giving the same name to more than one method within a class

### LISTING 6.15 Overloading

```
/ * *
This class illustrates overloading.
public class Overload
    public static void main(String[] args)
        double average1 = Overload.getAverage(40.0, 50.0);
        double average2 = Overload.getAverage(1.0, 2.0, 3.0);
        char average3 = Overload.getAverage('a', 'c');
        System.out.println("average1 = " + average1);
        System.out.println("average2 = " + average2);
        System.out.println("average3 = " + average3);
    public static double getAverage(double first, double second)
        return (first + second) / 2.0;
    public static double getAverage(double first, double second,
                                    double third)
    {
        return (first + second + third) / 3.0;
    public static char getAverage(char first, char second)
        return (char)(((int)first + (int)second) / 2);
    }
}
```

#### Sample Screen Output

```
average1 = 45.0
average2 = 2.0
average3 = b
```

Now suppose that an invocation of the method getAverage has two arguments of type char. Java knows that it should use the third definition of getAverage because of the types of the arguments. Only one of the definitions has two arguments of type char. (For now, don't worry about how this method averages two characters. That's a side issue that we will come back to shortly.)

If you overload a method name—that is, if you give the same name to more than one method definition within the same class—Java distinguishes them according to the number of parameters and the types of the parameters. If an invocation of a method matches a definition of a method in name, and if the first argument has the same type as the first parameter, the second argument has the same type as the second parameter, and so forth—then that method definition is used. If there is no such match, Java will try some simple type conversions of the kinds we discussed earlier in this book, such as casting an int to a double, to see whether that produces a match. If this fails, you will get an error message.

Methods in a class need unique signatures A method's name and the number and types of its parameters are called the method's **signature**. So another way to describe the rule about overloading is to say that the methods in a class must have different signatures. Alternatively, a class cannot define two or more methods with the same signature.

Note that you have already been using overloading, even though you may not have known the term before. The method names print and println are overloaded in the class PrintStream of the Java Class Library. Each method has one parameter, but in one version, the parameter type is String, in another it is int, or double, and so on. In addition, many of the methods of the class Math, which we discussed earlier in this chapter, use overloading. For example, Math has several versions of the method max, all having the same name and each with two parameters. Their invocations also are distinguished according to the type of the arguments. If its two arguments are of type int, max returns a value of type int. If its two arguments are of type double, it returns a value of type double.

Overloading can be applied to any kind of method. It can be applied to void methods, to methods that return a value, to static methods, to non-static methods, or to any combination of these. You can also overload constructors. The constructors in the class Pet in Listing 6.1 all have the same name and so are overloaded. They provide an explicit example that we can analyze.

Let's recall the headings of the constructors defined in Listing 6.1:

```
    public Pet()
    public Pet(String initialName, int initialAge, double initialWeight)
    public Pet(String initialName)
    public Pet(int initialAge)
    public Pet(double initialWeight)
```

Notice that each constructor has either a different number of parameters or a parameter whose type is different from those in the other constructors. Thus, each invocation of a constructor involves a different definition.

For example, each of the following Pet objects is created by a call to a different constructor:

Calling various constructors of the class Pet

```
Pet aPet = new Pet();
Pet myCat = new Pet("Fluffy", 2, 4.5);
Pet myDog = new Pet("Spot");
Pet myTurtle = new Pet(20);
Pet myHorse = new Pet(750.5);
```

The first statement calls the default constructor, since no arguments are provided. In the second statement, the object assigned to myCat is the result of calling the constructor that takes three arguments. Each of the remaining three statements calls a constructor that requires only one argument. Which constructor is chosen? The one whose parameter matches in type the argument in the invocation. Thus, Pet("Spot") calls the constructor whose parameter is a String, Pet(20) calls the constructor whose parameter is an int, and Pet(750.5) calls the constructor whose parameter is a double.

### **RECAP** Overloading

Within one class, you can have two or more definitions of a method that have the same name but either have different numbers of parameters or have corresponding parameters with differing types. That is, the methods must have different signatures. This is called overloading the method name.

### Overloading and Automatic Type Conversion

In some situations, two friends are not better than one. Two good things can sometimes interact in a bad way. Overloading is a friend, or at least a helpful feature of the Java language. Automatic type conversion of arguments—whereby an int like 2 is converted to a double like 2.0 when a method wants a double as an argument—is also a helpful feature of the Java language. But these two nice features can sometimes get in the way of each other.

Overloading and automatic type conversion can conflict

For example, the statement

```
Pet myHorse = new Pet(750.0);
```

creates a Pet object weighing 750 pounds. Suppose, however, that we forget the decimal point and the zero, and write the following instead:

```
Pet myHorse = new Pet(750);
```

Instead of creating a Pet object whose weight is 750, we create one whose age is 750. Because the argument 750 is of type int, it matches the constructor that has one parameter of type int. That constructor sets the instance variable age, not the instance variable weight, to the value of the argument. If Java can find a definition of a method whose parameters match the number and types of arguments, it will not do any type conversions, such as from int to double.

In the case we just looked at, we needed a type conversion, but we did not get one. There are also cases in which you do not want a type conversion but

#### **ASIDE** Averaging Two Characters

Let's take a short side trip to explain how we average two characters. For our previous example, it does not matter whether we use a crazy way of averaging two characters, but, in fact, the technique we use in Listing 6.15 for the third version of getAverage is a very sensible way to average characters, or at least to average two letters. If the two letters are both lowercase, the average computed will be the lowercase letter halfway between them in alphabetical order, or as close to halfway as possible. Similarly, if the two letters are both uppercase, the average computed will be the uppercase letter halfway between them in alphabetical order. This approach works because Unicode assigns sequential numbers to the letters when arranged in alphabetical order. The number assigned to 'b' is one more than the number assigned to 'a', the number assigned to 'c' is one more than the number assigned to 'b', and so forth. So if you convert two letters to numbers, average the numbers, and then convert them back to letters, you get the letter halfway in between.

you do get one. For example, suppose my dog is named Cha Cha, weighs 2 pounds, and is 3 years old. We might try the following:

```
Pet myDog = new Pet("Cha Cha", 2, 3);
```

This will set myDog's age to 2, not 3, and its weight to 3.0, not 2.0. The real problem, of course, is that we have reversed the second and third arguments, but let's look at it as Java does. Given the preceding invocation, Java looks for a constructor whose heading has the following form:

Pet has no such constructor, so there is no exact match for the invocation. Java then tries to convert an int to a double to get a match. It notices that if it converts the 3 to 3.0, it will have a match to

and so it does the type conversion.

What went wrong—besides reversing two arguments? We should have given the weight as 2.0, not 2. If we had used 2.0, or if Java had

not done any automatic type conversions for us, we would have received an error message. In this case, Java tried to help, but the help just got in the way.

## **GOTCHA** Overloading and Automatic Type Conversion

Sometimes a method invocation can be resolved in two different ways, depending on how overloading and type conversion interact. Such ambiguous method invocations are not allowed in Java and will produce a run-time error message or sometimes even a compiler error message. For example, you can overload the method name problemMethod in SampleClass as follows:

```
public class SampleClass
{
    public static void problemMethod(double n1, int n2)
    . . .
    public static void problemMethod(int n1, double n2)
    . . .
```

The class will compile with no problem. However, an invocation such as

```
SampleClass.problemMethod(5, 10);
```

will produce an error message, because Java cannot decide which overloaded definition of problemMethod to use: Should it convert the int value 5 to a double value and use the first definition of problemMethod, or should it convert the int value 10 to a double value and use the second definition? In this situation, Java issues an error message indicating that the method invocation is ambiguous.

Although the following two method invocations are allowed

```
SampleClass.problemMethod(5.0, 10);
SampleClass.problemMethod(5, 10.0);
```

such situations, while valid, are confusing and should be avoided.

# REMEMBER Overloading Before Automatic Type Conversion

Java always tries to use overloading before it tries to use automatic type conversion. If Java can find a definition of a method that matches the types of the arguments, it will use that definition. Java will not do an automatic type conversion of a method's argument until after it has tried and failed to find a definition of the method name with parameter types that exactly match the arguments in the method invocation.

# PROGRAMMING TIP Choose Descriptive Names to Avoid Overloading

Had we given the four set methods of the class Pet in Listing 6.1 the same name—set, for instance—these methods would have demonstrated the same issues we just raised about overloading and automatic type conversion. Instead of overloading their names, we avoided these difficulties by choosing distinct names. Instead of calling each of them set, we used the more descriptive names setName, setAge, setWeight, and setPet. Use overloading when you have a good reason to do so, but don't use it when a distinct method name is more descriptive. You cannot follow this advice for constructors, since they must be named after the class. Even so, multiple, overloaded constructors are common.

## Overloading and the Return Type

You cannot overload a method name by giving two definitions whose headings differ only in the type of the value returned. For example, you might have wanted to add another method called getWeight to the class Pet in Listing 6.1. Imagine that this new method returns a character telling you whether the pet is overweight or underweight—say, '+' for overweight, '-' for underweight, and '\*' for just right. The return type would be char. So suppose we had two methods with the following headings:

```
/**
Returns the weight of the pet.

*/

public double getWeight()

/**

Returns '+' if overweight, '-' if
underweight, and *if weight is OK.

*/

public char getWeight()
```

A method's signature does not include its return type

Unfortunately, this is invalid. In any class definition, two definitions of the same method name must have either different numbers of parameters or at least one pair of corresponding parameters of differing types. You cannot overload on the basis of the type returned. Recall that the definition of a method's signature does not include its return type. Thus, the signatures of the two getWeight methods are the same, which is illegal.

If you think about it, it is not even possible to write a compiler that overloads on the basis of the type returned. For example, suppose we have

```
Pet myPet = new Pet();
...
double value = myPet.getWeight();
```

Now suppose that, contrary to actual fact, we were able to include both versions of the getWeight method. Consider the job of the poor compiler in this situation. Although we have not made an issue of it, you can store a value of type char in a variable of type double. Java will perform an automatic type cast to change the char to a double. Thus, in this hypothetical scenario, the variable value is happy with either a double or a char.

So the compiler has no way to judge which version of getWeight the programmer wanted. The compiler would have to ask the programmer for advice, and compilers are not allowed to ask the programmer questions.

### **GOTCHA** You Cannot Overload on the Basis of the Return Type

A class cannot have several methods that have the same name and the same parameters but different return types. Such methods would have the same signature, and that is illegal in Java.

## **SELF-TEST QUESTIONS**

32. Would the following constructor invocation be valid to include in the program in Listing 6.2?

```
Pet myDog = Pet("Fido", 2, 7);
```

33. Can a class possibly contain both of the following method definitions?

```
/**
  Postcondition: Returns the number of people in
  numberOfCouples couples.
*/
public static int countPeople(int numberOfCouples)
{
    return 2 * numberOfCouples;
}
/**
  Postcondition: Returns the number of children,
  assuming that each couple has 2.3 children.
*/
public static double countPeople(int numberOfCouples)
{
    return 2.3 * numberOfCouples;
}
```

34. Can a class possibly contain both of the following method definitions?

```
/**
Postcondition: Returns the integer portion of a
positive number or zero if the number is negative.
public static int convertValue(double number)
{
   int result = 0;
   if (number > 0.0)
        result = (int)number;
   return result;
}
Postcondition: Returns the integer portion of a
positive number or zero if the number is negative.
public static double convertValue(int number)
{
   double result = 0;
   if (number > 0.0)
        result = (double)number;
   return result:
}
```

- 35. Consider the class Species in Listing 5.19 of Chapter 5. It has a method called setSpecies that sets the name, population, and growth rate of a species. Could this class have another method setSpecies that has only one parameter for the name of the species and that sets both the population and the growth rate to zero? If so, give the definition of this other method named setSpecies.
- 36. Repeat the previous question for a method setSpecies that sets only the name of the species, not any other instance variables.
- 37. Still considering the class Species in Listing 5.19 of Chapter 5, could both of the methods named setSpecies defined in Self-Test Questions 35 and 36 of this chapter be added to the class Species?

## PROGRAMMING EXAMPLE

A Class for Money

Listing 6.16 contains a class, named Money, whose objects represent amounts of U.S. money, such as \$9.99, \$500.00, \$0.50, and so forth. You might be inclined to think of money amounts as values of type double, but to the programmer who uses the class Money, or to the end user of any software product using Money, the data values are not thought of as having the type double or int or any other Java predefined type. The data values are of type Money. To the "person on the street," \$9.99 is not a value of type double. And it shouldn't be to you. Sometimes you can get away with using values of type double to represent amounts of money, but doing so has a potential problem. A value of type double is, practically speaking, an approximate quantity, and for an accounting program in particular, approximate quantities are usually not good enough. If a bank has account balances that are off by a few dollars or even a few cents, customers will be dissatisfied and legal action would be likely.

Of course, to implement the class Money, we must choose some sort of data representation. We want to represent money amounts as exact quantities, so we will use an integer type. However, the type int cannot represent very large numbers, and so we will use the type long. An amount of money, such as \$3500.36, can be represented as two integers—in this case, 3500 and 36—

<sup>&</sup>lt;sup>3</sup> In Listing 6.14 we defined a class named DollarFormat that is concerned with displaying amounts of money given as values of type double. In this programming example, we do not use values of type double to represent amounts of money, and so we do not use the class DollarFormat.

### LISTING 6.16 The Money Class (part 1 of 3)

```
import java.util.Scanner;
/**
Class representing nonnegative amounts of money,
such as $100, $41.99, $0.05.
*/
public class Money
    private long dollars;
    private long cents;
    public void set(long newDollars)
        if (newDollars < 0)</pre>
            System.out.println(
                "Error: Negative amounts of money are not allowed.");
            System.exit(0);
        }
        else
        {
            dollars = newDollars;
            cents = 0;
        }
    }
    public void set(double newAmount)
    {
        if (newAmount < 0)</pre>
            System.out.println(
               "Error: Negative amounts of money are not allowed.");
            System.exit(0);
        }
        else
        {
            long allCents = Math.round(newAmount * 100);
            dollars = allCents / 100;
            cents = allCents % 100;
        }
    }
    public void set(Money moneyObject)
        this.dollars = moneyObject.dollars;
        this.cents = moneyObject.cents;
    }
```

(continued)

### LISTING 6.16 The Money Class (part 2 of 3)

```
/ * *
Precondition: The argument is an ordinary representation
of an amount of money, with or without a dollar sign.
Fractions of a cent are not allowed.
*/
public void set(String amountString)
    String dollarsString;
    String centsString;
    //Delete '$' if any:
    if (amountString.charAt(0) == '$')
        amountString = amountString.substring(1);
    amountString = amountString.trim();
    //Locate decimal point:
    int pointLocation = amountString.indexOf(".");
    if (pointLocation < 0) //If no decimal point</pre>
    {
        cents = 0;
        dollars = Long.parseLong(amountString);
    else //String has a decimal point.
    {
        dollarsString =
            amountString.substring(0, pointLocation);
        centsString =
            amountString.substring(pointLocation + 1);
        //one digit in cents means tenths of a dollar
        if (centsString.length() <= 1)</pre>
            centsString = centsString + "0";
        // convert to numeric
        dollars = Long.parseLong(dollarsString);
        cents = Long.parseLong(centsString);
        if ((dollars < 0) || (cents < 0) || (cents > 99))
            System.out.println(
               "Error: Illegal representation of money.");
            System.exit(0);
        }
    }
}
```

(continued)

### LISTING 6.16 The Money Class (part 3 of 3)

```
public void readInput()
    System.out.println("Enter amount on a line by itself:");
    Scanner keyboard = new Scanner(System.in);
    String amount = keyboard.nextLine();
    set(amount.trim());
                                         We used nextLine instead of next
}
                                         because there may be a space between
                                         the dollar sign and the number.
/ * *
Does not go to the next line after displaying money.
public void writeOutput()
{
    System.out.print("$" + dollars);
    if (cents < 10)
        System.out.print(".0" + cents);
    else
        System.out.print("." + cents);
}
/ * *
Returns n times the calling object.
public Money times(int n)
{
    Money product = new Money();
    product.cents = n * cents;
    long carryDollars = product.cents / 100;
    product.cents = product.cents % 100;
    product.dollars = n * dollars + carryDollars;
    return product;
}
/**
Returns the sum of the calling object and the argument.
public Money add(Money otherAmount)
{
    Money sum = new Money();
    sum.cents = this.cents + otherAmount.cents;
    long carryDollars = sum.cents / 100;
    sum.cents = sum.cents % 100;
    sum.dollars = this.dollars
                 + otherAmount.dollars + carryDollars;
    return sum;
}
```

Four methods named set

stored in instance variables of type long. Negative amounts of money certainly make sense—and a final professional-strength Money class would allow for negative amounts of money—but we will limit ourselves to nonnegative amounts since we want a fairly simple example for learning purposes.

Notice the overloaded method name set. The four methods named set allow a programmer to set an amount of money in any way that is convenient. The programmer can use a single integer value for an amount of dollars without any cents, a single value of type double, another object of type Money, or a string, such as "\$9.98" or "9.98". The programmer does not, and should not, worry about what instance variables are used inside the class Money. Instead, the programmer should think only in terms of money amounts.

Let's look at some details in the definitions of the set methods. The set method having one parameter of type long is straightforward. It sets the whole number of dollars. The set method having one parameter of type double works by converting the double value to a value that represents the amount of money as the number of pennies in the amount. This is done as follows:

```
long allCents = Math.round(newAmount * 100);
```

The method Math.round eliminates any fractional part of a penny. It returns a value of type long when its argument is of type double, as it is here. The integer division operators / and % are then used to convert the pennies to dollars and cents.

The set method whose parameter is of type Money is also straightforward, but you should notice one important point. The instance variables of the parameter moneyObject are accessible by name inside the definition of the class Money. In this case, they are moneyObject.dollars and moneyObject.cents. Within the definition of any class, you can directly access the instance variables of any object of the class.

The set method whose parameter is of type String changes a string, such as "\$12.75" or "12.75", into two integers, such as 12 and 75. First, it checks whether the first character in the string is a dollar sign, as follows:

```
if (amountString.charAt(0) == '$')
  amountString = amountString.substring(1);
```

Use String methods to process the input

The first character in the string amountString is returned by an invocation of the String method charAt. If this character is a dollar sign, the string—which has index positions 0 through some last index—is replaced by the substring at indices 1 through the end of the string, effectively removing the first character. The String method substring does this for us. You may want to review the descriptions of the substring methods given in Figure 2.5 of Chapter 2.

One or more blanks might be between the \$ symbol and the dollar amount. Blanks are trimmed off with an invocation of the String method trim, as follows:

```
amountString = amountString.trim();
```

The string is then broken into two substrings—one for dollars and one for cents—by locating the decimal point and breaking the string at the decimal point. The decimal point position is stored in the variable pointLocation as follows:

```
int pointLocation = amountString.indexOf(".");
```

The dollars and cents substrings are recovered as follows:

```
dollarsString = amountString.substring(0, pointLocation);
centsString = amountString.substring(pointLocation + 1);
```

Finally, the dollars and cents substrings are converted to values of type long by calling the static method parseLong in the wrapper class Long, which we introduced earlier in this chapter:

```
dollars = Long.parseLong(dollarsString);
cents = Long.parseLong(centsString);
```

Our method times is used to multiply an amount of money by an integer. The method add is used to add two objects of type Money. For example, if m1 and m2 are objects of type Money that both represent the amount \$2.00, then m1.times(3) returns an object of the class Money that represents \$6.00, and m1. add(m2) returns an object of the class Money that represents \$4.00.

Methods that perform arithmetic on Money objects

To understand the definition of the methods times and add, remember that one dollar is 100 cents. So if product.cents has a value of 100 or more, the following will set the variable carryDollars equal to the number of whole dollars in that many cents.

```
long carryDollars = product.cents / 100;
```

The number of cents left over after removing that many dollars is given by

```
product.cents % 100
```

A demonstration program for the class Money is given in Listing 6.17.



### LISTING 6.17 Using the Money Class (part 1 of 2)

```
public class MoneyDemo
{
    public static void main(String[] args)
    {
        Money start = new Money();
        Money goal = new Money();
        System.out.println("Enter your current savings:");
        start.readInput();
        (continued)
```

### LISTING 6.17 Using the Money Class (part 2 of 2)

```
goal = start.times(2);
        System.out.print(
            "If you double that, you will have ");
        goal.writeOutput();
        System.out.println(", or better yet:");
        goal = start.add(goal);
        System.out.println(
            "If you triple that original amount, you will have:");
        goal.writeOutput();
                                        End the line, because writeOutput
        System.out.println();
                                       does not end the line.
        System.out.println("Remember: A penny saved");
        System.out.println("is a penny earned.");
    }
}
```

### Sample Screen Output

```
Enter your current savings:
Enter amount on a line by itself:
$500.99

If you double that, you will have $1001.98, or better yet:
If you triple that original amount, you will have
$1502.97

Remember: A penny saved
is a penny earned.
```

### **SELF-TEST QUESTIONS**

- 38. Rewrite the method add in Listing 6.16 so that it does not use the this parameter.
- 39. In Listing 6.16, the set method that has a String parameter does not allow extra leading and trailing blanks in the string. Rewrite it so that it ignores leading and trailing whitespace. For example, it should allow "\$5.43" as an argument.

### **6.5** INFORMATION HIDING REVISITED

I don't like to meddle in my private affairs.

```
-KARL KRAUS (1874-1936)
```

The material in this section is not needed to understand most of the rest of this book. If you prefer, you can safely postpone reading this material until you are more comfortable with classes. This section discusses a subtle problem that can arise when defining certain kinds of classes. The problem does not apply to any class you define whose instance variables are either of a primitive type—such as int, double, char, and boolean—or of the type String. So you can define lots of classes without being concerned with this problem.

### **Privacy Leaks**

A class can have instance variables of any type, including any class type. These often can be natural and useful things to have. However, using instance variables of a class type can introduce a problem that requires special care. The problem occurs because variables of a class type contain the memory address of the location where an object is stored in memory. For example, suppose that goodGuy and badGuy are both variables of the class type Pet, which we defined in Listing 6.1. Now suppose that goodGuy names some object and your program executes the following assignment statement:

```
badGuy = goodGuy;
```

After this assignment statement is executed, badGuy and goodGuy are two names for the same object. So if you change badGuy, you will also change goodGuy. (There must be a moral lesson there.)

Let's give this assignment statement a bit more context to see its implications:

```
Pet goodGuy = new Pet();
goodGuy.set("Faithful Guard Dog", 5, 75);
Pet badGuy = goodGuy;
badGuy.set("Dominion Spy", 1200, 500);
goodGuy.writeOutput();
```

Because badGuy and goodGuy name the same object, this code will produce the following output:

```
Name: Dominion Spy
Age: 1200 years
Weight: 500.0 pounds
```

The change to badGuy also changed goodGuy because goodGuy and badGuy name the same object. The same thing can happen with instance variables and can cause some subtle problems. Let's look at an example.

Listing 6.18 contains the definition of a class called PetPair, which represents a pair of Pet objects. The class has two private instance variables of type Pet. The programmer who wrote this class mistakenly thinks that the data named by the instance variables first and second cannot be changed by any program using the class PetPair. This is an easy mistake for a programmer to make. After all, the instance variables are private, so they cannot be accessed by name outside of the class. And just to be super safe, the programmer did not include any mutator methods that change the private instance variables. But anybody can look at the objects in a pair by using the public accessor methods getFirst and getSecond. Sound good? Unfortunately, the programmer is in for a rude awakening.

The program in Listing 6.19 creates an object of PetPair and then changes the state of that object's private instance variable first! How could that be? The problem is that a variable of a class type contains a memory address, and as you saw at the beginning of this section, you can use the assignment operator to produce two names for the same object. That is what our hacker

#### LISTING 6.18 An Insecure Class

```
Class whose privacy can be breached.
public class PetPair
    private Pet first, second;
    public PetPair(Pet firstPet, Pet secondPet)
    {
        first = firstPet;
        second = secondPet:
    public Pet getFirst()
        return first;
    public Pet getSecond()
    {
        return second;
    public void writeOutput()
        System.out.println("First pet in the pair:");
        first.writeOutput();
        System.out.println("\nSecond pet in the pair:");
        second.writeOutput();
    }
}
```

# LISTING 6.19 Changing a Private Object in a Class (part 1 of 2)

```
/**
Toy program to demonstrate how a programmer can access and
change private data in an object of the class PetPair.
*/
public class Hacker
    public static void main(String[] args)
    {
        Pet goodDog = new Pet("Faithful Guard Dog", 5, 75.0);
        Pet buddy = new Pet("Loyal Companion", 4, 60.5);
        PetPair pair = new PetPair(goodDog, buddy);
        System.out.println("Our pair:");
        pair.writeOutput( );
        Pet badGuy = pair.getFirst();
        badGuy.setPet("Dominion Spy", 1200, 500);
        System.out.println("\nOur pair now:");
        pair.writeOutput( );
        System.out.println("The pet wasn't so private!");
        System.out.println("Looks like a security breach.");
}
```

#### Screen Output

```
Our pair:
First pet in the pair:
Name: Faithful Guard Dog
Age: 5 years
Weight: 75.0 pounds
Second pet in the pair:
Name: Loyal Companion
Age: 4 years
Weight: 60.5 pounds
Our pair now:
First pet in the pair:
                                This program has changed an
Name: Dominion Spy <
                                object named by a private instance
Age: 1200 years
                                variable of the object pair.
Weight: 500.0 pounds
Second pet in the pair:
Name: Loyal Companion
Age: 4 years
```

### LISTING 6.19 Changing a Private Object in a Class (part 2 of 2)

Weight: 60.5 pounds

The pet wasn't so private! Looks like a security breach.

A private instance variable having a class type could be changed outside of the class

Ways to avoid a privacy leak

A clone is an exact duplicate

Instance variables of a class type are natural and useful

programmer who wrote the program in Listing 6.19 did. By invoking the accessor method getFirst, one can get the address of the private instance variable first. That memory address is stored in the variable badGuy. So badGuy is another name for first. Our hacker cannot use the private name first but can use the equivalent name badGuy. All that our hacker needed to do was to use the name badGuy to invoke the method setPet of the class Pet, and because badGuy is another name for the object named by first, our hacker has changed the object named by the private instance variable first. This phenomenon is called a privacy leak.

How can you write your class definitions to avoid this problem? It might seem impossible to have a private instance variable of a class type that is truly secure. A hacker can always find a way to get at it, or so it would seem. There are, however, ways around this problem: Some are easier than others.

One easy way around this problem is to use only instance variables of a primitive type. This, of course, is a severe restriction. We can also use instance variables of a class type that has no mutator methods. String is such a class. Once a String object is created, its data cannot be changed, and so our hacker's trick will not work on these variables. Primitive types are not class types, and so the hacker's trick will not work on them either. This easy solution is the one we will take in this book.

Another easy way is to define accessor methods that return individual attributes of an object named by an instance variable of a class type instead of the object itself. Of course, any attribute that is itself another object might be a source of a similar problem. So, for example, instead of defining an accessor method in PetPair like getFirst, we could define three methods: getNameOfFirst, getAgeOfFirst, and getWeightOfFirst.

A more difficult solution also exists, but it is beyond the scope of this book. However, we can give you a hint of it. We could write a method to produce an exact duplicate of an object. These exact duplicates are called clones. Instead of returning an object named by a private instance variable of a class type that could be insecure, we return a clone of the object. That way a hacker can damage the clone, but the private data will not be affected. A brief introduction to cloning is given in Appendix 10 (on the book's Web site). After you become comfortable with classes, you may wish to look at that appendix.

Do not get the impression that instance variables of a class type are a bad idea. They are very natural and very useful. However, dealing with them effectively requires some care. We will talk more about such instance variables later in this book.

### **GOTCHA** Privacy Leaks

A private instance variable of a class type names an object that, for certain classes, can be modified outside of the class containing the instance variable. To avoid this problem, you can do any of the following:

- Declare the instance variable's type to be of a class that has no set methods, such as the class String.
- Omit accessor methods that return an object named by an instance variable
  of a class type. Instead, define methods that return individual attributes of
  such an object.
- Make accessor methods return a clone of any object named by an instance variable of a class type, instead of the object itself.



### **SELF-TEST QUESTION**

40. Give the definitions of three accessor methods that you can use instead of the single accessor method getFirst within the definition of the class PetPair in Listing 6.18. One method will return the pet's name, one will return the pet's age, and one will return the pet's weight. These new accessor methods will not produce the problem described in this section. They will return all of the data in an object of the class PetPair, but will not return any object whose mutator methods can change its state.

## **6.6** ENUMERATION AS A CLASS

The sands are number'd that make up my life.

-WILLIAM SHAKESPEARE, Henry VI, Part 3

Chapter 3 introduced enumerations and mentioned that the compiler creates a class when it encounters an enumeration. This section talks about that class. Although you should consider using enumerations in your programs, the ideas in this section are not central to the presentation in the rest of the book.

Let's define a simple enumeration for the suits of playing cards, as follows:

```
enum Suit {CLUBS, DIAMONDS, HEARTS, SPADES}
```

The compiler creates a class Suit. The enumerated values are names of public static objects whose type is Suit. As you know, you reference each of these values by prefacing its name with Suit and a dot, as in the following assignment statement:

Some enumeration methods

Suit s = Suit.DIAMONDS;

The class Suit has several methods, among which are equals, compareTo, ordinal, toString, and valueOf. The following examples show how we can use these methods, assuming that the variable s references Suit.DIAMONDS:

- s.equals (Suit.HEARTS) tests whether s equals HEARTS. In this case, equals returns false, since DIAMONDS is not equal to HEARTS.
- s.compareTo(Suit.HEARTS) tests whether s is before, at, or after HEARTS in the definition of Suit. Like the method compareTo in the class String—which Chapter 3 describes—compareTo here returns an integer that is negative, zero, or positive, according to the outcome of the comparison. In this case, compareTo return a negative integer, since DIAMONDS appears before HEARTS in the enumeration.
- s.ordinal() returns the position, or **ordinal value**, of DIAMONDS in the enumeration. The objects within an enumeration are numbered beginning with 0. So in this example, s.ordinal() returns 1.
- s.toString() returns the string "DIAMONDS". That is, toString returns the name of its invoking object as a string.
- Suit.valueOf("HEARTS") returns the object Suit.HEARTS. The match between the string argument and the name of an enumeration object must be exact. Any whitespace within the string is *not* ignored. The method valueOf is a static method, so its name in an invocation is preceded by Suit and a dot.

You can define private instance variables and additional public methods—including constructors—for any enumeration. By defining an instance variable, you can assign values to the objects in the enumeration. Adding a get method will provide a way to access these values. We have done all of these things in the new definition of the enumeration Suit shown in Listing 6.20.

#### LISTING 6.20 An Enhanced Enumeration Suit

```
/** An enumeration of card suits. */
enum Suit
{
    CLUBS("black"), DIAMONDS("red"), HEARTS("red"),
    SPADES("black");
    private final String color;
    private Suit(String suitColor)
    {
        color = suitColor;
    }
    public String getColor()
    {
        return color;
    }
}
```

We chose strings as the values for the enumerated objects, so we have added the instance variable color as a String object, as well as a constructor that sets its value. Notation such as CLUBS("black") invokes this constructor and sets the value of CLUBS's private instance variable color to the string "black". Note that color's value cannot change, since it is declared as final. Also observe that the constructor is private, so you cannot invoke it directly. It is called only within the definition of Suit. The method getColor provides public access to the value of color.

color is an instance variable; it is not static

Enumerations can have an access modifier such as public or private. If you omit the access modifier, the enumeration is private by default. You can define a public enumeration within its own file, just as you would define any other public class.



### **SELF-TEST QUESTION**

- 41. If cardSuit is an instance of Suit and is assigned the value Suit. SPADES, what is returned by each of the following expressions?
  - a. cardSuit.ordinal()
  - b. cardSuit.equals(Suit.CLUBS)
  - c. cardSuit.compareTo(Suit.CLUBS)
  - d. Suit.valueOf("CLUBS")
  - e. Suit.valueOf(cardSuit.toString())
  - f. cardSuit.getColor()
  - g. cardSuit.toString()

### **6.7** PACKAGES

From mine own library with volumes that i prize above my dukedom.

-WILLIAM SHAKESPEARE, The Tempest

A package is a named collection of related classes that can serve as a library of classes for use in any program. With packages, you do not need to place all those classes in the same directory as your program. Although this is an important and useful topic, the rest of the material in this book does not use the discussion of packages presented here. Therefore, you may cover this section at any time during your reading of this book.

To understand this material, you need to know about folders, or directories; path names for folders; and how your operating system uses a path (environment) variable. If you do not know about these things, you may wish to skip this section until you have had some experience with them. These are not Java topics. They are part of your operating system, and the details depend on your particular system. If you can find out how to set the path variable, you will know enough about path variables to understand this section.

### **Packages and Importing**

A package is a collection of classes

A package is simply a collection of classes that have been grouped together into a folder. The name of the folder is the name of the package. The classes in the package are each placed in a separate file, and the file name begins with the name of the class, just as we have been doing all along. The only difference is that each file in a package has the following line at the start of the file:

```
package Package_Name;
```

Each class in a package needs a package statement

Blank lines or comments can appear before this line, but nothing else may come before it. The *Package\_Name* typically consists of all lowercase letters, often punctuated with the dot symbol. For example, if general.utilities is the name of the package, each of the files in the package would have the following statement at the start of the file:

```
package general.utilities;
```

Any program or class definition can use all of the classes in the package by placing a suitable import statement at the start of the file containing the program or class definition. This is true even if the program or class definition is not in the same directory as the classes in the package. For example, if you want to use the class HelpfulClass that is in the package general.utilities, you would place the following at the start of the file you are writing:

Using one class in a package

```
import general.utilities.HelpfulClass;
```

Notice that you write the class name, HelpfulClass, not the name of the class's file, HelpfulClass.java.



#### **RECAP The package Statement**

A package is a collection of classes grouped together into a folder and given a package name. Each class is in a separate file named after the class. Each file in the package must begin with a package statement, ignoring blank lines and comments.

#### SYNTAX FOR A CLASS IN A PACKAGE

```
<Blank lines or comments.>
package Package_Name;
<A class definition.>
```

#### **EXAMPLES**

```
package general.utilities;
package java.io;
```

#### **RECAP The import Statement**

You can use all the classes that are in a package within any program or class definition by placing an import statement that names the package at the start of the file containing the program or class definition. The program or class need not be in the same folder as the classes in the package.

#### **SYNTAX**

```
import Package_Name.Class_Name_Or_Asterisk;
```

Writing a class name imports just a single class from the package; writing an \* imports all the classes in the package.

#### **EXAMPLES**

```
import java.util.Scanner;
import java.io.*;
```

To import all the classes in the package general.utilities, you would use the following import statement:

Using an entire package

```
import general.utilities.*;
```

The asterisk indicates that you want to import all of the files in the package. Although you might see this statement used, we prefer to import specific classes.

## **Package Names and Directories**

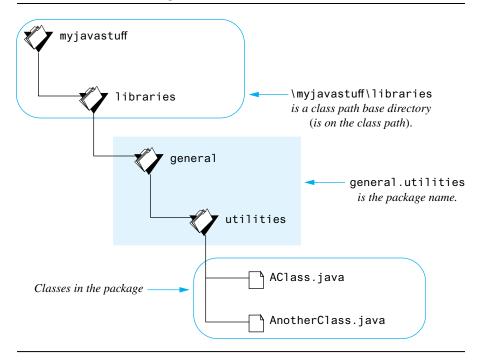
A package name is not an arbitrary identifier. It tells the compiler where to find the classes in the package. In effect, the package name tells the compiler the path name for the directory containing the classes in the package. To find the directory for a package, Java needs two things: the name of the package and the directories listed in the value of your class path variable.

The value of your **class path variable** tells Java where to begin its search for a package, so we will discuss it first. The class path variable is not a Java variable. It is a variable that is part of your operating system and that contains the path names of a list of directories. When Java is looking for a package, it begins its search in these directories. Let us call these directories the **class path base directories**. We will tell you how Java uses these class path base directories and how packages are named, and then we will give you some information on how to set the class path variable.

The name of a package specifies the relative path name for the directory that contains the package classes. It is a relative path name because it assumes that you start in a class path base directory and follow the path of subdirectories

A search for a package begins in the class path base directory

FIGURE 6.5 A Package Name



given by the package name. For example, suppose the following is a class path base directory (your operating system might use / instead of \):

\myjavastuff\libraries

and suppose your package classes are in the directory

\myjavastuff\libraries\general\utilities

In this case, the package must be named

general.utilities

Notice that a package name is not arbitrary, but must be a list of directories leading from a class path base directory to the package classes. Thus, the package name tells Java what subdirectories to go through—starting from the base class directory—to find the package classes. This organization is depicted in Figure 6.5. The dot in the package name means essentially the same thing as the \ or /, whichever symbol your operating system uses for directory paths.

You specify the class path base directories by setting the class path (environment) variable. The way you set the class path variable depends on your operating system. If you are on a UNIX system, you are likely to be able to set the class path with some command similar to the following:

export CLASSPATH=/myjavastuff/libraries:/home/username/
javaclasses;.

Setting the class path variable

### **RECAP Package Names**

A package name must be a path name for the directory that contains the classes in the package, but the package name uses dots in place of \ or / (whichever your operating system uses). When naming the package, you use a relative path name that starts from any directory named in the class path (environment) variable.

#### **EXAMPLES**

```
general.utilities
java.io
```

If you are using a Windows machine, you can set the class path variable by using the Control Panel to set or create an environment variable named CLASSPATH.

You can list more than one base directory in a class path variable, typically by separating them with semicolons. For example, the following might be a class path:

```
c:\myjavastuff\libraries;f:\yourjavastuff
```

This means that you can create package directories as either subdirectories of

```
c:\myjavastuff\libraries
```

or subdirectories of

```
f:\yourjavastuff
```

When looking for package directories, Java will first look in subdirectories of

```
c:\myjavastuff\libraries
```

If it does not find the package there, it will then look in subdirectories of

```
f:\yourjavastuff
```

Whenever you set or change the class path variable, be sure to include the current directory as one of the alternatives. The **current directory** is the directory in which your program (or other class) is located. On most systems, the current directory is indicated by a dot. So you would use the following for your class path variable:

The current directory contains your program

```
c:\myjavastuff\libraries;f:\yourjavastuff;.
```

with the dot—the current directory—added to the end. Then if the package is not found in either of the previous two base directories, Java will look in the subdirectories of the current directory—that is, in subdirectories of your program (or whatever class you are compiling). If you want Java to check the current directory before it checks the other directories on the class path, list the current directory (the dot) first.

### **GOTCHA** Not Including the Current Directory in Your Class Path

Omitting the current directory from the class path variable not only will limit the locations you can use for your packages, but can interfere with programs that do not use packages. If you do not create packages, but instead place all classes in the same directory—as we do in the rest of this book—Java will not be able to find the classes unless the current directory is on the class path. On most systems, the current directory is referenced by a period, i.e., ".". (This problem will not occur if you have no class path variable at all; it arises only if you decide to set the class path variable.)

### Name Clashes

Packages are a convenient way to group and use libraries of classes, but there is also another reason for using packages. They can help in dealing with name clashes; that is, they can help in handling situations in which two classes have the same name. If different programmers writing different packages have used the same name for a class, the ambiguity can be resolved by using the package name.

For example, suppose a package named mystuff contains a class called CoolClass, and another package named yourstuff contains a different class named CoolClass. You can use both of these classes in the same program by using the more complete names mystuff.CoolClass and yourstuff. CoolClass, as the following statements demonstrate:

```
mystuff.CoolClass object1 = new mystuff.CoolClass();
yourstuff.CoolClass object2 = new yourstuff.CoolClass();
```

If you list the package name along with the class name like this, you do not need to import the package, since this longer class name includes the package name.

### **SELF-TEST QUESTIONS**

- 42. Suppose you want to use classes in the package mypackages.library1 in a program you write. What do you need to put near the start of the file containing your program?
- 43. Suppose you want to add a class to a package named mypackages. library1. What do you need to put in the file containing the class definition? Where does this statement go in the file?
- 44. Can a package have any name you might want, or are there restrictions on what you can use for a package name? Explain any restrictions.
- 45. On your system, place the class Pet (Listing 6.1) into a package so that you can use the class in any Java program by including a suitable import statement without moving Pet to the same directory (folder) as your program.

Avoid name clashes

### **6.8** GRAPHICS SUPPLEMENT

Now you see it; now you don't.

—COMMON MAGICIAN'S SAYING

In this section we show you how to add buttons and icons to a JavaFX application. A **button** is an object in your application that has a button-like appearance and that does something when you click it with your mouse. An **icon** is a small picture.

### **Adding Buttons**

You create a button object in the same way that you create a label object, but you use the class Button instead of the class Label. Import the Button class from javafx.scene.control.Button. For example, the application in Listing 6.21 creates a button as follows:

```
Button btnSunny = new Button("Sunny");
```

The argument to the constructor for the class Button, in this case "Sunny", is a string that will appear on the button when the button is displayed. If you look at the program's output in Listing 6.21, you will see that the two buttons are labeled Sunny and Cloudy.

After you create a button, you add it to the layout in the same way that you add a label. For example, btnSunny is added to the VBox layout of the program in Listing 6.21 as follows:

Add buttons to the content pane

```
root.getChildren().add(btnSunny);
```

Unlike labels, you can associate an action with a button so that when the user clicks the button with a mouse, the program performs some action. If you click either of the buttons in the program in Listing 6.21, nothing happens, because we haven't yet programmed actions for them. To do this, we use a different kind of programming technique known as **event-driven programming**. We show you how to program actions for the buttons in Chapter 8, after we have covered the concept of interfaces. If you want to implement button actions now, you can look ahead to Chapter 8.

### **Adding Icons**

As we mentioned at the beginning of this section, an icon is simply a picture. The picture usually is small, although it is not actually required to be. The picture you use can be of anything. Pictures are produced in a number of formats—such as GIF and JPEG—that can be displayed on a computer screen. You can use a picture in almost any standard format as the basis for an icon. You store the picture files in the same folder (directory) as your program.

### LISTING 6.21 Adding Buttons to JavaFX Application

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.text.Font;
import javafx.scene.layout.VBox;
import javafx.scene.control.Button;
Simple demonstration of adding buttons to a JavaFX application.
These buttons do not do anything. That comes in a later version.
public class PreliminaryButtonDemo extends Application
{
   public static void main(String[] args)
   {
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
   {
        VBox root = new VBox();
        Button btnSunny;
        Button btnCloudy;
        btnSunny = new Button("Sunny");
        btnCloudy = new Button("Cloudy");
        root.getChildren().add(btnSunny);
        root.getChildren().add(btnCloudy);
        Scene scene = new Scene(root, 300, 100);
        primaryStage.setTitle("Button Demo");
        primaryStage.setScene(scene);
        primaryStage.show();
   }
}
Program Output
 Button Demo
                                               X
 Sunny
                                                      If the user clicks
                                                      either of these
 Cloudy
                                                      buttons, nothing
                                                      happens.
```

JavaFX converts a digital picture file into an icon, and you can then add the icon to a label, button, or other component. You can display an icon, a string, or both an icon and a string on any label or button.

The classes Image and ImageView in the JavaFX library are used to convert a digital picture file into an icon. For example, the following statement converts the digital picture file named duke\_waving.gif to an image named imgDuke:

Use ImageIcon to convert a picture file to an icon

```
Image imgDuke = new Image("duke_waving.gif");
```

You can add this icon to a button by using the method setGraphic, as follows:

```
btn.setGraphic(new ImageView(imgDuke));
```

Listing 6.22 contains a simple example of these steps. The button btnSunny also has the string "Sunny", so in this case the button displays both a string and an icon.

Add an icon to a label

# LISTING 6.22 A JavaFX Application with an Icon Picture (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.text.Font;
import javafx.scene.layout.VBox;
import javafx.scene.control.Button;
import javafx.scene.image.Image;
import javafx.scene.image.ImageView;
Simple demonstration of adding buttons to a JavaFX application.
This version displays an icon for the Sunny Button.
Nothing happens when the buttons are clicked.
public class ButtonImageDemo extends Application
{
   public static void main(String[] args)
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
   {
       VBox root = new VBox();
       Button btnSunny;
       Button btnCloudy;
       btnSunny = new Button("Sunny");
       btnCloudy = new Button("Cloudy");
```

(continued)

# LISTING 6.22 A JavaFX Application with an Icon Picture (part 2 of 2)

```
Image imgSmiley = new Image("smiley.gif");
btnSunny.setGraphic(new ImageView(imgSmiley));

root.getChildren().add(btnSunny);
root.getChildren().add(btnCloudy);

Scene scene = new Scene(root, 300, 100);
primaryStage.setTitle("Button Demo");
primaryStage.setScene(scene);
primaryStage.show();
}
```

### Program Output



You can also use the setGraphic method on a Label or any other JavaFX component.

For example:

```
Label lbl = new Label("Hello");
lbl.setGraphic(new ImageView(imgSmiley));
```

### **SELF-TEST QUESTION**

46. The previous section showed you how to change the code in the JavaFX application in Listing 6.21 so that the button labeled Sunny contained the picture smiley.gif as well as text. Make additional changes to the code so that the button labeled Cloudy contains the picture nasty.gif as well as text. (The file nasty.gif is included with the source code provided on the Web.)

#### **CHAPTER SUMMARY**

- A constructor is a method that creates and initializes an object of the class when you invoke it using the operator new. A constructor must have the same name as the class.
- A constructor without parameters is called a default constructor. A class that does not define a constructor will be given a default constructor automatically. A class that defines one or more constructors, none of which is a default constructor, will have no default constructor.
- When defining a constructor for a class, you can use this as a name for another constructor in the same class. Any call to this must be the first action taken by the constructor.
- The declaration of a static variable contains the keyword static. A static variable is shared by all the objects of its class.
- The heading of a static method contains the keyword static. A static method is typically invoked using the class name instead of an object name. A static method cannot reference an instance variable of the class, nor can it invoke a non-static method of the class without using an object of the class.
- Each primitive type has a wrapper class that serves as a class version of that primitive type. Wrapper classes also contain a number of useful predefined constants and methods.
- Java performs an automatic type cast from a value of a primitive type to an object of its corresponding wrapper class—and vice versa—whenever it is needed.
- When writing a method definition, divide the task to be accomplished into subtasks.
- Every method should be tested in a program in which it is the only untested method.
- Two or more methods within the same class can have the same name if they have different numbers of parameters or some parameters of differing types. That is, the methods must have different signatures. This is called overloading the method name.
- An enumeration is actually a class. Thus, you can define instance variables, constructors, and methods within an enumeration.
- You can form a package of class definitions you use frequently. Each such class must be in its own file within the same folder (directory) and contain a package statement at its beginning.
- You can use the classes in a package within any program without needing to move them to the same folder (directory) by simply including an import statement at the beginning of your program.
- You can add buttons and icons to JavaFX Applications.

#### **Exercises**

- 1. Create a class that will bundle together several static methods for interest calculations. This class should not have a constructor. Its attributes are
  - principal—as a static double variable that starts at \$10000
  - rate—as a static double variable that starts at 7%

#### Its methods are

- calculateSimpleInterest(time)—a static method that returns the amount calculated with the simple interest formula, rounded to the nearest penny.
- computeCompoundInterest(time)—a static method that returns the amount calculated with the compound interest formula, rounded to the nearest penny.
- changePrincipalTo(newPrincipal)—a static method that changes the value of the principal.
- changeRateTo(newRate)—a static method that changes the value of the rate.
- roundToNearestPenny(amount)—a private static method that returns the given amount rounded to the nearest penny. For example, if the amount is 1023.659, the method will return 1023.66.
- 2. Consider a class Time that represents a time of day. It has attributes for the hour and minute. The hour value ranges from 0 to 23, where the range 0 to 11 represents a time before noon. The minute value ranges from 0 to 59.
  - a. Write a default constructor that initializes the time to 0 hours, 0 minutes.
  - b. Write a private method isValid(hour, minute) that returns true if the given hour and minute values are in the appropriate range.
  - c. Write a method setTime(hour, minute) that sets the time if the given values are valid.
  - d. Write another method setTime(hour, minute, isAM) that sets the time if the given values are valid. The given hour should be in the range 1 to 12. The parameter isAm is true if the time is an a.m. time and false otherwise.
- 3. Write a default constructor and a second constructor for the class RatingScore, as described in Exercise 9 of the previous chapter.
- 4. Write a constructor for the class ScienceFairProjectRating, as described in Exercise 10 of the previous chapter. Give this constructor three parameters corresponding to the first three attributes that the exercise describes. The constructor should give default values to the other attributes.
- 5. Consider a class Characteristic that will be used in an online dating service to assess how compatible two people are. Its attributes are
  - description—a string that identifies the characteristic
  - rating—an integer between 1 and 10 that indicates a person's desire for this characteristic in another person

- a. Write a constructor that sets the description of the characteristic to a given string and sets the rating to zero to indicate that it has not yet been determined.
- b. Write a private method is Valid (a Rating) that returns true if the given rating is valid, that is, is between 1 and 10.
- c. Write a method setRating(aRating) that sets the rating to aRating if it is valid.
- d. Write a method setRating that reads a rating from the keyboard, insisting that the rating supplied by the user be valid.
- 6. Create a class MarksObtained that can be used to record the marks of subjects of the student in a school. The class has the attributes
  - marksInSubject—the marks of a student in a subject
  - totalMarksObt—the total marks obtained by a student in all subjects as a static variable

The class has the following methods:

- increaseMarksInSubject—adds given marks to the subject and increases the value of totalMarksObt
- decreaseMarksInSubject—subtracts given marks from the subject and decreases the value of totalMarksObt, ensuring that marksInSubject does not go below zero
- getMarks—returns the marks in a subject of the student
- getTotalMarks—a static method that returns the total marks of the student
- 7. Write a program that tests the class MarksObtained described in the previous exercise.
- 8. Sometimes we would like a class that has just a single unique instance. Create a class Merlin that has one attribute, theWizard, which is static and of type Merlin. The class has only one constructor and two methods, as follows:
  - Merlin—a private constructor. Only this class can invoke this constructor; no other class or program can create an instance of Merlin.
  - summon—a static method that returns the Wizard if it is not null; if the Wizard is null, this method creates an instance of Merlin using the private constructor and assigns it to the Wizard before returning it.
  - consult—a non-static method that returns the string "Pull the sword from the stone".
- 9. Create a program that tests the class Merlin described in the previous exercise. Use the toString method to verify that a unique instance has been created.
- 10. In the previous chapter, Self-Test Question 16 described a class Person to represent a person. The class has instance variables for a person's name,

which is a string, and an integer age. These variables are name and age, respectively.

- a. Write a default constructor for Person that sets name to the string "No name yet" and age to zero.
- b. Write a second constructor for Person that sets name to a given string and age to a given age.
- c. Write a static method createAdult for Person that returns a special instance of this class. The instance represents a generic adult and has the name "An adult" and the age 21.
- 11. Create a class Android whose objects have unique data. The class has the following attributes:
  - tag—a static integer that begins at 1 and changes each time an instance is created
  - name—a string that is unique for each instance of this class

Android has the following methods:

- Android—a default constructor that sets the name to "Bob" concatenated with the value of tag. After setting the name, this constructor changes the value of tag by calling the private method changeTag.
- getName—returns the name portion of the invoking object.
- isPrime(n)—a private static method that returns true if n is prime—that is, if it is not divisible by any number from 2 to n 1.
- changeTag—a private static method that replaces tag with the next prime number larger than the current value of tag.
- 12. Create a program that tests the class Android described in the previous exercise.

#### **PRACTICE PROGRAMS**

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

- 1. Modify the definition of the class Species in Listing 5.19 of Chapter 5 by removing the method setSpecies and adding the following methods:
  - Five constructors: one for each instance variable, one with three parameters for the three instance variables, and a default constructor. Be sure that each constructor sets all of the instance variables.
  - Four methods named set that can reset values: one is the same as the method setSpecies in Listing 5.16, and the other three each reset one of the instance variables.

Then write a test program to test all the methods you have added. Finally, repeat Practice Program 1 in Chapter 5, but be sure to use some constructor

- other than the default constructor when you define new objects of the class Species.
- 2. Repeat Programming Project 2 in Chapter 5. This time, add the following four constructor methods: one for each instance variable, one with two parameters for the two instance variables, and a default constructor. Be sure that each constructor sets all of the instance variables. Write a driver program to test each of the methods, including each of the four constructors and at least one true and one false case for each of the test methods.
- 3. Using the class Pet from Listing 6.1, write a program to read data for five pets and display the following data: name of smallest pet, name of largest pet, name of oldest pet, name of youngest pet, average weight of the five pets, and average age of the five pets.
- 4. Do Practice Program 4 from Chapter 5 except define and use a constructor to initialize the Trivia object with a question and answer.
- 5. The following class displays a disclaimer every time an instance is created using the default constructor. However, we would like the disclaimer to appear only once when the very first Vehicle object is created. Any future Vehicle objects that are created should display no disclaimer. Modify the code to use a static boolean variable that is initialized to false when it is defined. Once the disclaimer is displayed the variable should be set to true, and an if statement added around the display so the disclaimer is only output if the variable has the value false. This should force the program to display the disclaimer only once. Add a main method and test code to verify that the disclaimer is only displayed once.

- 6. Do Practice Program 5 from Chapter 5 but add a constructor that allows the user to initialize the name and alcoholic content of the beer.
- 7. We can improve the Beer class from the previous Practice Program by using principles of information hiding. The instance variable percent holds the percent of alcohol in the beer. If this variable is public then someone might enter the alcohol percentage the wrong way. For example, if the alcohol percentage is 5% then someone might set the variable to 5.0 instead of 0.05 that the program expects. As a result, the program would compute that someone would be legally intoxicated after a miniscule sip of beer.

Address this problem by adding or modifying the mutator method, setAlcohol. If the variable that is being set is over 1 then set the alcohol variable to the incoming value divided by 100. Otherwise set the alcohol variable to the incoming value. You should also do this check for the percentage set by the constructor. Test your program by setting the percent alcohol to 5.0 and to 0.05. The results should be unchanged.

#### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

1. Define a utility class for displaying values of type double. Call the class DoubleOut. Include all the methods from the class DollarFormat in Listing 6.14, all the methods from the class OutputFormat of Self-Test Question 30, and a method called scienceWrite that displays a value of type double using e notation, such as 2.13e-12. (This e notation is also called scientific notation, which explains the method name.) When displayed in e notation, the number should appear with exactly one nonzero digit before the decimal point—unless the number is exactly zero. The method scienceWriteIn that is the same as scienceWrite except that it does advance to the next line. All but the last two method definitions can simply be copied from the text (or more easily from the source code for this book that is available on the Web.). Note that you will be overloading the method names write and writeIn.

Write a driver program to test your method scienceWriteln. This driver program should use a stub for the method scienceWrite. (Note that this means you can write and test scienceWriteln before you even write scienceWrite.) Then write a driver program to test the method scienceWrite. Finally, write a program that is a sort of super driver program that takes a double value as input and then displays it using the two writeln methods and the scienceWriteln method. Use the number 5 for the number of digits after the decimal point when you need to specify such a number. This super driver program should allow the user to repeat this testing with additional numbers of type double until the user is ready to end the program.

- 2. Write a new class TruncatedDollarFormat that is the same as the class DollarFormat from Listing 6.14, except that it truncates rather than rounds to obtain two digits after the decimal point. When truncating, all digits after the first two are discarded, so 1.229 becomes 1.22, not 1.23. Repeat Programming Project 3 in Chapter 4 using this new class.
- 3. Complete and fully test the class Time that Exercise 2 describes. Add two more constructors that are analogous to the setTime methods

described in Parts c and d of Exercise 2. Also include the following methods:

- getTime24 returns a string that gives the time in 24-hour notation *hhmm*. For example, if the hour value is 7 and the minute value is 25, return "0725". If the hour value is 0 and the minute value is 5, return "0005". If the hour value is 15 and the minute value is 30, return "1530".
- getTime12 returns a string that gives the time in 12-hour notation *h:mm xx*. For example, if the hour value is 7 and the minute value is 25, return "7:25 am". If the hour value is 0 and the minute value is 5, return "12:05 am". If the hour value is 15 and the minute value is 30, return "3:30 pm".
- 4. Complete and fully test the class Characteristic that Exercise 5 describes. Include the following methods:
  - getDescription—returns the description of this characteristic.
  - getRating—returns the rating of this characteristic.
  - getCompatability(Characteristic otherRating)—returns the compatibility measure of two matching characteristics, or zero if the descriptions do not match.
  - getCompatibilityMeasure(Characteristic otherRating)—a private method that returns a compatibility measure as a double value using the formula

$$m = 1 - \frac{(r_1 - r_2)^2}{81}$$

when both ratings are nonzero; *m* is zero if either rating is zero. (Recall from Exercise 5 that the constructor sets the rating to zero, indicating that it has not yet been determined.)

- isMatch(Characteristic otherRating)—a private method that returns true if the descriptions match.
- 5. Write a Java enumeration LetterGrade that represents letter grades A through F, including plus and minus grades. Define a private instance variable to hold a boolean value that is true if the grade is passing. Also, define a constructor that initializes this instance variable, an accessor method isPassing to return its value, and a method toString that returns the grade as a string. Finally, write a program to demonstrate the enumeration.
- 6. Complete and fully test the class Person that Exercise 10 describes. Include the following additional methods:
  - getName—returns the name of the person as a string.
  - getAge—returns the age of the person.
  - setName(first, last)—sets the name of the person, given a first and last name as strings.

- setName(name)—sets the name of the person, given the entire name as one string.
- setAge(age)—sets the age of the person.
- createToddler—a static method that returns a special instance of the class to represent a toddler. The instance has the name "A toddler" and the age 2.
- createPreschooler—a static method that returns a special instance of the class to represent a preschooler. The instance has the name "A preschooler" and the age 5.
- createAdolescent—a static method that returns a special instance of the class to represent an adolescent. The instance has the name "An adolescent" and the age 9.
- createTeenager—a static method that returns a special instance of the class to represent a teenager. The instance has the name "A teenager" and the age 15.
- 7. Write a Temperature class that represents temperatures in degrees in both Celsius and Fahrenheit. Use a floating-point number for the temperature and a character for the scale: either 'C' for Celsius or 'F' for Fahrenheit. The class should have
  - Four constructors: one for the number of degrees, one for the scale, one for both the degrees and the scale, and a default constructor. For each of these constructors, assume zero degrees if no value is specified and Celsius if no scale is given.
  - Two accessor methods: one to return the temperature in degrees Celsius, the other to return it in degrees Fahrenheit. Use the formulas from Practice Program 5 of Chapter 3 and round to the nearest tenth of a degree.
  - Three set methods: one to set the number of degrees, one to set the scale, and one to set both.
  - Three comparison methods: one to test whether two temperatures are equal, one to test whether one temperature is greater than another, and one to test whether one temperature is less than another.

Write a driver program that tests all the methods. Be sure to invoke each of the constructors, to include at least one true and one false case for each comparison method, and to test at least the following three temperature pairs for equality: 0.0 degrees C and 32.0 degrees F, -40.0 degrees C and -40.0 degrees F, and 100.0 degrees C and 212.0 degrees F.

- 8. Repeat Programming Project 8 of the previous chapter, but include constructors.
- 9. Write and fully test a class that represents rational numbers. A rational number can be represented as the ratio of two integer values, a and b, where b is not zero. The class has attributes for the numerator and denominator of this ratio. The ratio should always be stored in its simplest form. That is, any common factor of a and b should be removed. For example, the rational number 40/12 should be stored as 10/3.





The class has the following constructors and methods:

- A default constructor that sets the rational number to 0/1.
- A constructor that has parameters for the numerator and denominator and converts the resulting ratio to simplified form.
- simplify—a private method that converts the rational number to simplified form.
- getGCD(x, y)—a private static method that returns the largest common factor of the two positive integers x and y, that is, their greatest common divisor. For example, the greatest common divisor of 40 and 12 is 4.
- getValue—returns the rational number as a double value.
- toString—returns the rational number as a string in the form a/b.
- 10. Write a program that will record the votes for one of two candidates by using the class VoteRecorder, which you will design and create. Vote Recorder will have static variables to keep track of the total votes for candidates and instance variables to keep track of the votes made by a single person. It will have the following attributes:
  - nameCandidatePresident1—a static string that holds the name of the first candidate for president
  - nameCandidatePresident2—a static string that holds the name of the second candidate for president
  - nameCandidateVicePresident1—a static string that holds the name of the first candidate for vice president
  - nameCandidateVicePresident2—a static string that holds the name of the second candidate for vice president
  - votesCandidatePresident1—a static integer that holds the number of votes for the first candidate for president
  - votesCandidatePresident2—a static integer that holds the number of votes for the second candidate for president
  - votesCandidateVicePresident1—a static integer that holds the number of votes for the first candidate for vice president
  - votesCandidateVicePresident2—a static integer that holds the number of votes for the second candidate for vice president
  - myVoteForPresident—an integer that holds the vote of a single individual for president (0 for no choice, 1 for the first candidate, and 2 for the second candidate)
  - myVoteForVicePresident—an integer that holds the vote of a single individual for vice president (0 for no choice, 1 for the first candidate, and 2 for the second candidate)

In addition to appropriate constructors, VoteRecorder has the following methods:

• setCandidatesPresident(String name1, String name2)—a static method that sets the names of the two candidates for president

- setCandidatesVicePresident(String name1, String name2)—a static method that sets the names of the two candidates for vice president
- resetVotes—a static method that resets the vote counts to zero
- getCurrentVotePresident—a static method that returns a string with the current total number of votes for both presidential candidates
- getCurrentVoteVicePresident—a static method that returns a string with the current total number of votes for both vice presidential candidates
- getAndConfirmVotes—a non-static method that gets an individual's votes, confirms them, and then records them
- getAVote(String name1, String name2)—a private method that returns a vote choice for a single race from an individual (0 for no choice, 1 for the first candidate, and 2 for the second candidate)
- getVotes—a private method that returns a vote choice for president and vice president from an individual
- confirmVotes—a private method that displays a person's vote for president and vice president, asks whether the voter is happy with these choices, and returns true or false according to a yes-or-no response
- recordVotes—a private method that will add an individual's votes to the appropriate static variables

Create a program that will conduct an election. The candidates for president are Annie and Bob. The candidates for vice president are John and Susan. Use a loop to record the votes of many voters. Create a new Vote Recorder object for each voter. After all the voters are done, present the results.

- 11. Repeat Programming Project 10 from Chapter 5, but include constructors.
- 12. Create a JavaFX application that displays a button with the text "Button 1". Underneath the button add a label with the text "Label 1". Repeat with and additional "Button 2" and "Label 2". Add an image icon of your choice to the first button and the first label.
- 13. Write a program that plays a simplified dice version of blackjack. Instead of selecting from a deck of cards a 14-sided die is rolled to represent a card. The rules of the game for one round, as played against the house, are as follows:
  - a. A roll randomly selects from the values 2–10 or Jack, Queen, King, or Ace. An Ace always has the value of 11. Jack, Queen, and King all have the value of 10. In other words, with equal probability, a roll selects one of 2,3,4,5,6,7,8,9,10,10,10,10,11.
  - b. The human player enters a wager. The wager must be positive and must not exceed the amount of money possessed by the player.
  - c. The player is given two rolls. The house, played by the computer, is given one roll. The player is shown the value of the house's roll.
  - d. If the total of the rolls is 22 or greater than the player "busts", loses the wager, and the round is over.

**Graphics** 

- e. If the total of the rolls is 21 or less then the player has the option to "hit" or "stand". If the player opts to "hit" then the player is given another roll. Return to step 4. If the player opts to "stand" then continue to step 6.
- f. It is now the house's turn. The house is given an additional roll and the values are summed. If the total is less than 17 then the house must "hit". If the house has a total of 22 or greater than the house "busts", the player wins the wager, and the round is over. The house must continue to hit until it either "busts" or has a value between 17 and 21.
- g. If the house did not "bust" then its value is compared to the player's total. If the totals are the same then it is a "push" and the player does not win or lose anything. If the house's total is greater than the player's, then the player loses the wager. If the player's total is greater than the house's, then the player wins the wager.

Write a program that repeats a round until the player decides to quit or runs out of money. Start the player with \$100. Design your program using classes and methods. Your entire program should not be in a single main method.

### **Answers to Self-Test Questions**

- 1. If a class is named Student, every constructor for this class must also be named Student.
- 2. You specify no return type for a constructor, not even void.
- 3. A default constructor is a constructor without parameters.
- 4. Classes do not always have a default constructor. If you give no constructor definition for a class, Java will automatically provide a default constructor. However, if you provide one or more constructors of any sort, Java does not provide any constructors for you. So if none of your constructors is a default constructor, the class has no default constructor.
- 5. yourPet.setPet(correctName, correctAge, correctWeight);
- 6. The declaration of an instance variable within a class definition has no keyword static, but the declaration of a static variable does use static. Every object of the class has its own instance variables. A class has only one of each static variable, and all objects share that static variable.
- 7. Yes.
- 8. Yes. An example is the static variable interestRate in the method setInterestRate in Listing 6.7.
- 9. No, you cannot reference an instance variable within the definition of a static method, because a static method can be invoked without an object, and so there are no instance variables.

- 10. Yes.
- 11. Yes. Note that this means you can reference both static variables and instance variables within a non-static method.
- 12. It is valid, but a more normal way of doing the same thing is

```
double inches = DimensionConverter.convertFeetToInches(2.5);
```

- 13. Yes.
- 14. Yes, you can invoke a non-static method within the definition of a static method, but only if you have an object of the class and use that object in the invocation of the non-static method.
- 15. Yes. Invoking a static method within the definition of a non-static method requires nothing special.
- 16. No, because addInterest is not a static method.
- 17. 2; b. 3; c. 2.0; d. 2.0; e. 3.0; f. 3.0; g. A random integer ≥10 and ≤ 19. Note that the first two values are of type long, while the last four values are of type double.
- 18. approxSpeed = (int)Math.round(speed);

Because Math.round returns a value of type long, and you want a value of type int, you must use a type cast.

19. longSpeed = Math.round(speed);

Because Math.round returns a value of type long, no type cast is necessary.

- 20. long. Since one argument is of type long, the result is of type long.
- 21. The following class and a demonstration program are included in the code that is on the Web.

```
public class CircleCalculator
{
    public static double getArea(double radius)
    {
        return Math.PI * radius * radius;
    }
    public static double getCircumference(double radius)
    {
        return Math.PI * (radius + radius);
    }
}
```

- 22. They are all legal.
- 23. Double.toString(x)

```
24. Integer.parseInt(s)
25. Integer.parseInt(s.trim())
26. System.out.println("Largest double is " + Double.MAX_VALUE);
    System.out.println("Smallest double is " + Double.MIN_VALUE);
27. $7.00
```

28. Use variables of type long, rather than variables of type int. Note that, because the method Math.round returns a value of type long, you will not need a type cast in the method writePositive. For example,

```
int allCents = (int)(Math.round(amount * 100));
would become
long allCents = Math.round(amount * 100);
```

The variables dollars and cents should also be changed to type long.

29. This will produce a "Null Pointer Exception" error message. The variables s1 and s2 do not name any objects. The lines

```
Species s1 = null;
Species s2 = null;
should be changed to
Species s1 = new Species();
Species s2 = new Species();
```

30. The class OutputFormat is in the file OutputFormat.java included with the source code provided on the Web. We also list it here:

```
public class OutputFormat
{
    /**
        Displays a number with digitsAfterPoint digits after the
        decimal point. Rounds any extra digits.
        Does not advance to the next line after output.

*/
public static void write(double number, int digitsAfterPoint)
{
    if (number >= 0)
        writePositive(number, digitsAfterPoint);
    else
    {
        double positiveNumber = -number;
        System.out.print('-');
        writePositive(positiveNumber, digitsAfterPoint);
    }
}
```

```
//Precondition: number >= 0
//Displays a number with digitsAfterPoint digits after
//the decimal point. Rounds any extra digits.
private static void writePositive(double number,
int digitsAfterPoint)
{
    int mover = (int)(Math.pow(10, digitsAfterPoint));
        //1 followed by digitsAfterPoint zeros
    int allWhole; //number with the decimal point
        //moved digitsAfterPoint places
    allWhole = (int)(Math.round(number * mover));
    int beforePoint = allWhole / mover;
    int afterPoint = allWhole % mover:
    System.out.print(beforePoint);
    System.out.print('.');
    writeFraction(afterPoint, digitsAfterPoint);
//Displays the integer afterPoint with enough zeros
//in front to make it digitsAfterPoint digits long.
private static void writeFraction(int afterPoint,
int digitsAfterPoint)
{
    int n = 1;
    while (n < digitsAfterPoint)</pre>
        if (afterPoint < Math.pow(10, n))</pre>
            System.out.print('0');
        n = n + 1;
    System.out.print(afterPoint);
}
/**
Displays a number with digitsAfterPoint digits after the
decimal point. Rounds any extra digits.
Advances to the next line after output.
    public static void writeln(double number,
    int digitsAfterPoint)
        write(number, digitsAfterPoint);
        System.out.println();
    }
}
```

31. Yes, you could use the names print and println, rather than write and writeln, in the class OutputFormat. Java would have no name confusion with System.out.println, because when you invoke a method in OutputFormat, you specify the class name before the dot. (If you invoke

the method with an object instead of the class name, Java still knows the class name because it knows the type of the object.) However, the methods in OutputFormat behave a little differently from the method System.out.println, so using a different name would be clearer to people.

- 32. Yes, the 7 would be converted to 7.0 by Java so that the types would match the heading of the constructor having three parameters.
- 33. No, you cannot overload a method name on the basis of return type. These two methods have the same signatures.
- 34. Yes, they differ in the type of their parameter, so this is a valid overloading of the method name convertValue. The fact that the methods return values of different types does not affect whether or not both definitions can be used. Only the types of the parameters matter in making overloading valid in this case.
- 35. Yes, it would be valid because no other method named setSpecies has the same number and types of parameters. The definition follows:

```
public void setSpecies(String newName)
{
    name = newName;
    population = 0;
    growthRate = 0;
}
```

36. Yes, it would be valid because no other method named setSpecies has the same number and types of parameters. The definition follows:

```
public void setSpecies(String newName)
{
    name = newName;
}
```

- 37. No; if you add both of these new methods setSpecies, the class will have two definitions of this method that have the same number and types of parameters. That is, both methods have the same signature.
- 38. Simply delete all occurrences of this from the definition.
- 39. Add an invocation of the method trim. The rewritten version follows

```
public void set(String amountString)
{
    String dollarsString;
    String centsString;
    amountString = amountString.trim();
<The rest of the method definition is the same as in Listing 6.16.>
```

```
40. public String getNameOfFirst()
   {
        return first.getName();
   public int getAgeOfFirst()
        return first.getAge();
   public double getWeightOrFirst()
        return first.getWeight();
   }
41. a. 3
   b. false
   c. A positive integer
   d. Suit.CLUBS
   e. Suit.SPADES
   f. "black"
   g. "spades"
```

- 42. import mypackages.library1.\*;
- 43. You must make the following the first instruction line in the file, ignoring blank lines and comments: package mypackages.library1;
- 44. A package name must be a path name for the directory that contains the classes in the package, but the package name uses dots in place of slashes. When naming the package, you use a relative path name that starts from any directory named in the setting of the class path (environment) variable.
- 45. The way to do this depends a little on your operating system and on your personal preferences. Here is an outline of what you should do: Choose a package name and insert the following at the start of the file Pet.java:

```
package Package_Name;
```

Compile the modified file Pet. java. Place both of the files Pet. java and Pet.class into the directory corresponding to Package\_Name.

46. Change the code

```
Image imgNasty = new Image("nasty.gif");
btnCloudy.setGraphic(new ImageView(imgNasty));
```



#### **7.1 ARRAY BASICS** 515

Creating and Accessing Arrays 516 Array Details 519 The Instance Variable 1ength 522 More About Array Indices 525 Initializing Arrays 528

# 7.2 ARRAYS IN CLASSES AND METHODS 530

Case Study: Sales Report 530
Indexed Variables as Method Arguments 538
Entire Arrays as Arguments to a Method 541
Arguments for the Method main 542
Array Assignment and Equality 543
Methods That Return Arrays 546

# 7.3 PROGRAMMING WITH ARRAYS AND CLASSES 550

Programming Example: A Specialized List Class 550 Partially Filled Arrays 558

# 7.4 SORTING AND SEARCHING ARRAYS 560

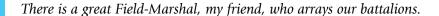
Selection Sort 560 Other Sorting Algorithms 564 Searching an Array 566

#### 7.5 MULTIDIMENSIONAL ARRAYS 567

Multidimensional-Array Basics 568
Multidimensional-Array Parameters and Returned
Values 571
Java's Representation of Multidimensional
Arrays 574
Ragged Arrays (*Optional*) 575
Programming Example: Employee Time
Records 577

#### **7.6 GRAPHICS SUPPLEMENT** 583

Layout Panes 583
Text Areas, Text Fields, and Combining
Layouts 591
Drawing Polygons 596



—ARTHUR HUGH CLOUGH, The Bothie of Tober-na-Vuolich (1819-1861)

An array is a special kind of object used to store a collection of data. An array differs from the other objects you have seen in two ways:

- All the data stored in an array must be of the same type. For example, you
  might use an array to store a list of values of type double that record rainfall
  readings in centimeters. Or you might use an array to store a list of objects
  of some class called Species that contain the records for various endangered
  species.
- An array object has only a small number of predefined methods. Because arrays were used by programmers for many years before classes were invented, they use a special notation of their own to invoke those few predefined methods, and most people do not even think of them as methods.

In this chapter, we introduce you to arrays and show you how to use them in Java.

#### **OBJECTIVES**

After studying this chapter, you should be able to

- Describe the nature and purpose of an array
- Use arrays in simple Java programs
- Define methods that have an array as a parameter
- Define methods that return an array
- Use an array as an instance variable in a class
- Use an array that is not filled completely
- Order, or sort, the elements in an array
- Search an array for a particular item
- Define and use multidimensional arrays
- Insert text fields and text areas into your JavaFX applications using layouts
- Draw arbitrary polygons in your JavaFX applications

### **PREREQUISITES**

This is the first point in this book where you have a significant choice as to what to read next. If you prefer, instead of reading this chapter now, you can go on in the book and return to this discussion of arrays at a later time. You

can read Chapters 8.1 through 8.2, 8.5, 9, and 10, except for Section 10.5, as you wish before you read this chapter. Sections 8.3 and 8.4 include references to arrays for some of the examples.

Section 7.1 depends only on Chapters 1 through 4. However, you should be familiar with the material in all of the previous chapters before reading the remaining sections of this chapter.

If you are reading the graphics supplement sections in each chapter, you can—and are encouraged to—read the first part of this chapter's graphic supplement, whether you read the rest of the chapter or not.

### 7.1 ARRAY BASICS

And in such indexes, although small pricks To their subsequent volumes, there is seen The baby figure of the giant mass Of things to come.

-WILLIAM SHAKESPEARE, Troilus and Cressida

Suppose you want to compute the average temperature for the seven days in a week. You might use the following code:

```
Scanner keyboard = new Scanner(System.in);
System.out.println("Enter 7 temperatures:");
double sum = 0;
for (int count = 0; count < 7; count++)
{
    double next = keyboard.nextDouble();
    sum = sum + next;
}
double average = sum / 7;</pre>
```

This works fine if all you want to know is the average. But let's say you also want to know which temperatures are above and which are below the average. Now you have a problem. In order to compute the average, you must read the seven temperatures, and you must compute the average before comparing each temperature to it. Thus, to be able to compare each temperature to the average, you must remember the seven temperatures. How can you do this? The obvious answer is to use seven variables of type double. This is a bit awkward, because seven is a lot of variables to declare, and in other situations, the problem can be even worse. Imagine doing the same thing for each day of the year instead of just each day of the week. Writing 365 variable declarations would be absurd. Arrays provide us with an elegant way to declare a collection of related variables. An **array** is a collection of items of the same type. It is something like a list of variables, but it handles the naming of the variables in a nice, compact way.

Items in an array have the same data type

# **Creating and Accessing Arrays**

In Java, an array is a special kind of object, but it is often more useful to think of an array as a collection of variables of the same type. For example, an array consisting of a collection of seven variables of type double can be created as follows:

```
double[] temperature = new double[7];
```

This is like declaring the following seven strangely named variables to have the type double:

```
temperature[0], temperature[1], temperature[2],
temperature[3], temperature[4], temperature[5], temperature[6]
```

An index is an integer expression that indicates an array element

Variables like temperature[0] and temperature[1] that have an integer expression in square brackets are called **indexed variables**, **subscripted variable**, **array elements**, or simply **elements**. The integer expression within the square brackets is called an **index** or a **subscript**. Note that the numbering starts with 0, not 1.

### **REMEMBER Array Indices Begin at 0**

In Java, the indices of an array always start with 0. They never start with 1 or any number other than 0.

Each of these seven variables can be used just like any other variable of type double. For example, all of the following statements are allowed in Java:

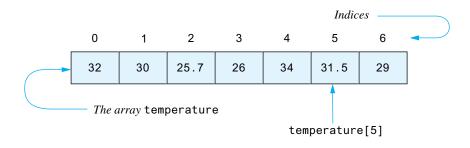
```
temperature[3] = 32;
temperature[6] = temperature[3] + 5;
System.out.println(temperature[6]);
```

When we think of these indexed variables as being grouped together into one collective item, we will call them an array. So we can refer to the array named temperature without using any square brackets. Figure 7.1 illustrates the array temperature.

But these seven variables are more than just seven plain old variables of type double. The number in square brackets is part of the name of each of these variables, and it does not have to be an integer constant. Instead, you can use any expression that evaluates to an integer that is at least 0 and—for this example—at most 6. So the following code, for instance, is allowed:

```
Scanner keyboard = new Scanner(System.in);
System.out.println("Enter day number (0 - 6):");
int index = keyboard.nextInt();
System.out.println("Enter temperature for day " + index);
temperature[index] = keyboard.nextDouble();
```

FIGURE 7.1 A Common Way to Visualize an Array



Since an index can be an expression, we can write a loop to read values into the array temperature, as follows:

```
System.out.println("Enter 7 temperatures:");
for (int index = 0;index < 7; index++)
    temperature[index] = keyboard.nextDouble();</pre>
```

The user could type the seven values on separate lines or all on one line, separated by spaces. After the array values are read in, we can display them as follows:

```
System.out.println("The 7 temperatures are:");
for (int index = 0; index < 7; index++)
        System.out.print(temperature[index] + " ");
System.out.println();</pre>
```

The program in Listing 7.1 shows an example that uses our sample array temperature as seven indexed variables, all of type double. Note that the program uses for loops similar to the ones we just considered.

# LISTING 7.1 An Array of Temperatures (part 1 of 2)

### LISTING 7.1 An Array of Temperatures (part 2 of 2)

```
{
             temperature[index] = keyboard.nextDouble();
             sum = sum + temperature[index];
        double average = sum / 7;
        System.out.println("The average temperature is " +
                            average);
        // Display each temperature and its relation to the average:
        System.out.println("The temperatures are");
        for (int index = 0; index < 7; index++)</pre>
        {
            if (temperature[index] < average)</pre>
                  System.out.println(temperature[index] +
                                " below average");
            else if (temperature[index] > average)
                  System.out.println(temperature[index] +
                                       " above average");
            else //temperature[index] == average
                  System.out.println(temperature[index] +
                                       " the average");
        System.out.println("Have a nice week.");
    }
}
```

### Sample Screen Output

```
Enter 7 temperatures:
32
30
25.7
26
34
31.5
29
The average temperature is 29.7428
The temperatures are
32.0 above average
30.0 above average
25.7 below average
26.0 below average
34.0 above average
31.5 above average
29.0 below average
Have a nice week.
```

# **Array Details**

You create an array in the same way that you would create an object of a class type using the operation new, but the notation is slightly different. When creating an array of elements of type Base\_Type, the syntax is as follows:

```
Base_Type[] Array_Name = new Base_Type[Length];
```

For example, the following creates an array named pressure that is equivalent to 100 variables of type int:

```
int[] pressure = new int[100];
```

Alternatively, the preceding can be broken down into two steps:

```
int[] pressure;
pressure = new int[100];
```

The first step declares as an array of integers. The second step allocates enough memory for the array to hold up to 100 integers.

The type for the array elements is called the base type of the array. In this example, the base type is int. The number of elements in an array is called the length, size,

### **ASIDE** Alternative Syntax for Declaring an Array

Although we do not encourage its use, there is an alternative syntax for array declarations that you may encounter. You can write the square brackets after the variable instead of after the base type, as in the following example:

```
char alphabet[];
```

or capacity of the array. So this sample array pressure has length 100, which means it has indexed variables pressure[0]through pressure[99]. Note that because the indices start at 0, an array of length 100, such as pressure, will have *no* indexed variable pressure[100].

The base type of an array can be any data type. In particular, it can be a class type. The following statement creates an array named entry whose elements are Species objects, where Species is a class:

This array is a collection of the three variables entry[0], entry[1], and entry[2], all of type Species.

# Species[] entry = new Species[3];

### **RECAP** Declaring and Creating an Array

You declare and create an array in almost the same way that you declare and create objects of classes. There is only a slight difference in the syntax.

(continued)

The number of elements in an array is its length

The type of the array elements is the array's base type

#### **SYNTAX**

```
Base_Type[] Array_Name = new Base_Type[Length];

EXAMPLES

char[] symbol = new char[80];
double[] reading = new double[100];
Species[] specimen = new Species[80]; //Species is a class
```

### **REMEMBER** How to Use Square Brackets with Arrays

There are three different ways to use square brackets [] with an array name. They can be used

• With a data type when declaring an array. For example,

```
int[] pressure;
```

declares—but does not allocate memory for—pressure as an array of integers.

 To enclose an integer expression when creating a new array. For example,

```
pressure = new int[100];
```

allocates memory for the array pressure of 100 integers.

• To name an indexed variable of the array. For example, pressure [3] in the following two lines is an indexed variable:

```
pressure[3] = keyboard.nextInt();
System.out.println("You entered" + pressure[3]);
```

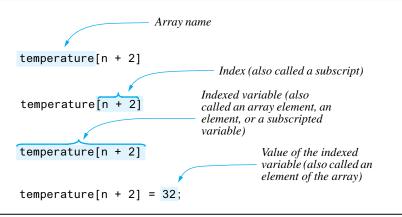
As we mentioned previously, the value inside the square brackets can be any expression that evaluates to an integer. When creating an array, instead of using an integer literal, you can—and should—use a named constant. For example, you should use a constant such as NUMBER\_OF\_READINGS instead of 100 when you create the array pressure:

Use a named constant when defining an array

```
public static final int NUMBER_OF_READINGS = 100;
int[] pressure = new int[NUMBER_OF_READINGS];
```

Java allocates memory for an array, as well as for any other object, at execution time. So if you do not know how large to make an array when you write a program, you can read the array's length from the keyboard, as follows:

### FIGURE 7.2 Array Terminology



```
System.out.println("How many temperatures do you have?");
int size = keyboard.nextInt();
double[] temperature = new double[size];
```

Reading an array length

You can also use any expression that evaluates to an appropriate integer when naming an indexed variable of an array, as in the following examples:

```
int point = 2;
temperature[point + 3] = 32;
System.out.println("Temperature is " + temperature[point + 3]);
```

Note that temperature[point + 3] in the preceding code is the same indexed variable as temperature[5], because point + 3 evaluates to 5.

Figure 7.2 illustrates some of the most common terms used when referring to arrays. Notice that the word *element* has two meanings. It can be used to refer to an indexed variable as well as to the value of an indexed variable.

# PROGRAMMING TIP In General, Use Singular Names for Arrays

If you want an array to hold entries, each of which is an object of a class called Species, you might be tempted to use something like the following:

```
Species[] entries = new Species[20]; //Valid but not nice.
```

Using a plural, like entries, seems to make sense, since the array holds more than one element. However, programmers find that their programs often read better if they use a singular form for an array name, like the following:

```
Species[] entry = new Species[20]; //Nicer.
```

The reason that the singular form works better here is that, when the array name is used in some sort of computation, the name refers to only one element. The expression entry[2] is a single element of the array, as in a statement such as

```
System.out.println("The entry is " + entry[2]);
```

The use of singular names for arrays is not an absolute rule. Sometimes it makes sense to use plural names. For example, if an indexed variable contains the number of hours worked by employee number n, the plural form hours [n] makes sense. The only sure test of whether to use a singular or plural name is to consider how an indexed variable would read in the context of your Java code.

# The Instance Variable length

An array is a kind of object, and like other objects, it might have instance variables. As it turns out, an array has only one public instance variable, namely the variable length, which is equal to the length of the array. For example, if you create an array by writing

```
Species[] entry = new Species[20];
```

entry.length has a value of 20. By using the instance variable length instead of a literal like 20, you can make your program clearer and more general. A name like entry.length means more to a reader of your program than a number whose meaning may not always be obvious. In addition, if you later decide to change the size of the array, you have no need to change occurrences of entry.length. Note that length is final, so its value cannot be changed.

# GOTCHA Assigning a Value to the Instance Variable Tength

Your program cannot assign a value to the instance variable length, as it is a final variable. For example, the following attempt to change the size of an array is invalid:

```
entry.length = 10; //Illegal!
```

In Listing 7.2 we have rewritten the program in Listing 7.1 using the instance variable length. We have also read the size of the array temperature from the user into the variable size. In this example, we could use size instead of temperature.length. However, since size is not final, its value can change and so might not always equal the value of temperature.length.

The array entry has a length of entry.length

# LISTING 7.2 An Array of Temperatures-Revised (part 1 of 2)

```
/**
Reads temperatures from the user and shows which are above
and which are below the average of all the temperatures.
* /
import java.util.Scanner;
public class ArrayOfTemperatures2
    public static void main(String[] args)
    {
        Scanner keyboard = new Scanner(System.in);
        System.out.println("How many temperatures do you have?");
        int size = keyboard.nextInt( );
        double[] temperature = new double[size];
        // Read temperatures and compute their average:
        System.out.println("Enter " + temperature.length +
                            " temperatures:");
        double sum = 0;
        for (int index = 0; index < temperature.length; index++)</pre>
        {
            temperature[index] = keyboard.nextDouble();
            sum = sum + temperature[index];
        }
        double average = sum / temperature.length;
        System.out.println("The average temperature is " +
                             average);
        // Display each temperature and its relation to the
        // average:
        System.out.println("The temperatures are");
        for (int index = 0; index < temperature.length; index++)</pre>
        {
             if (temperature[index] < average)</pre>
                 System.out.println(temperature[index] +
                                    " below average");
             else if (temperature[index] > average)
                 System.out.println(temperature[index] +
                                     " above average");
             else //temperature[index] == average
                 System.out.println(temperature[index] +
                                     " the average");
        System.out.println("Have a nice week.");
    }
}
```

# LISTING 7.2 An Array of Temperatures-Revised (part 2 of 2)

### Sample Screen Output

```
How many temperatures do you have?

3
Enter 3 temperatures:

32
26.5
27
The average temperature is 28.5
The temperatures are
32.0 above average
26.5 below average
27.0 below average
Have a nice week.
```

# **PROGRAMMING TIP** Use a for Loop to Step Through an Array

The for statement is the perfect mechanism for stepping through the elements of an array. For example, the following for loop from Listing 7.2 illustrates one way to step through an array:

```
for (int index = 0; index <temperature.length; index++)
{
   temperature[index] = keyboard.nextDouble();
   sum = sum + temperature[index];
}</pre>
```

Another way to step through an entire array—after its elements have been given values—uses the for-each statement that we introduced in Chapter 4. For example, the last loop in Listing 7.2 that displays the values in the array temperature can be revised as follows:

```
for (int value : temperature)
{
   if (value < average)
        System.out.println(value + " below average.");
   else if (value > average)
        System.out.println(value + " above average.");
   else //value == average
        System.out.println(value + " the average.");
}
```

# **More About Array Indices**

You know that the index of the first element in any Java array is 0. The last valid index of an array whose length is n is n-1. In particular, the last valid index of the array temperature is temperature.length - 1.

An easy mistake to make when programming with arrays is to use an indexed expression that evaluates to an invalid array index. For example, consider the following array declaration:

```
double[] entry = new double[5];
```

Every index value for the array entry must be one of the five integers 0, 1, 2, 3, or 4. For example, if your program contains the indexed variable entry [n + 2], the value of the index n + 2 must be one of these five integers. If an index expression evaluates to some integer other than 0 through one less than the length of the array, the index is said to be **out of bounds** or **invalid**. If your code uses an index expression that is out of bounds, your code will compile without any error message, but you will get one when you run your program.

Beware of invalid indices

#### **REMEMBER** Array Indices Must Be Within Bounds to Be Valid

Since the index of the first element in a Java array is always 0, the last index number is not the length of the array, but is one less than the length of the array. Be sure that your indices stay within this range.

One common way that array indices go out of bounds is when an array-processing loop is iterated one too many times. For example, let's consider a loop that fills an array. Suppose we want to read a sequence of nonnegative numbers from the keyboard, using a negative number as a sentinel value at the end of the data. We might use the following code:

```
System.out.println("Enter a list of nonnegative integers.");
System.out.println("Place a negative integer at the end.");
int[] list = new int[10];
Scanner keyboard = new Scanner(System.in);
int number = keyboard.nextInt();
int i = 0;
while (number >= 0)
{
    list[i] = number;
    i++;
    number = keyboard.nextInt();
}
```

If the user enters more numbers than can fit in the array, this code produces an array index that is out of bounds.

A better version of the preceding while loop is the following:

This while loop will end if the array becomes full, because we ensure that the index i is less than list.length.

### **GOTCHA** Secure Programming: Array Index Out of Bounds

An array index that is less than 0 or greater than or equal to the size of the array will cause an error message during program execution. This type of error can usually be avoided by carefully checking to ensure that array indices are within a valid range. Often, user input plays a role. Consider the following code which counts how many 0's, 1's, 2's, and 3's are entered by the user. The array index corresponds to the number entered by the user. The contents of the array contain how many times that number has been seen. For example, count[0] contains how many 0's have been entered, count[1] contains how many 1's have been entered, and so forth.

This program runs fine as long as the user enters numbers between 0 and 3. But if the user enters a number like 4 then the program will crash when trying to access count [4], which is beyond the size of the array. Input validation can address this problem by ensuring that only numbers between 0 and 3 are entered.

Suppose that you want to number the data stored in an array starting with 1. Perhaps your company's employees are numbered starting with 1. But Java always begins an array at index 0. One way to handle this situation is to have your code reconcile the array indices with the existing numbering scheme. For example, you might use code such as the following in a payroll program:

With this code, the employees are numbered 1 through 100, but their hours worked are stored in elements hours [0] through hours [99].

Situations like this one might confuse you, however, leading to mistakes in your program. Overall, the code will be easier to understand if the two numbering schemes match. You can achieve this by rewriting the previous code to increase the size of the array by 1 and ignore the element at index 0, as follows:

```
int[] hours = new int[NUMBER_OF_EMPLOYEES + 1];
Scanner keyboard = new Scanner(System.in);
System.out.println("Enter hours worked for each employee:");
for (int index = 1; index <hours.length; index++);
{
    System.out.println("Enter hours for employee" + index);
    hours[index] = keyboard.nextInt();
}</pre>
```

Ignoring the element at index 0

With this revised code, the employees are still numbered 1 through 100, but their hours worked are stored in the elements hours [1] through hours [100]. We do not use hours [0], and since the size of the array is 101 instead of 100, hours [100] is valid.

Note that the last valid value of index is hours.length - 1, as it was in our first version of this code. However, hours.length here is one larger than it was earlier. Replacing

```
index < hours.length
in the for statement with
index <= NUMBER OF EMPLOYEES</pre>
```

is likely to be clearer to most people. However, if other programmers are going to be looking at your code, they may be expecting a value to be stored

at index 0. The bottom line is that all programmers collaborating on a project should use the same coding practices or confusion and errors may result.

# PROGRAMMING TIP Don't Be Afraid to Waste an Element in an Array

In our previous example, we never use hours [0]. Yes, we "wasted" an array element, but we also made our code easier to write and to understand. As a result, we likely will make fewer mistakes. However, other programmers who may be working with your code should be aware of your coding practice. In Java, the amount of memory we wasted is not significant. Even if we create an array of large objects, Java stores only the addresses of the objects in the array. This might not be the case for other programming languages. For example, C++ would store the object itself, not its address, in the array. Wasting a location in a C++ array might be more significant than doing so in a Java program.

### PROGRAMMING TIP Get Used to Index Values That Are 0

The index of the first element in an array is 0. Java programmers know this. Unless your application gives you a good reason to adjust your code so that you can ignore this index, don't. The previous example showed an adjustment that aligns two numbering systems, reducing confusion and making errors less likely. However, adjusting your code to avoid using a 0 index should *not* be a routine practice.

# **Initializing Arrays**

An array can be initialized at the time that it is declared. To do this, you enclose the values for the individual indexed variables in braces and place them after the assignment operator, as in the following example:

```
double[] reading = {3.3, 15.8, 9.7};
```

The size of the array—that is, its length—is set to the minimum that will hold the given values. So this initializing declaration is equivalent to the following statements:

```
double[] reading = new double[3];
reading[0] = 3.3;
reading[1] = 15.8;
reading[2] = 9.7;
```

If you do not initialize the elements of an array, they might automatically be initialized to a default value for the base type. For example, if you do not initialize an array of integers, each element of the array will be initialized to 0. However, it is usually clearer to do your own explicit initialization. You can initialize an array either by using the braces, as we just described, by reading

Explicit initialization is safer than default initialization

values directly into array elements, or by assigning values, as we do in the following for loop:

```
int[] count = new int[100];
for (int i = 0; i < 100; i++)
    count[i] = 0;</pre>
```

### **SELF-TEST QUESTIONS**

1. What output will be produced by the following code?

```
int[] anArray = new int[10];
for (int i = 0; i <anArray.length; i++)
    anArray[i] = 2 * i;
for (int element : anArray)
    System.out.print(element + " ");
System.out.println();</pre>
```

2. What output will be produced by the following code?

3. What output will be produced by the following code?

```
double tide[] = {12.2, -7.3, 14.2, 11.3};
System.out.println("Tide 1 is " + tide[1]);
System.out.println("Tide 2 is " + tide[2]);
```

4. Consider the following array:

```
int[] a = new int[10];
```

What is the last index of a? What is the value of a.length?

5. What is wrong with the following code to initialize an array b?

```
int[] b = new int[10];
for (int i = 1; i <= b.length; i++)
    b[i] = 5 * i;</pre>
```

6. Write a complete Java program that reads 20 values of type double from the keyboard into an array. Display the last (20th) number read. Then display the numbers in the array and how much each number differs from the 20th number read. For example, if the last value typed by the user is 5.0, the difference between the array element 2.0 and 5.0 is −3.0. If an array element is 7.0, the difference is 2.0. Assume that the user enters 20 numbers, one per line, at the keyboard. You need not give elaborate instructions to the user.

### 7.2 ARRAYS IN CLASSES AND METHODS

A little more than kin, and less than kind.

-WILLIAM SHAKESPEARE, Hamlet

Arrays can be used as instance variables in classes. Methods can have an indexed variable or an entire array as an argument and can return an array. In short, arrays can be used with classes and methods just as other objects can. We begin with a case study that uses an array as an instance variable in a class.

# **CASE STUDY** Sales Report

The task's specification

In this case study, we will write a program to generate sales reports for a company's team of sales associates. The company wants to easily see which associate or associates have the highest sales and to know how the sales of each associate compare to the average.

Since we need to record a name and the sales figures for each associate, we can design a class for a single sales associate that holds these two data items. Our class can perform input and output and have a reasonable complement of accessor and mutator methods. This class definition is rather routine and is shown in Listing 7.3.

# LISTING 7.3 Sales Associate Class (part 1 of 2)

### LISTING 7.3 Sales Associate Class (part 2 of 2)

```
{
        name = newName;
        sales = newSales;
    public void readInput()
    {
        System.out.print("Enter name of sales associate: ");
        Scanner keyboard = new Scanner(System.in);
        name = keyboard.nextLine();
        System.out.print("Enter associate's sales: $");
        sales = keyboard.nextDouble();
    }
    public void writeOutput()
        System.out.println("Name: " + name);
        System.out.println("Sales: $" + sales);
    public String getName()
        return name;
    public double getSales()
        return sales;
}
```

Our program will need an array to keep track of the data for all sales associates. It will also need to record the highest sales and the average sales. Therefore, we will need to design another class. We can give our new class the following instance variables to record the desired data:

```
private double highestSales;
private double averageSales;
private SalesAssociate[] team;
```

The instance variables

We need to know the number of associates. This number will be the same as team.length, but having a separate well-named variable for the number of associates is a good idea. So let's include the following instance variable:

```
private int numberOfAssociates; //Same as team.length
```

The program's subtasks

The job of our program breaks down into these main subtasks:

- 1. Get ready.
- 2. Obtain the data.
- 3. Compute some statistics (update the instance variables).
- 4. Display the results.

We should name our new class and its methods. To organize our thoughts, we can draw the class diagram shown in Figure 7.3. Thus, we know that our class will look like this:

```
public class SalesReporter
{
    private double highestSales;
    private double averageSales;
    private SalesAssociate[] team;
    private int numberOfAssociates; //Same as team.length
    public static void main(String[] args)
    {
        SalesReporter clerk = new SalesReporter();
        clerk.getData();
        clerk.computeStats();
        clerk.displayResults();
    }
    <More stuff needs to be added here.>
}
```

All that remains is to write the three methods, getData, computeStats, and displayResults and to test and debug the program. We will tackle the three methods in order.

FIGURE 7.3 Class Diagram for the Class Sales Reporter

```
SalesReporter

- highestSales: double
- averageSales: double
- team: SalesAssociate[]
- numberOfAssociates: int

+ getData(): void
+ computeStats(): void
+ displayResults(): void
```

The input method getData is relatively straightforward, especially since we have an input method for objects of the class SalesAssociate. After we read the number of associates, we can write the following basic input loop:

The loop in getData

```
for (int i = 1; i <= numberOfAssociates; i++)
{
    System.out.println("Enter data for associate number" + i);
    team[i].readInput();
}</pre>
```

Although the array indices begin at 0, and the associates are numbered starting with 1, we have used team[i] for associate i. That is, we decided to ignore team[0]. Thus, we need to allocate an extra location in the array, as follows:

Associate i is in team[i]

```
team = new SalesAssociate[numberOfAssociates + 1];
```

Since we read numberOfAssociates in getData, we will place this statement in that method as well.

But another problem remains. When we test the previous loop, we will get an error message saying something about a "null pointer." This problem arises because the base type of the array team is a class type. To see the problem, consider another situation first. Suppose we had the following code:

```
SalesAssociate s;
s.readInput();
```

This code would produce the same error message regarding a "null pointer." The problem is that the variable s is just a name; it does not yet reference any object of the class SalesAssociate. The preceding code omitted the usual use of new. The code should be

```
SalesAssociate s = new SalesAssociate();
s.readInput();
```

The indexed variable team[i] is also a variable of a class type, and so it is also just a name. You need to assign a SalesAssociate object to team[i] before executing

```
team[i].readInput();
```

Thus, we need to add the following statement to our loop:

```
team[i] = new SalesAssociate();
```

The complete definition of the method getData with this line inserted is shown in Listing 7.4.

### LISTING 7.4 A Sales Report Program (part 1 of 3)

```
import java.util.Scanner;
                                             The main method is
                                             at the end of the class.
Program to generate sales report.
public class SalesReporter
    private double highestSales;
    private double averageSales;
    private SalesAssociate[] team;
                                      //The array object is
                                      //created in getData.
    private int numberOfAssociates; //Same as team.length
    / * *
    Reads the number of sales associates and data for each one.
    public void getData()
    {
        Scanner keyboard = new Scanner(System.in);
        System.out.println("Enter number of sales associates:");
        numberOfAssociates = keyboard.nextInt();
        team = new SalesAssociate[numberOfAssociates + 1];
        for (int i = 1; i <= numberOfAssociates; i++) Array object
        {
                                                           created here
            team[i] = new SalesAssociate();
            System.out.println("Enter data for associate " + i);
            team[i].readInput();
            System.out.println();
                                                     SalesAssociate
        }
                                                     objects created here
   }
     Computes the average and highest sales figures.
    Precondition: There is at least one salesAssociate.
    public void computeStats()
    {
        double nextSales = team[1].getSales();
        highestSales = nextSales;
        double sum = nextSales;
        for (int i = 2; i <= numberOfAssociates; i++)</pre>
                                                    Already processed
            nextSales = team[i].getSales();
                                                    team[1], so the loop
            sum = sum + nextSales;
                                                    starts with team[2]
            if (nextSales > highestSales)
            highestSales = nextSales; //highest sales so far.
        averageSales = sum / numberOfAssociates;
    }
                                                           (continued)
```

### LISTING 7.4 A Sales Report Program (part 2 of 3)

/ \* \*

```
Displays sales report on the screen.
    public void displayResults()
    {
        System.out.println("Average sales per associate is $" +
                             averageSales);
        System.out.println("The highest sales figure is $" +
                             highestSales);
        System.out.println();
        System.out.println("The following had the highest sales:");
        for (int i = 1; i <= numberOfAssociates; i++)</pre>
        {
            double nextSales = team[i].getSales();
            if (nextSales == highestSales)
            {
                team[i].writeOutput();
                System.out.println("$" + (nextSales - averageSales)
                                   + " above the average.");
                System.out.println();
            }
        }
        System.out.println("The rest performed as follows:");
        for (int i = 1; i <= numberOfAssociates; i++)</pre>
        {
            double nextSales = team[i].getSales();
            if (team[i].getSales() != highestSales)
            {
                team[i].writeOutput();
                if (nextSales >= averageSales)
                    System.out.println("$" + (nextSales -
                           averageSales) + " above the average.");
                else
                    System.out.println("$" + (averageSales -
                              nextSales) + " below the average.");
                System.out.println();
            }
        }
    }
    public static void main(String[] args)
    {
        SalesReporter clerk = new SalesReporter();
        clerk.getData();
        clerk.computeStats();
        clerk.displayResults();
    }
}
                                                          (continued)
```

### LISTING 7.4 A Sales Report Program (part 3 of 3)

### Sample Screen Output

```
Enter number of sales associates:
Enter data for associate number 1
Enter name of sales associate: Dusty Rhodes
Enter associate's sales: $36000
Enter data for associate number 2
Enter name of sales associate: Natalie Dressed
Enter associate's sales: $50000
Enter data for associate number 3
Enter name of sales associate: Sandy Hair
Enter associate's sales: $10000
Average sales per associate is $32000.0
The highest sales figure is $50000.0
The following had the highest sales:
Name: Natalie Dressed
Sales: $50000.0
$18000.0 above the average.
The rest performed as follows:
Name: Dusty Rhodes
Sales: $36000.0
$4000.0 above the average.
Name: Sandy Hair
Sales: $10000.0
$22000.0 below the average.
```

Next we turn our attention to the method computeStats and come up with the following code:

A draft of the loop in computeStats

This loop is basically OK, but the variables sum and highest must be initialized before the loop begins. We can initialize sum to 0, but what value do we use to initialize highest? Perhaps a negative number, since sales cannot be negative. Or can they? If a customer returns goods that is considered a negative sale, so sales can indeed be negative. However, we know that the company always has

A revised loop in computeStats

at least one sales associate, and so we can initialize both sum and highest to the sales for the first associate. This takes one case outside the loop and places it before the loop, as follows:

The preceding loop will work, but notice the repeated calculation. We have three identical method invocations of team[i].getSales(). To avoid this duplication, we can store the result of one such invocation in a variable as follows:

```
double nextSales = team[1].getSales();
highestSales = nextSales;
double sum = nextSales;
for (int i = 2; i <= numberOfAssociates; i++)
{
    nextSales = team[i].getSales();
    sum = sum + nextSales;
    if (nextSales> highest)
        highest = nextSales; //highest sales so far.
}
average = sum / numberOfAssociates;
```

The final loop in computeStats

The complete definition of the method computeStats is given in Listing 7.4.

The design of the last method, displayResults, uses only techniques that you have already seen, and so we will not go over the details. Its definition is shown in Listing 7.4.



# **GOTCHA** Creating an Array of Objects Doesn't Create Instances of the Objects

When you create an array of objects Java does not create instances of any of the objects! For example, consider the code:

```
SalesAssociate[] team = new SalesAssociate[10];
```

An array is created that holds ten references. In other words, there are ten addresses to memory locations that can store SalesAssociate objects. However, Java only creates the array; it doesn't create any SalesAssociate objects. Java uses the special value null to mark empty references. Before we

try to access the array we must reference an object. The following code sets references for entries at index 0 and 1 to new objects but entries from index 2 to 9 are still null:

```
team[0] = new SalesAssociate("Jane Doe", 5000);
team[1] = new SalesAssociate("John Doe", 5000);
```

We can now access team[0].getName() or team[1].getSalary().

### **SELF-TEST QUESTIONS**

- 7. Write some Java code that will declare an array named entry that has length 3, has SalesAssociate (Listing 7.3) as its base type, and is filled with three identical records. The records use the name "Jane Doe" and sales of \$5000. Use a for loop.
- 8. Rewrite the method displayResults of the program SalesReporter (Listing 7.4) so that it uses the methods in the class DollarFormat (Listing 6.14 of Chapter 6) to display the dollar amounts in the correct format for dollars and cents.

# **Indexed Variables as Method Arguments**

An indexed variable for an array a, such as a[i], can be used anywhere that you can use any other variable of the base type of the array. So an indexed variable can be an argument to a method in exactly the same way that any other variable of the array's base type can be an argument.

For example, the program in Listing 7.5 illustrates the use of an indexed variable as an argument to a method. The method getAverage takes two arguments of type int. The array nextScore has the base type int, and so the program can use nextScore[i] as an argument to the method getAverage, as in the following line from that program:

```
double possibleAverage = getAverage(firstScore,nextScore[i]);
```

The variable firstScore is an ordinary variable of type int. To help drive home the point that the indexed variable nextScore[i] can be used just like any other variable of type int, note that getAverage would behave in exactly the same way if we interchanged its two arguments, as follows:

```
double possibleAverage = getAverage(nextScore[i],firstScore);
```

The definition of the method getAverage contains no indication that its arguments can be indexed variables for an array of int. The method accepts arguments of type int, and neither parameter knows nor cares whether those ints came from an indexed variable, a regular int variable, or a constant value.

An indexed variable can be an argument

The value of the index affects the value of the argument

### LISTING 7.5 Indexed Variables as Arguments

```
import java.util.Scanner;
/**
A demonstration of using indexed variables as arguments.
public class ArgumentDemo
{
    public static void main(String[] args)
        Scanner keyboard = new Scanner(System.in);
        System.out.println("Enter your score on exam 1:");
        int firstScore = keyboard.nextInt();
        int[] nextScore = new int[3];
        for (int i = 0; i < nextScore.length; i++)</pre>
            nextScore[i] = firstScore + 5 * i;
        for (int i = 0; i < nextScore.length; i++)</pre>
        {
            double possibleAverage =
                             getAverage(firstScore, nextScore[i]);
            System.out.println("If your score on exam 2 is " +
                                 nextScore[i]);
            System.out.println("your average will be " +
                                 possibleAverage);
    }
    public static double getAverage(int n1, int n2)
        return (n1 + n2) / 2.0;
}
```

### Sample Screen Output

```
Enter your score on exam 1:
80

If your score on exam 2 is 80
your average will be 80.0

If your score on exam 2 is 85
your average will be 82.5

If your score on exam 2 is 90
your average will be 85.0
```

There is one subtlety that applies to indexed variables when used as method arguments. For example, consider either of the previous method calls. If the value of i is 2, the argument is nextScore[2]. On the other hand, if the value of i is 0, the argument is nextScore[0]. The expression used as an index is evaluated to determine exactly which indexed variable is the argument.

Be sure to note that an indexed variable of an array a, such as a[i], is a variable of the base type of the array. When a[i] is used as an argument to a method, it is handled in exactly the same way as any other variable of the base type of the array a. In particular, if the base type of the array is a primitive type, such as int, double, or char, the method cannot change the value of a[i]. On the other hand, if the base type of the array is a class type, the method can change the *state* of the object named by a[i]. This is nothing new. Just remember that an indexed variable, such as a[i], is a variable of the base type of the array and is handled just like any other variable of that data type.

# **RECAP** Indexed Variables as Arguments

An indexed variable can be used as an argument anywhere that a variable of the array's base type can be used. For example, suppose you have

```
double[] a = new double[10];
```

Indexed variables such as a[3] and a[index] can then be used as arguments to any method that accepts a value as an argument.

# FAQ When can a method change an argument that is an indexed variable?

Suppose a[i] is an indexed variable of the array a and a[i] is used as an argument in a method invocation such as

```
doStuff(a[i]);
```

Whether the method doStuff can change the array element a[i] depends on the base type of the array a. If the base type of the array a is a primitive type, such as int, double or char, the method doStuff receives the *value* of a[i], and so cannot change a[i] itself, However, if the base type of the array a is a class, the method dostuff receives a reference to a[i]. Thus, the method can change the *state* of the object named by a[i], but cannot replace the object with another one. (To review the details on method arguments, see Chapter 5.)

# Entire Arrays as Arguments to a Method

You have already seen that an indexed variable of an array can be used as an argument to a method. An entire array can also be used as an argument to a method. The way you specify an array parameter in a method definition is similar to the way you declare an array. For example, the following method incrementArrayBy2 will accept as its one argument any array whose base type is double:

When you specify an array parameter, you give the base type of the array, but you do not fix the length of the array.

To illustrate the use of this sample class, suppose you have the statements

```
double[] a = new double[10];
double[] b = new double[30];
```

within some method definition, and suppose that the elements of the arrays a and b have been given values. Both of the following method invocations are then valid:

```
SampleClass.incrementArrayBy2(a);
SampleClass.incrementArrayBy2(b);
```

# ASIDE Alternative Syntax for Array Parameters

There is an alternative syntax for array parameters, similar to the alternative syntax for declaring an array. You can write the square brackets after the parameter instead of after the base type, as in the following example:

```
public static void showArray
(char a[])
```

We do not encourage the use of this alternative syntax, however.

The method incrementArrayBy2 can take an array of any length as its argument and can change the values of the elements in the array. Following the previous invocations of the method, the elements in the arrays a and b have each been increased by 2.

A method can change the values of the elements in its array argument

### **RECAP Array Parameters**

An argument to a method may be an entire array. You use the following syntax for the method's heading:

### **SYNTAX**

```
public static Return_Type Method_Name(Base_Type[] Param_Name)
You can use other modifiers instead of public and static.
```

(continued)

### **EXAMPLES**

```
public static int getOneElement(char[] anArray, int index)
public void readArray(int[] anotherArray)
```

### **REMEMBER** Array Parameters Do Not Specify the Array Length

An array parameter in a method's heading specifies the base type of the array, but not the length of the array. For example, the following method heading specifies an array of characters as a parameter:

```
public static void showArray(char[] a)
```

## **REMEMBER Characteristics of Array Arguments**

- No square brackets are written when you pass an entire array as an argument to a method.
- An array of any length can be the argument corresponding to an array parameter.
- A method can change the values in an array argument.
   Each of these points is demonstrated by the preceding method

# Arguments for the Method main

incrementArrayBy2.

The heading for the main method of a program is as follows:

```
public static void main(String[] args)
```

The parameter declaration String[] args indicates that args is an array whose base type is String. That is, the method main takes an array of String values as an argument. But we never have given main an argument when we ran any of our programs. In fact, we have never invoked main! What's the story?

As you know, an invocation of main is a very special sort of invocation that we do not make. When you run your program, main is invoked automatically and given a default array of strings as a default argument. But you can, if you like, provide additional strings when you run a program, and those strings will automatically be made elements of the array args that is provided to main as

an argument. Normally, you do this by running the program from the command line of the operating system, like so:

```
java TestProgram Sally Smith
```

This command sets args[0] to "Sally" and args[1] to "Smith". These two indexed variables can then be used within the method main.

For example, consider the following sample program:

```
public class TestProgram
{
    public static void main(String[] args)
    {
        System.out.println("Hello" + args[0] + " " + args[1]);
    }
}
```

After running TestProgram using the one-line command

```
java TestProgram Josephine Student
```

the output produced by the program will be

```
Hello Josephine Student
```

Be sure to note that the argument to main is an array of *strings*. If you want numbers, you must convert the string representations of the numbers to values of one or more number types. For example, to convert the first argument to an integer, you could use Integer.parseInt(args[0]). Since the identifier args is a parameter, you can use any other valid identifier in place of args, as long as you change any occurrences of args that also occur in the body of main. However, it is traditional to use the identifier args for this parameter.

You can pass an array of strings to main as an argument

# Array Assignment and Equality

Arrays are objects, and so the assignment operator = and the equality operator == behave (and misbehave) in the same way with arrays as they do with the kinds of objects we saw before discussing arrays. To understand how this applies to arrays, you need to know a little bit about how arrays are stored in the computer's main memory. The important point for this discussion is that the entire array contents—that is, the contents of all of the indexed variables—are stored together in one, possibly large, section of memory. In this way, the location of the entire array contents can be specified by one memory address.

Recall that a variable for an object really contains the memory address of the object. The assignment operator copies this memory address. For example, consider the following code:

```
int[] a = new int[3];
int[] b = new int[3];
for (int i = 0; i <a.length; i++)
    a[i] = i;</pre>
```

```
b = a;

System.out.println("a[2] = " + a[2] + ", b[2] = " + b[2]);

a[2] = 2001;

System.out.println("a[2] = " + a[2] + ", b[2] = " + b[2]);
```

This will produce the following output:

```
a[2] = 2, b[2] = 2
a[2] = 2001, b[2] = 2001
```

The assignment b = a in the preceding code gives the array variable b the same memory address as the array variable a. So a and b are two different names for the same array. Thus, when we change the value of a[2], we are also changing the value of b[2]. For this reason, it is best simply not to use the assignment operator = with arrays. If you want the arrays a and b in the preceding code to be different arrays having the same values, you must write something like the following:

Assigning one array to another results in one array having two names

```
for (int i = 0; i < a.length; i++)
  b[i] = a[i];</pre>
```

instead of the assignment statement

```
b = a;
```

Note that the preceding loop assumes that the arrays a and b have the same length.

The equality operator = = tests whether two arrays are stored in the same place in the computer's memory. For example, the code

```
int[] a = new int[3];
int[] b = new int[3];
for (int i = 0; i < a.length; i++)
    a[i] = i;
for (int i = 0; i < b.length; i++)
    b[i] = i;
if (b == a)
    System.out.println("Equal by ==");
else
    System.out.println("Not equal by ==");</pre>
```

The operator == tests whether two arrays are at the same place in memory

produces the output

```
Not equal by ==
```

Even though the arrays contain the same integers in the same order, the arrays are stored in different places in memory. So b == a is false, since == tests for equal memory addresses.

If you want to test whether two arrays contain the same elements, you must test whether each element in one array equals the corresponding element in the other array. Listing 7.6 contains a small demonstration class that shows one possible way to do this.

## LISTING 7.6 Two Kinds of Equality (part 1 of 2)

```
/ * *
A demonstration program to test two arrays for equality.
*/
public class TestEquals
    public static void main(String[] args)
        int[] a = new int[3];
                                                  The arrays a and b
        int[] b = new int[3];
                                                  contain the same integers
        setArray(a);
                                                  in the same order.
        setArray(b);0
        if (b == a)
            System.out.println("Equal by ==.");
        else
            System.out.println("Not equal by ==.");
        if (equals(b, a))
            System.out.println("Equal by the equals method.");
        else
            System.out.println("Not equal by the equals method.");
    }
    public static boolean equals(int[] a, int[] b)
        boolean elementsMatch = true;//tentatively
        if (a.length != b.length)
            elementsMatch = false;
        else
        {
            int i = 0;
            while (elementsMatch && (i < a.length))</pre>
                 if (a[i] != b[i])
                     elementsMatch = false;
                 i++;
            }
        }
        return elementsMatch;
    }
    public static void setArray(int[] array)
        for (int i = 0; i < array.length; i++)</pre>
             array[i] = i;
    }
}
```

## LISTING 7.6 Two Kinds of Equality (part 2 of 2)

## Screen Output

```
Not equal by ==.
Equal by the equals method.
```

# **GOTCHA** Using the Operators = and == with Arrays

You can use the assignment operator = to give an array more than one name. You cannot use it to copy the contents of one array to another, different array. Likewise, the equality operator == tests whether two array names reference the same memory address. It does not test whether two different arrays contain the same values.

# **REMEMBER** Array Types Are Reference Types

A variable of an array type holds only the address where the array is stored in memory. This memory address is called a reference to the array object in memory. For this reason, array types are often called reference types. Recall from Chapter 5 that a reference type is any type whose variables hold references—that is, memory addresses—as opposed to the actual item named by the variable. Array types and class types are both reference types. Primitive types are not reference types.

## FAQ Are arrays really objects?

Arrays do not belong to any class. Some other features of class objects—such as inheritance, which we will discuss in Chapter 8—do not apply to arrays. So whether arrays should be considered objects is not 100 percent clear. However, that is primarily an academic debate. In Java, arrays are officially objects. Whenever Java documentation says that something applies to all objects, it also applies to arrays.

# **Methods That Return Arrays**

A Java method may return an array. To have it do so, you specify the method's return type in the same way that you specify the type of an array parameter. For example, Listing 7.7 contains a revised version of the program in Listing 7.5. Both programs perform pretty much the same computations, but this new version computes the various possible average scores within a method named

### LISTING 7.7 A Method That Returns an Array

```
import java.util.Scanner;
/**
A demonstration of a method that returns an array.
public class ReturnArrayDemo
    public static void main(String[] args)
    {
        Scanner keyboard = new Scanner(System.in);
        System.out.println("Enter your score on exam 1:");
        int firstScore = keyboard.nextInt();
        int[] nextScore = new int[3];
        for (int i = 0; i < nextScore.length; i++)</pre>
             nextScore[i] = firstScore + 5 * i;
        double[] averageScore =
                  getArrayOfAverages(firstScore, nextScore);
        for (int i = 0; i < nextScore.length; i++)</pre>
            System.out.println("If your score on exam 2 is " +
                                 nextScore[i]);
            System.out.println("your average will be " +
                                 averageScore[i]);
        }
    }
    public static double[] getArrayOfAverages(int firstScore,
                                                int[] nextScore)
        double[] temp = new double[nextScore.length];
        for (int i = 0; i < temp.length; i++)
            temp[i] = getAverage(firstScore, nextScore[i]);
        return temp;
    }
    public static double getAverage(int n1, int n2)
        return (n1 + n2) / 2.0;
                                            The sample screen output is
    }
                                            the same as in Listing 7.5.
}
```

getArrayofAverages. This new method returns these average scores as an array. The method does so by creating a new array and then returning it, using the following steps:

```
double temp = new double[nextScore.length];
<Fill the array temp.>
return temp;
```

## **RECAP** Returning an Array

A method can return an array in basically the same way that it returns a value of another type.

### **SYNTAX**

```
public static Base_Type[] Method_Name(Parameter_List)
{
    Base_Type[] temp = new Base_Type[Array_Size];
    Statements_To_Fill_Array
    return temp;
}
```

The method need not be static and need not be public. The following are some of the other acceptable method headings:

```
public Base_Type[] Method_Name(Parameter_List)
private static Base_Type[] Method_Name(Parameter_List)
private Base_Type[] Method_Name(Parameter_List)
```

### **EXAMPLE**

```
public static char[] getVowels()
{
    char[] newArray = {'a', 'e', 'i', 'o', 'u'};
    return newArray;
}
```

## **RECAP** The Name of an Array's Data Type

The data-type name for an array is always of the form

```
Base_Type[]
```

This is true when declaring an array variable, specifying the type of an array parameter, or specifying that a method returns an array.

### **EXAMPLES**

```
int[] counter = new int[10];
Species[] ghost = new Species[20];
public static double[] halfAll(int[] arrayToBeHalved);
{
    . . . .
```



# **GOTCHA** Privacy Leaks with Arrays

A private instance variable that has an array type can be modified outside of its class, if a public method in the class returns the array. This is the same problem we discussed in the previous chapter, and it has analogous solutions.



# **SELF-TEST QUESTIONS**

9. What output will be produced by the following code?

```
char[] a = new char[3];
for (int i = 0; i <a.length; i++)
        c[i] = 'a';
char[] b = a;
System.out.println("a[1] = " + a[1] + ", b[1] = " + b[1]);
System.out.println("a[2] = " + a[2] + ", b[2] = " + b[2]);
b[2] = 'b';
System.out.println("a[1] = " + a[1] + ", b[1] = " + b[1]);
System.out.println("a[2] = " + a[2] + ", b[2] = " + b[2]);</pre>
```

- 10. Give the definition of a static method called showArray that has an array of base type char as a single parameter and that writes one line of text to the screen consisting of the characters in the array argument written in order.
- 11. Give the definition of a static method called getArrayOfHalves that has an array of base type double as a single parameter and that returns another array whose base type and length are the same as those of the parameter, but whose elements have each been divided by 2.0.
- 12. The following method compiles and executes but does not work as you might hope. What is wrong with it?

```
/** Copies an array. */
public static int[] copyArray(int[] anArray)
{
    int[] temp = new int[anArray.length];
    temp = anArray;
    return temp;
}
```

13. The following method compiles and executes but does not work as you might hope. What is wrong with it?

```
/** Doubles the size of an array. */
public static void doubleSize(int[] a)
{
    a = new int[a.length * 2];
}
```

14. Suppose that we add the following method to the class SalesReporter in Listing 7.4 so that a program using this class can access the sales associates:

```
/** Returns an array of SalesAssociate objects. */
public SalesAssociate[] getSalesTeam()
{
    return team;
}
```

Will this method compile and execute as indicated? Is adding this method to the class SalesReporter a good idea?

# 7.3 PROGRAMMING WITH ARRAYS AND CLASSES

The Moving Finger writes; and, having writ, Moves on; nor all your Piety nor Wit Shall lure it back to cancel half a Line. Nor all your tears wash out a word of it.

—OMAR KHAYYAM, The Ruba'iyat (Fitzgerald Translation)

In this section, we present some additional techniques for working with arrays. In particular, we discuss using an array variable as an instance variable in a class. We begin with a programming example that illustrates some basic techniques.

# PROGRAMMING EXAMPLE

# **A Specialized List Class**

One way to use an array for a special purpose is to make the array an instance variable of a class. The array is accessed only through the class methods, and so you can add any checks and automatic processing that you want. This allows you to define classes whose objects are something like special-purpose arrays. In this programming example, we present an example of one such class.

We will define a class whose objects can be used for keeping lists of items, such as a grocery list or a list of things to do. The class will have the rather long name OneWayNoRepeatsList.<sup>1</sup>

<sup>&</sup>lt;sup>1</sup> Long names are traditional in Java, but we did not choose a long name just to be traditional. All the short names, like *Collection* and *List*, already have a meaning in Java, and it could be confusing to use these short names for something other than their usual meaning.

The class OneWayNoRepeatsList will have a method for adding items to the list. An item on the list is a string, which in an application would say whatever you want the item to say, such as "Buy milk." This class has no method to change a single item or delete an item from the list. It does, however, have a method that lets you erase the entire list and start over again with a blank list. Each object of the class OneWayNoRepeatsList has a maximum number of items it can hold. At any time, the list might contain anywhere from zero to the maximum number of items.

A class of lists of strings

An object of the class OneWayNoRepeatsList has an array of strings as an instance variable. This array holds the items on the list. However, you do not access the array directly. Instead, you use accessor and mutator methods. You can use int variables to hold numbers that indicate positions in the list. One of these int variables is the same thing as an index, but the positions are numbered starting with 1 rather than 0. For example, a method named getEntryAt lets you recover the item at a given position. If toDoList is an object of the class OneWayNoRepeatsList, the following statement sets the string variable next to the entry at the second position:

An array of strings as an instance variable

String next = toDoList.getEntryAt(2);

Other methods add an entry to the end of the list or erase the entire list. These are the only ways that the list can be changed. You cannot change or delete a particular entry on the list, and you cannot add an entry anywhere other than at the end of the list.

Access to the strings in a list is only via methods

In Chapter 5 we discussed encapsulation. The class OneWayNoRepeatsList is a good example of a well-encapsulated class, since it hides its details from the programmer who uses it. But clearly, the programmer needs to know how to use the class. So it makes sense to tell you how to use this class before we give the definition.

Listing 7.8 contains a program that demonstrates how to use some of the methods for the class OneWayNoRepeatsList. Notice that the constructor takes an integer argument. This integer specifies the maximum number of entries that can be placed on the list. The number is small for our demonstration.

The method addItem adds a string to the end of the list. For example, the following adds the string named by the variable next to the end of the list toDoList:

toDoList.addItem(next);

If you look at the sample output in Listing 7.8, you will see that Buy milk is added to the list twice, but that it appears on the list only once. If the item being added is already on the list, the method addItem has no effect. That way the list has no repeats.

You can use an int variable to step through the list from beginning to end. The technique is illustrated at the end of Listing 7.8. You begin by initializing an int variable to the first position on the list, as follows:

int position = toDoList.START\_POSITION;

Stepping through a list

# LISTING 7.8 Using the Class OneWayNoRepeatsList (part 1 of 2)

```
import java.util.Scanner;
public class ListDemo
    public static final int MAX_SIZE = 3; //Assumed > 0
    public static void main(String[] args)
    {
        OneWayNoRepeatsList toDoList =
                                new OneWayNoRepeatsList(MAX_SIZE);
        System.out.println(
                    "Enter items for the list, when prompted.");
        boolean moreEntries = true;
        String next = null;
        Scanner keyboard = new Scanner(System.in);
        while (moreEntries && !toDoList.isFull())
        {
            System.out.println("Enter an item:");
            next = keyboard.nextLine();
            toDoList.addItem(next);
            if (toDoList.isFull())
                 System.out.println("List is now full.");
            }
            else
            {
                 System.out.print("More items for the list? ");
                 String ans = keyboard.nextLine();
                 if (ans.trim().equalsIgnoreCase("no"))
                     moreEntries = false; //User says no more
            }
        }
        System.out.println("The list contains:");
        int position = toDoList.START_POSITION;
        next = toDoList.getEntryAt(position);
        while (next != null) //null indicates end of list
            System.out.println(next);
            position++;
            next = toDoList.getEntryAt(position);
        }
    }
}
                                                        (continued)
```

# LISTING 7.8 Using the Class OneWayNoRepeatsList (part 2 of 2)

### Sample Screen Output

```
Enter items for the list, when prompted.
Enter an item:
Buy milk
More items for the list? yes
Enter an item:
Walk dog
More items for the list? yes
Enter an item:
Buv milk
More items for the list? yes
Enter an item:
Write program
The list is now full.
The list contains:
Buy milk
Walk dog
Write program
```

The named constant toDoList.START\_POSITION is simply another name for 1, but we use it because we are thinking of this as the start of the list, not as the number 1.You can invoke the method getEntryAt to retrieve the item at a given position in the list. For example, the following sets the string variable next equal to the string at the position given by the variable position:

```
next = toDoList.getEntryAt(position);
```

To obtain the next item on the list, the program simply increments the value of position. The following code, taken from Listing 7.8, illustrates stepping through the list:

```
int position = toDoList.START_POSITION;
next = toDoList.getEntryAt(position);
while (next != null)
{
    System.out.println(next);
    position++;
    next = toDoList.getEntryAt(position);
}
```

Once the value of position is incremented beyond the last position in the list, no entry will be at position. So we need some way to conveniently indicate

null signals the list's end

Garbage values occur after the last entry in the list

that the end of the list has been reached. Otherwise, we might access some "garbage" value in the unused portion of the array. To take care of this problem, we will make getEntryAt return the value null when there is no entry at the given position. Note that null is different from any real string, and so it will not appear on any list. Thus, your program can test for the end of the list by checking for the value null. Recall that to test for equality or inequality with null, you use == or !=; you do not use an equals method.

The complete definition of the class OneWayNoRepeatsList is given in Listing 7.9. The entries on a list are kept in the instance variable entry, which is an array of base type String. Thus, the maximum number of entries that the list can hold is entry.length. However, the list normally will not be full, and so will contain fewer than entry.length entries. To keep track of how much of the array entry is currently used, the class has an instance variable called countOfEntries. The entries themselves are kept in the indexed variables entry[0], entry[1], entry[2], and so on through entry[countOfEntries - 1]. The values of the elements whose indices are countOfEntries or higher are just garbage values and do not represent entries on the list. Thus, when you want to step through the items on the list, you stop after entry[countOfEntries - 1].

For example, the definition of the method isOnList has a while loop that steps through the array, checking to see whether the argument is equal to any of the entries on the list:

The loop in the method isOnList

```
while ((!found) && (i <countOfEntries))
{
    if (item.equalsIgnoreCase(entry[i]))
        found = true;
else
    i++;
}</pre>
```

The code checks only array elements whose indices are less than countOfEntries. It does not check the rest of the array, because those array entries are not on the list.

The complete class OneWayNoRepeatsList has a few more methods than those we used in the demonstration program in Listing 7.8. These extra methods make the class more useful for a wider variety of applications.

Note that although the array entry has indices starting with 0, if we use an int variable as a position marker—such as the variable position in Listing 7.9—the numbering starts at 1, not 0. The class methods automatically adjust the indices, so when you want the item at location position, you get entry[position-1]. We could, of course, have compensated for the difference between array indices and list positions by allocating an extra element in the array entry and ignoring entry[0], as we suggested earlier near the end of the section entitled "More About Array Indices." Exercise 14 at the end of the previous section asks you to do just that.

Positions of entries on a list begin at 1, but in an array, they begin at 0

# LISTING 7.9 An Array Wrapped in a Class to Represent a List (part 1 of 3)

```
/**
An object of this class is a special kind of list of strings. You
can write the list only from beginning to end. You can add only
to the end of the list. You cannot change individual entries, but
you can erase the entire list and start over. No entry may appear
more than once on the list. You can use int variables as position
markers into the list. Position markers are similar to array
indices, but are numbered starting with 1.
public class OneWayNoRepeatsList
     public static int START_POSITION = 1;
     public static int DEFAULT_SIZE = 50;
     //entry.length is the total number of items you have room
    //for on the list (its capacity); countOfEntries is the number of
     //items currently on the list.
     private int countOfEntries; //can be less than entry.length.
     private String[] entry;
     /**
      Creates an empty list with a given capacity.
     public OneWayNoRepeatsList(int maximumNumberOfEntries)
        entry = new String[maximumNumberOfEntries];
        countOfEntries = 0;
     }
     /**
     Creates an empty list with a capacity of DEFAULT_SIZE.
    * /
     public OneWayNoRepeatsList()
        entry = new String[DEFAULT_SIZE];
        countOfEntries = 0;
     // or replace these two statements with this(DEFAULT_SIZE);
     public boolean isFull()
        return countOfEntries == entry.length;
     public boolean isEmpty()
        return countOfEntries == 0;
```

# LISTING 7.9 An Array Wrapped in a Class to Represent a List (part 2 of 3)

```
/**
Precondition: List is not full.
Postcondition: If item was not on the list.
it has been added to the list.
* /
public void addItem(String item)
   if (!isOnList(item))
   {
       if (countOfEntries == entry.length)
           System.out.println("Adding to a full list!");
           System.exit(0);
       }
       else
       {
           entry[countOfEntries] = item;
           countOfEntries++;
   } //else do nothing. Item is already on the list.
}
If the argument indicates a position on the list,
the entry at that specified position is returned;
otherwise, null is returned.
public String getEntryAt(int position)
{
   String result = null;
   if ((1 <= position) && (position <= countOfEntries))</pre>
       result = entry[position - 1];
   return result:
}
Returns true if position indicates the last item
on the list; otherwise, returns false.
public boolean atLastEntry(int position)
   return position == countOfEntries;
}
```

# LISTING 7.9 An Array Wrapped in a Class to Represent a List (part 3 of 3)

```
/**
    Returns true if item is on the list;
    otherwise, returns false. Does not differentiate
    between uppercase and lowercase letters.
    public boolean isOnList(String item)
        boolean found = false;
        int i = 0:
        while (!found && (i < countOfEntries))</pre>
            if (item.equalsIgnoreCase(entry[i]))
                found = true;
            else i++;
        }
            return found;
    }
    public int getMaximumNumberOfEntries()
        return entry.length;
    public int getNumberOfEntries()
    {
        return countOfEntries;
    public void eraseList()
       countOfEntries = 0;
    }
}
```

Note that the class OneWayNoRepeatsList provides three ways to detect the end of a list, assuming you use an int variable position to access entries in the list:

- If position equals getNumberOfEntries(), position is at the last entry.
- If atLastEntry (position) returns true, position is at the last entry.
- If getEntryAt (position) returns null, position is beyond the last entry.

We end this programming example with a mention that the Java Class Library contains the class ArrayList that you can use to create lists that are more general and flexible than the list we used here. Like our class, ArrayList uses an array to represent the list. Chapter 12 will introduce you to this class, but if you like, you can skip ahead and read about it now.

Ways to detect the end of a list

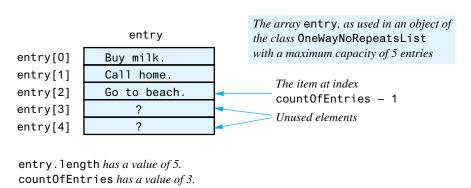
# **SELF-TEST QUESTIONS**

- 15. Replace the last loop in Listing 7.8 with a for loop that uses the number of entries in the list.
- 16. Replace the last loop in Listing 7.8 with a loop that uses the method atLastEntry.

# **Partially Filled Arrays**

An array can have fewer meaningful entries than its capacity The array entry in the class OneWayNoRepeatsList in Listing 7.9 contains the entries on a list. When the list is not vet full, entry is a partially filled array. In some situations, such as this one, we need some but not all of the indexed variables in an array. In these cases, we must keep track of how much of the array has been used so that we know how much of it is available. Normally, we can use an int variable to count the items in the array. For example, the class OneWayNoRepeatsList in Listing 7.9 uses the instance variable countOfEntries for this purpose. In particular, countOfEntries implies that the list contains the array elements whose indices are 0 through countOfEntries - 1, as Figure 7.4 illustrates. It is very important to keep track of how much of the array is currently being used, because the other array entries contain irrelevant values. When accessing a partially filled array, you want to access only those elements in the array that contain meaningful values. You want to ignore the rest of the array. Of course, as you add or delete entries from a partially filled array, the borderline between meaningful values and irrelevant values can move, and this movement must be recorded by changing the value of a suitable int variable, such as countOfEntries.

# FIGURE 7.4 A Partially Filled Array



Typically, the meaningful part of an array begins at the beginning of the array, but this is not an absolute requirement. When you want to consider a portion of an array that does not begin at the index 0, you can define two int variables—such as first and last—to record the indices of the first and last elements, respectively, of the range of elements that you want to consider. These variables might be either instance variables or parameters to a method. For example, we could define a static method having the following heading:

# REMEMBER The Number of Entries in an Array Versus the Array's Length

Distinguish between the number of entries that you use in an array and the array's capacity. The capacity of an array a is a .1 ength . This is the number of array elements that are created for you when you define the array. You might not use all of these elements. In this case, you need to keep track of how many you have used. Typically, you will have two integers: One is the capacity of the array, and one is the number of elements you have used.



## **SELF-TEST OUESTIONS**

- 17. Suppose a is an array of values of type double. Write some code to display all the elements in a on the screen, one element per line.
- 18. Suppose a is an array of values of type double that is partially filled. The array contains meaningful values in only the first numberUsed elements, where numberUsed is a variable of type int. Write some code to display all the meaningful values in the array a.
- 19. If the array a in the previous question has room for ten elements but contains only three elements, what indexed variables will contain the three elements? What is the value of number Used?
- 20. Consider the partially filled array a from Self-Test Question 18. Write some code that will place the number 42 right after the last number currently in a. You can assume that the array a is not full. (*Hint*: You must update numberUsed.)

- 21. Repeat the previous question, but this time assume that you do not know whether the array a is full. If the array a is full, your code should display an appropriate message to the screen.
- 22. Write an accessor method getEntryArray for the class OneWayNoRepeats List that returns a copy of the array entry. Since entry is an array of strings, you need not copy the strings themselves.

# 7.4 SORTING AND SEARCHING ARRAYS

A place for everything and everything in its place.

—ISABELLA MARY BEETON, Book of Household Management (1861)

Sorting arranges array elements into a particular order, such as ascending or descending Suppose you have an array of values. You might want the array values to be ordered in some way. For example, you might want to order an array of numbers from lowest to highest or from highest to lowest, or you might want to arrange an array of strings into alphabetical order. Arranging a collection of items into a particular order is called **sorting**. Typically, we sort arrays into ascending or descending order.

In this section, we will discuss and implement a simple sorting algorithm. We will present this algorithm as a way to sort an array of integers. However, with only minor changes, it can be adapted to sort arrays of values of any type that can be ordered. For example, we could sort an array of employee records according to identification numbers.

We also will consider searching a given array for a particular entry. We can search an array whose entries are sorted or one whose entries are completely unorganized. Both sorting and searching are quite important tasks, and efficient algorithms are important. We will, however, just introduce you to these topics.

### **Selection Sort**

Imagine an array of integers that we want to sort into ascending order. That is, we will rearrange the values in the indexed variables of the array so that

```
a[0] \le a[1] \le a[2] \le ... \le a[a.length - 1]
```

We will discuss one of the easiest of the sorting algorithms to understand, the **selection sort**. This algorithm follows from the specification of what we want the algorithm to do. That is, we want the algorithm to rearrange the values of the array a so that a[0] is the smallest, a[1] is the next smallest, and so forth. That desire leads to the following pseudocode:

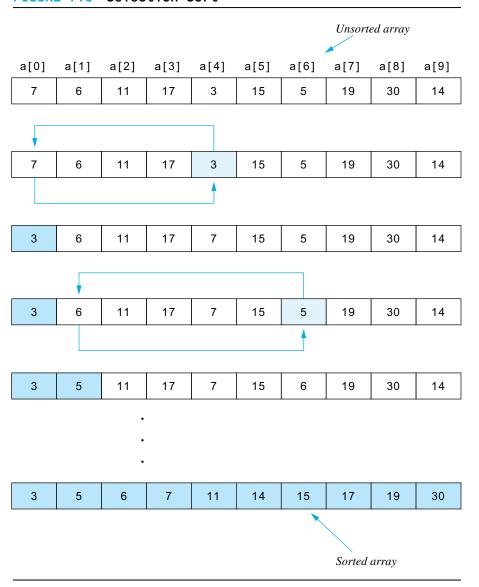
```
for (index = 0; index <a.length; index++)
   Place the (index + 1)<sup>th</sup> smallest element in a[index]
```

We want this algorithm to use only the one array a. Thus, the only way we can move an array element without losing any of the other elements is to make it swap places with another element of the array. Any sorting algorithm that swaps, or interchanges, values is called an **interchange sorting algorithm**. Thus, our selection sort algorithm is an interchange sorting algorithm.

Interchange sorts swap values in an array

Let's start with an example to see how the array elements are interchanged. Figure 7.5 shows how an array is sorted by interchanging values. Beginning

FIGURE 7.5 Selection Sort



with an array of unsorted values, we locate the smallest value in the array. In our example, this value is the 3 in a [4]. Since we want this smallest value to be first in the array, we interchange the value in a [4] with the value in a [0]. After that interchange, the smallest value is in a [0] where it belongs.

The next smallest value in the array is the 5 in a[6]. It needs to be second in the array, so we interchange the value in a[6] with the value in a[1]. After that swap, the values in a[0] and a[1] are the smallest and next smallest values, which is what they should be in the final sorted array. The algorithm then interchanges the next smallest element with a[2] and so forth until the entire array is sorted.

Finding the smallest value in an array is analogous to finding the largest value, and we did that in the method computeStats in Listing 7.4. But how do we find the second smallest value, the third smallest, and so on? After finding the smallest value among a[0], a[1], . . . , a[n] and placing it into a[0], the second smallest value in the array a is the smallest value among a[1], . . . , a[n]. After placing it into a[2], the third smallest value in a is the smallest value among a[2], . . . , a[n], and so on.

The following pseudocode describes the selection sort algorithm:

Pseudocode for a selection sort

```
Algorithm for a selection sort of an array
```

Notice that we effectively have two regions of the array: One region is sorted, and the other is not. The assertion in our algorithm implies that the sorted region encompasses the elements a[0] through a[index]. Notice that this assertion is true after each iteration of the loop. We repeatedly find the smallest value in the unsorted region and move it to the end of the sorted region by swapping elements. Thus, the sorted region grows by one element at each repetition of the loop, while the unsorted region shrinks by one element. In Figure 7.5, the sorted region is shaded blue.

Note that the for loop ends after correctly filling the element a[a.length-2], even though the index of the last array element is a.length-1. After the algorithm gets all but one element sorted, the correct value for the last element a[a.length-1] is already in a[a.length-1].

Listing 7.10 contains a class defining a static method named selectionSort that implements this selection sort algorithm. The method uses two private

helping methods named getIndexOfSmallest and interchange. Once you understand these private methods, you will see that the definition of the method selectionSort is a direct translation of our pseudocode into Java code. So let's discuss these two private methods.

# LISTING 7.10 Implementation of the Selection Sort (part 1 of 2)

```
/**
Class for sorting an array of base type int from smallest to largest.
public class ArraySorter
{
    / * *
     Precondition: Every element in anArray has a value.
     Action: Sorts the array into ascending order.
    */
    public static void selectionSort(int[] anArray)
        for (int index = 0; index < anArray.length - 1; index++)</pre>
            // Place the correct value in anArray[index]
            int indexOfNextSmallest = getIndexOfSmallest(index, anArray);
            interchange(index, indexOfNextSmallest, anArray);
            //Assertion:anArray[0] <= anArray[1] <=...<= anArray[index]
            //and these are the smallest of the original array elements.
            //The remaining positions contain the rest of the original
            //array elements.
        }
    }
     Returns the index of the smallest value in the portion of the
     array that begins at the element whose index is startIndex and
     ends at the last element.
    private static int getIndexOfSmallest(int startIndex, int[] a)
    {
        int min = a[startIndex];
        int indexOfMin = startIndex;
        for (int index = startIndex + 1; index < a.length; index++)</pre>
        {
            if (a[index] < min)</pre>
            {
                min = a[index];
                indexOfMin = index;
                //min is smallest of a[startIndex] through a[index]
            }
        }
        return indexOfMin;
    }
```

# LISTING 7.10 Implementation of the Selection Sort (part 2 of 2)

```
/**
    Precondition: i and j are valid indices for the array a.
    Postcondition: Values of a[i] and a[j] have been interchanged.
*/
private static void interchange(int i, int j, int[] a)
{
    int temp = a[i];
    a[i] = a[j];
    a[j] = temp; //original value of a[i]
}
```

The method getIndexOfSmallest searches the array elements

```
a[startIndex], a[startIndex + 1], ..., a[a.length - 1]
```

and returns the index of the smallest one. It does this using the two local variables min and indexOfMin. At any point in its search, min is equal to the smallest array value found so far, and indexOfMin is the index of that value. Thus, a[indexOfMin] has the value min. Initially, min is set to a[startIndex], which is the first value considered for min, and indexOfMin is set to startIndex. Then each array element is considered in turn to see whether it is a new minimum. If it is, the values of min and indexOfMin are updated. After checking all of the candidate array elements, the method returns the value of indexOfMin.

The method named interchange interchanges the values of a[i] and a[j]. There is one subtle point about this method. If you execute the code

Place the next entry in its correct position by swapping

```
a[i] = a[j];
```

you will lose the value originally held in a[i]. So before this statement is executed, we must save the value of a[i] in the local variable temp.

Listing 7.11 contains a demonstration program that shows the selection sort method in action.

# **Other Sorting Algorithms**

Selection sort is simple, but not the fastest way to sort

Although the selection sort algorithm will suffice as an introduction to the general topic of sorting, it is not the most efficient sorting algorithm. In fact, it is significantly less efficient than a number of well-known sorting algorithms. The selection sort is, however, much simpler than these other algorithms. A simpler algorithm is less likely to have errors creep in when you code it. So if you need to code a sorting algorithm in a hurry, it is safer to use either a selection sort or some other simple algorithm.

Find the next smallest entry in the array

### LISTING 7.11 Demonstration of the Method selectionSort

### Screen Output

```
Array values before sorting:
7 5 11 2 16 4 18 14 12 30
Array values after sorting:
2 4 5 7 11 12 14 16 18 30
```

On the other hand, if efficiency is a major issue, you may wish to use a more complicated and more efficient algorithm. But be aware that the more complicated algorithm will take longer to code, test, and debug. Efficiency can be a subtle topic. Remember, getting the wrong result is always inefficient, no matter how quickly your program can come up with the result.



Fortunately, the Java Class Library provides for efficient sorting. The class Arrays, in the package java.util, defines the static method sort. If anArray is an array of either primitive values or objects, the statement

```
Arrays.sort(anArray);
```

sorts the elements in the entire array into ascending order. To sort only the portion of the array beginning with the index first and ending with the index last, you would write

```
Arrays.sort(anArray, first, last);
```

The class Arrays defines several versions of the method—that is, the name sort is overloaded—to accommodate arrays of class types as well as all the primitive types. If you want to sort an array of objects with Arrays.sort then

the object must implement the Comparable interface. This is discussed in Section 8.4 of the next chapter.

Programming Projects 3 and 4 at the end of this chapter describe two other sorting algorithms. A more efficient sorting algorithm—one similar to the algorithm that Arrays.sort uses—is described in Chapter 11 when we talk about recursion.

# **SELF-TEST QUESTIONS**

- 23. Trace the steps that a selection sort takes as it sorts the following array into ascending order: 7 5 1 3 6.
- 24. Write the invocation of the method selectionSort to sort an array myArray of integers into ascending order.
- 25. How would you need to change the method selectionSort so that it can sort an array of values of type double instead of type int?
- 26. How would you need to change the method selectionSort so that it can sort an array of values of type int into decreasing order, instead of increasing order?
- 27. Consider an array b of int values in which a value occurs twice. For example, suppose 7 occurs in both b[0] and b[5]. If you sort the array using the method selectionSort, will the sorted array contain one or two copies of the repeated value?

# **Searching an Array**

The method isOnList of the class OneWayNoRepeatsList in Listing 7.9 searches the array entry to see whether it contains the value represented by the parameter item. This is an example of a **sequential search** of an array. The sequential search algorithm is very simple and straightforward: It looks at the array elements from first to last to see whether the sought-after item is equal to any of the array elements. The search ends when either the desired item is found in the array or the end of the array is reached without finding the item. In the latter case, of course, the search is unsuccessful. If the array is partially filled, the search considers only the portion of the array that contains meaningful values.

A sequential search can search an unsorted array, which is an advantage of this simple algorithm. If, however, the array is sorted, we can improve the sequential search in situations in which the desired item does not exist within the array. Exercise 19 asks you to write this improved sequential search. An even faster algorithm, the binary search, is possible for sorted arrays. We will study this algorithm in Chapter 11.

A sequential search looks for an array element from beginning to end

# 7.5 MULTIDIMENSIONAL ARRAYS

Never trust to general impressions, my boy, but concentrate yourself upon details.

—SIR ARTHUR CONAN DOYLE, A Case of Identity (Sherlock Holmes)

An array having more than one index is sometimes useful. For example, suppose you wanted to store the dollar amounts shown in Figure 7.6 in some sort of array. The highlighted part of the table contains 60 such entries. If you use an array that has one index, the length of the array would be 60. Keeping track of which entry goes with which index number would be difficult. On the other hand, if you allow yourself two indices, you can use one index for the row of this table and one index for the column. Such an array is illustrated in Figure 7.7.

Arrays that have exactly two indices can be displayed on paper as a two-dimensional table and are called **two-dimensional arrays**. By convention, we think of the first index as denoting the row of the table and the second index as denoting the column. Note that, as was true for the simple arrays we have already seen, we begin numbering indices with 0 rather than 1. The Java notation for an element of a two-dimensional array is

Two-dimensional arrays use two indices

Array\_Name[Row\_Index][Column\_Index]

For example, if the array is named table and it has two indices, table[3][2] is the entry whose row index is 3 and column index is 2. Because indices begin

FIGURE 7.6 A Table of Values

Savings Account Balances for Various Interest Rates Compounded Annually (Rounded to Whole Dollar Amounts)									
Year	5.00%	5.50%	6.00%	6.50%	7.00%	7.50%			
1	\$1050	\$1055	\$1060	\$1065	\$1070	\$1075			
2	\$1103	\$1113	\$1124	\$1134	\$1145	\$1156			
3	\$1158	\$1174	\$1191	\$1208	\$1225	\$1242			
4	\$1216	\$1239	\$1262	\$1286	\$1311	\$1335			
5	\$1276	\$1307	\$1338	\$1370	\$1403	\$1436			
6	\$1340	\$1379	\$1419	\$1459	\$1501	\$1543			
7	\$1407	\$1455	\$1504	\$1554	\$1606	\$1659			
8	\$1477	\$1535	\$1594	\$1655	\$1718	\$1783			
9	\$1551	\$1619	\$1689	\$1763	\$1838	\$1917			
10	\$1629	\$1708	\$1791	\$1877	\$1967	\$2061			

Column index 2 Row index 3 0 1 2 3 4 5 Indices \$1050 \$1055 \$1075 0 \$1060 \$1065 \$1070 \$1103 \$1113 \$1156 1 \$1124 \$1134 \$1145 2 \$1158 \$1174 \$1191 \$1208 \$1225 \$1242 \$1262 3 \$1216 \$1239 \$1286 \$1311 \$1335 \$1276 \$1338 4 \$1307 \$1370 \$1403 \$1436 5 \$1340 \$1379 \$1419 \$1459 \$1501 \$1543 6 \$1407 \$1455 \$1504 \$1554 \$1606 \$1659 7 \$1477 \$1535 \$1594 \$1655 \$1718 \$1783 8 \$1551 \$1619 \$1689 \$1763 \$1838 \$1917 \$1629 \$1708 \$1791 \$1877 \$1967 \$2061 9 table[3][2] has a value of 1262

FIGURE 7.7 Row and Column Indices for an Array Named table

at 0, this entry is in the fourth row and third column of table, as Figure 7.7 illustrates. Trying to relate array indices to actual row and column numbers gets confusing and is likely to be unnecessary.

Arrays having more than one index are generally called **multidimensional arrays**. More specifically, an array that has n indices is said to be an n-dimensional array. Thus, an ordinary one-index array is a **one-dimensional array**. Although arrays having more than two dimensions are rare, they can be useful for some applications.

# **Multidimensional-Array Basics**

Arrays having multiple indices are handled in much the same way as onedimensional arrays. To illustrate the details, we will take you through an example Java program that displays an array like the one in Figure 7.7. The program is shown in Listing 7.12. The array is called table. The following statement declares the name table and creates the array:

int[][] table = new int[10][6];

*n*-dimensional array

Declaring and creating a twodimensional array

## LISTING 7.12 Using a Two-Dimensional Array (part 1 of 2)

```
/**
                                                   A real application would
                                                   do something more with
Displays a two-dimensional table showing how
                                                   the array table. This
interest rates affect bank balances.
                                                   is just a demonstration
* /
                                                   program.
public class InterestTable
    public static void main(String[] args)
    {
        int[][] table = new int[10][6];
        for (int row = 0; row < 10; row++)</pre>
             for (int column = 0; column < 6; column++)</pre>
                 table[row][column] =
                      getBalance(1000.00, row + 1, (5 + 0.5 *
                                                      column));
        System.out.println("Balances for Various Interest Rates " +
                            "Compounded Annually");
        System.out.println("(Rounded to Whole Dollar Amounts)");
        System.out.println();
        System.out.println("Years 5.00% 5.50% 6.00% 6.50% " +
                             "7.00% 7.50%");
        for (int row = 0; row < 10; row++)
            System.out.print((row + 1) + "");
            for (int column = 0; column < 6; column++)</pre>
                  System.out.print("$" + table[row][column] + " ");
            System.out.println();
        }
    }
    Returns the balance in an account after a given number of years
    and interest rate with an initial balance of startBalance.
    Interest is compounded annually. The balance is rounded
    to a whole number.
    */
    public static int getBalance(double startBalance, int years,
                                   double rate)
    {
        double runningBalance = startBalance;
        for (int count = 1; count <= years; count++)</pre>
             runningBalance = runningBalance * (1 + rate / 100);
        return (int)(Math.round(runningBalance));
    }
}
```

# LISTING 7.12 Using a Two-Dimensional Array (part 2 of 2)

### Sample Screen Output

Balances for Various Interest Rates Compounded Annually (Rounded to Whole Dollar Amounts)										
Years	5.00%	5.50%	6.00%	6.50%	7.00%	7.50%				
1	\$1050	\$1055	\$1060	\$1065	\$1070	\$1075				
2	\$1103	\$1113	\$1124	\$1134	\$1145	\$1156				
3	\$1158	\$1174	\$1191	\$1208	\$1225	\$1242				
4	\$1216	\$1239	\$1262	\$1286	\$1311	\$1335				
5	\$1276	\$1307	\$1338	\$1370	\$1403	\$1436				
6	\$1340	\$1379	\$1419	\$1459	\$1501	\$1543				
7	\$1407	\$1455	\$1504	\$1554	\$1606	\$1659				
8	\$1477	\$1535	\$1594	\$1655	\$1718	\$1783				
9	\$1551	\$1619	\$1689	\$1763	\$1838	\$1917				
10	\$1629	\$1708	\$1791	\$1877	\$1967	\$2061				

The last line is out of alignment because 10 has two digits. This is easy to fix, but that would clutter the discussion of arrays with extraneous concerns.

This is equivalent to the following two statements:

```
int[][] table;
table = new int[10][6];
```

Note that this syntax is almost identical to the syntax we used for the onedimensional case. The only difference is that we added a second pair of square brackets in two places, and we gave a number specifying the size of the second dimension, that is, the number of columns. You can have arrays with any number of indices. To get more indices, you just use more square brackets in the declaration.

Indexed variables for multidimensional arrays are just like indexed variables for one-dimensional arrays, except that they have multiple indices, each enclosed in a pair of square brackets. This is illustrated by the following for loop from Listing 7.12:

Using nested loops to process a two-dimensional array

Note that we used two for loops, one nested within the other, which is a common way of stepping through all the indexed variables in a two-dimensional array. If we had three indices, we would use three nested for loops, and so forth for higher numbers of indices. The illustration in Figure 7.7 may help you understand the meaning of the indices in table[row][column] and the meaning of the nested for loops.

Like indexed variables for one-dimensional arrays, indexed variables for multidimensional arrays are variables of the base type and can be used anywhere that a variable of the base type is allowed. For example, the indexed variable table[3][2] in the array in Listing 7.12 is a variable of type int and can be used anywhere that an ordinary int variable can be used.

# **RECAP** Declaring and Creating a Multidimensional Array

You declare a name for a multidimensional array and then create the array in basically the same way that you declare and create a one-dimensional array. You simply use as many square brackets as there are indices.

## **SYNTAX**

```
[Length_n];

EXAMPLES

char[][] page = new char[100][80];
int[][] table = new int[10][6];
double[][][][threeDPicture = new double[10][20][30];
SomeClass[][]entry = new SomeClass[100][80];
```

Base\_Type[]. . . []Array\_Name = new Base\_Type[Length\_1]. . .

SomeClass is a class.

# Multidimensional-Array Parameters and Returned Values

Methods can have parameters and return values that are multidimensional arrays. The situation is similar to that of a one-dimensional array, except that you use more square brackets. For example, the program in Listing 7.13 is like the one in Listing 7.12, but it has a method to display the two-dimensional array passed to it as an argument. Note that the type for the array parameter is int[][]. We have also used named constants instead of literals to define the number of rows and columns.

Array parameters and return values can be multidimensional

## LISTING 7.13 A Multidimensional-Array Parameter

```
/**
Displays a two-dimensional table showing how interest
rates affect bank balances.
public class InterestTable2
{
    public static final int ROWS = 10;
    public static final int COLUMNS = 6;
    public static void main(String[] args)
    {
        int[][] table = new int[ROWS][COLUMNS];
        for (int row = 0; row < ROWS; row++)</pre>
            for (int column = 0; column < COLUMNS; column++)</pre>
              table[row][column] =
                    getBalance(1000.00, row + 1, (5 + 0.5 * column));
        System.out.println("Balances for Various Interest Rates " +
                            "Compounded Annually");
        System.out.println("(Rounded to Whole Dollar Amounts)");
        System.out.println();
        System.out.println("Years 5.00% 5.50% 6.00% 6.50% 7.00% 7.50%");
        showTable(table);
    }
    / * *
    Precondition: The array anArray has ROWS rows and COLUMNS columns.
    Postcondition: The array contents are displayed with dollar signs.
                                                              A better definition of
    public static void showTable(int[][] anArray)
                                                              showTable is possible,
    {
                                                              as you will see.
        for (int row = 0; row < ROWS; row++)</pre>
        {
            System.out.print((row + 1) + " ");
            for (int column = 0; column < COLUMNS; column++)</pre>
                 System.out.print("$" + anArray[row][column] + " ");
            System.out.println();
        }
    public static int getBalance(double startBalance, int years, double rate)
    <The rest of the definition of getBalance is the same as in Listing 7.12.>
}
                                  The output is the same
                                   as in Listing 7.12.
```

If you want to return a multidimensional array, you use the same sort of type specification as you use for a multidimensional-array parameter. For example, the following method returns a two-dimensional array whose base type is double:

## **RECAP Multidimensional-Array Parameters and Return Types**

A parameter or return type of a method can be an entire multidimensional array. The syntax for the method's heading is like that for one-dimensional-array parameters or return types, but you use more square brackets []:

### **SYNTAX**

You can use other modifiers instead of public and static.

### **EXAMPLES**

### Arrays of arrays

# Java's Representation of Multidimensional Arrays

The Java compiler represents a multidimensional array as several onedimensional arrays. For example, consider the two-dimensional array

```
int[][] table = new int[10][6];
```

The array table is in fact a one-dimensional array of length 10, and its base type is the type int[]. In other words, multidimensional arrays are arrays of arrays. Normally, you do not need to be concerned with this detail, since it is handled automatically by the compiler. However, a knowledge of how Java stores multidimensional arrays can come in handy.

For example, suppose you want to fill a two-dimensional array with values by writing a for loop. The program in Listing 7.13 uses the named constants ROWS and COLUMNS to control the for loops. A more general way would use the length instance variable to control the loops. But when using length with a multidimensional array, you need to think in terms of arrays of arrays.

The following is a revision of the nested for loop that appears in the main method in Listing 7.13:

Using length for multidimensional arrays

```
for (int row = 0; row <table.length; row++)
  for (int column = 0;column< table[row].length; column++)
    table[row][column]=
        getBalance(1000.00,row + 1,(5 + 0.5 * column));</pre>
```

Since the array table is actually a one-dimensional array of length 10, the first for loop can use table.length instead of ROWS, which is 10. Additionally, each of the 10 indexed variables table[0] through table[9] is a one-dimensional array whose length is 6 (COLUMNS). Thus, since table[row] is a one-dimensional array whose length is 6, the second for loop can use table[row].length instead of COLUMNS.

# REMEMBER The Instance Variable Tength for a Two-Dimensional Array

For a two-dimensional array b, the value of b.length is the number of rows, that is, the integer in the first pair of brackets in the array's declaration. The value of b[i].length is the number of columns, that is, the integer in the second pair of brackets in the array's declaration. For the two-dimensional array table in Listing 7.13, the value of table.length is the number of rows—in this case, 10—and the value of table[row].length is the number of columns—in this case, 6.

You can use the fact that multidimensional arrays are arrays of arrays to rewrite the method showTable in Listing 7.13. Notice that in Listing 7.13, the method showTable assumes that its array argument has ROWS (10) rows and

COLUMNS (6) columns. That is fine for this particular program, but a better definition of showTable would work for an array of any two dimensions. We leave such a revision for you as an exercise (Self-Test Question 29).





# **SELF-TEST QUESTIONS**

28. What output is produced by the following code?

```
int[][] testArray = new int[3][4];
for (int row = 0; row < testArray.length; row++)
    for (int col = 0;
        col < testArray[row].length; col++)
        testArray[row][col] = col;
for (int row = 0; row < testArray.length; row++)
{
    for (int col = 0;
        col < testArray[row].length; col++)
        System.out.print(testArray[row][col] + " ");
    System.out.println();
}</pre>
```

- 29. Revise the method showTable in Listing 7.13 so that it will work for any two-dimensional array of integers.
- 30. Write code that will fill the following array a with numbers typed at the keyboard:

```
int[][] a = new int[4][5];
```

Although the user will enter five numbers per line on four lines, your solution need not depend on how the input numbers are divided into lines.

31. Write a void method called display such that the invocation display (a) will display the contents of the array a in Self-Test Question 30 as four lines of five numbers per line. Your method definition should also work for two-dimensional arrays that have sizes other than 4 by 5. Write your method as a static method that can be added to a class.

# Ragged Arrays (Optional)

In our previous examples of two-dimensional arrays, all rows have the same number of entries. For example, consider the two-dimensional array created as follows:

```
int[][] a = new int[3][5];
```

This statement is equivalent to the following statements:

```
int[][] a;
a = new int[3][];
```

```
a[0] = new int[5];
a[1] = new int[5];
a[2] = new int[5];
```

The line

```
a = new int[3][];
```

declares a as the name of an array of length 3 whose entries each name an array that can be of any length. The next three lines each create an array of integers of length 5 to be named by a[0], a[1], and a[2]. The net result is a two-dimensional array of base type int with three rows and five columns.

The statements

```
a[0] = new int[5];
a[1] = new int[5];
a[2] = new int[5];
```

invite the question "Do all the lengths need to be 5?" The answer is "No!" Because a two-dimensional array in Java is an array of arrays, its rows can have varying numbers of entries. That is, different rows can have different numbers of columns. Such an array is called a **ragged array**. The following statements define a ragged array b in which each row has a different length:

```
int[][] b;
b = new int[3][];
b[0] = new int[5]; //First row, 5 elements
b[1] = new int[7]; //Second row, 7 elements
b[2] = new int[4]; //Third row, 4 elements
```

It is worth noting that after you fill the preceding array b with values, you could not display b using the method showTable as defined in Listing 7.13. However, we can revise that method, as Self-Test Question 29 asked you to do, as follows:

This revised method works for any two-dimensional array, even if it is ragged.

Rows in a twodimensional array can have different lengths

A revision of the method showTable from Listing 7.13

You can profitably use ragged arrays in some situations, but most applications do not require them. However, if you understand ragged arrays, you will have a better understanding of how all multidimensional arrays work in Java.

# PROGRAMMING EXAMPLE

**Employee Time Records** 

In this programming example, a two-dimensional array named hours is used to store the number of hours worked by each employee of a company for each of the five days Monday through Friday. The first array index is used to designate a day of the week, and the second array index is used to designate an employee. The two-dimensional array is a private instance variable in the class named TimeBook given in Listing 7.14. The class includes a method main that demonstrates the class for a small company having only three employees. The employees are numbered 1, 2, and 3 but are stored at array index positions 0, 1, and 2, since the array indices are numbered starting with 0. Thus, an adjustment of minus 1 is sometimes needed when specifying an employee's array index. We can number days as 0 for Monday, 1 for Tuesday, and so forth to avoid adjustments between day numbers and day indices.

For example, the hours worked by employee number 3 on Tuesday are recorded in hours [1][2]. The first index denotes the second workday of the week—Tuesday—and the second index denotes the third employee.

# FAQ This is confusing. Why don't we avoid 0 indices, as we did earlier for one-dimensional arrays?

For a one-dimensional array a, we suggested that you could ignore a[0] if you defined one extra array element. Wasting one memory location that contains an address is not really a big deal. But with a two-dimensional array, if we ignore elements whose indices include 0, we would waste either an entire row, an entire column, or both a row and a column. In general, doing so is not a good idea. We will not avoid 0 indices in this example.

#### **FAQ** Can we use an enumeration somehow?

Yes, we could define an enumeration for the days of the workweek, as follows:

enum Days {MON, TUE, WED, THU, FRI}

Recall that the ordinal value of MON is 0, the ordinal value of TUE is 1, and so on. Using an enumeration can make our program easier to understand.

Instead of using an enumeration for the workdays, we will simply define five named constants, as follows, and use them as indices:

setHours is a stub

The class TimeBook shown in Listing 7.14 is not yet complete. It needs more methods to be a really useful class, but it has enough methods for the demonstration program in main. You can think of the definition in Listing 7.14 as a first pass at writing the class definition. It even has a stub for the definition of the method setHours. Recall that a stub is a method whose definition can be used for testing but is not yet the final definition. At this stage, however, setHours is complete enough to illustrate the use of the two-dimensional array hours, which is an instance variable of the class.

In addition to the two-dimensional array hours, the class TimeBook uses two one-dimensional arrays as instance variables: The array weekHours records the total hours each employee works in a week. That is, weekHours[0] is the total number of hours worked by employee 1 in the week, weekHours[1] is the total number of hours worked by employee 2 in the week, and so forth. The array dayHours records the total number of hours worked by all the employees on each day of the week. That is, dayHours[MON] is the total number of hours worked on Monday by all of the employees combined, dayHours[TUE] is the total number of hours worked on Tuesday by all of the employees, and so on.

# LISTING 7.14 A Timekeeping Program (part 1 of 4)

```
Class that records the time worked by each of a
company's employees during one five-day week.
A sample application is in the main method.
* /
public class TimeBook
    private int numberOfEmployees;
    private int[][] hours;
                             //hours[i][j] has the hours for
                             //employee j on day i.
    private int[] weekHours; //weekHours[i] has the week's
                             //hours worked for employee i + 1.
    private int[] dayHours; //dayHours[i] has the total hours
                             //worked by all employees on day i.
    private static final int NUMBER_OF_WORKDAYS = 5;
    private static final int MON = 0;
    private static final int TUE = 1;
    private static final int WED = 2;
    private static final int THU = 3;
    private static final int FRI = 4;
                                                         (continued)
```

# LISTING 7.14 A Timekeeping Program (part 2 of 4)

```
/**
    Reads hours worked for each employee on each day of the
    work week into the two-dimensional array hours. (The method
    for input is just a stub in this preliminary version.)
    Computes the total weekly hours for each employee and
    the total daily hours for all employees combined.
    */
    public static void main(String[] args)
    {
        private static final int NUMBER_OF_EMPLOYEES = 3;
        TimeBook book = new TimeBook(NUMBER_OF_EMPLOYEES);
        book.setHours();
                                             A class generally has more
        book.update();
                                             methods. We have defined only
        book.showTable();
                                             the methods used in main.
    }
    public TimeBook(int theNumberOfEmployees)
        numberOfEmployees = theNumberOfEmployees;
        hours = new int[NUMBER_OF_WORKDAYS][numberOfEmployees];
        weekHours = new int[numberOfEmployees];
        dayHours = new int[NUMBER_OF_WORKDAYS];
    }
                                                The final program would
                                                replace the stub setHours
                                                with a complete method to
                                                obtain the employee data
    public void setHours() //This is a stub.
                                                from the user.
        hours[0][0] = 8; hours[0][1] = 0; hours[0][2] = 9;
        hours[1][0] = 8; hours[1][1] = 0; hours[1][2] = 9;
        hours[2][0] = 8; hours[2][1] = 8; hours[2][2] = 8;
        hours[3][0] = 8; hours[3][1] = 8; hours[3][2] = 4;
        hours[4][0] = 8; hours[4][1] = 8; hours[4][2] = 8;
    }
    public void update()
    {
        computeWeekHours();
        computeDayHours();
    }
    private void computeWeekHours()
        for (employeeNumber = 1; employeeNumber <=</pre>
             numberOfEmployees; employeeNumber++)
```

(continued)

# LISTING 7.14 A Timekeeping Program (part 3 of 4)

```
{//Process one employee:
       int sum = 0;
       for (int day = MON; day <= FRI; day++)</pre>
            sum = sum + hours[day][employeeNumber - 1];
            //sum contains the sum of all the hours worked in
             //one
            //week by the employee with number employeeNumber.
       weekHours[employeeNumber - 1] = sum;
    }
}
private void computeDayHours()
    for (int day = MON; day <= FRI; day++)</pre>
    {//Process one day (for all employees):
       int sum = 0;
       for (int employeeNumber = 1;
                 employeeNumber <= numberOfEmployees;</pre>
                 employeeNumber++)
            sum = sum + hours[day][employeeNumber - 1];
            //sum contains the sum of all hours worked by all
            //employees on one day.
       dayHours[day] = sum;
    }
                                      The method showTable can and
}
                                      should be made more robust. See
public void showTable()
                                      Programming Project 5.
{
    // heading
    System.out.print("Employee ");
    for (int employeeNumber = 1;
             employeeNumber <= numberOfEmployees;</pre>
             employeeNumber++)
        System.out.print(employeeNumber + " ");
    System.out.println("Totals");
    System.out.println( );
    // row entries
    for (int day = MON; day <= FRI; day++)</pre>
       System.out.print(getDayName(day) + " ");
       for (int column = 0; column < hours[day].length;</pre>
                 column++)
            System.out.print(hours[day][column] + " ");
       System.out.println(dayHours[day]);
    }
```

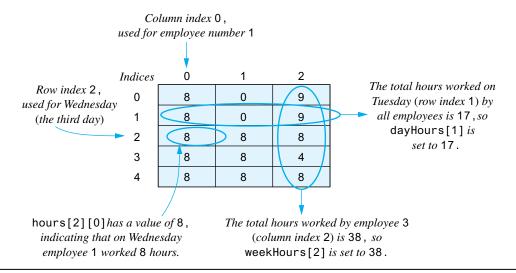
# LISTING 7.14 A Timekeeping Program (part 4 of 4)

```
System.out.println( );
        System.out.print("Total = ");
        for (int column = 0; column < numberOfEmployees; column++)</pre>
            System.out.print(weekHours[column] + " ");
        System.out.println( );
    }
    //Converts 0 to "Monday", 1 to "Tuesday", etc.
    //Blanks are inserted to make all strings the same length.
    private String getDayName(int day)
    {
        String dayName = null;
        switch (day)
        {
            case MON:
                 dayName = "Monday ";
                 break;
            case TUE:
                 dayName = "Tuesday ";
                 break:
            case WED:
                 dayName = "Wednesday";
                 break:
            case THU:
                 dayName = "Thursday ";
                 break:
            case FRI:
                 dayName = "Friday ";
                 break:
            default:
                 System.out.println("Fatal Error.");
                 System.exit(0);
                 break;
        }
        return dayName;
    }
}
```

#### Sample Screen Output

```
Employee
               2
                    3
                        Totals
           1
Monday
           8
               0
                    9
                        17
                    9
Tuesday
           8
               0
                        17
Wednesday
           8
               8
                    8
                        24
Thursday
           8
               8
                    4
                        20
Friday
          8
              8
                    8
                        24
Total =
          40
               24
                    38
```

# FIGURE 7.8 Arrays for the Class TimeBook



The methods computeWeekHours and computeDayHours compute the values for weekHours and dayHours, respectively, from the values in the two-dimensional array hours. Figure 7.8 shows some sample data for the array hours and illustrates the relationship between hours and each of the arrays weekHours and dayHours.

Be sure to notice how the method computeWeekHours uses the array indices of the two-dimensional array hours. A for loop is nested inside of a for loop. The outer for loop cycles through all employees, and the inner for loop is executed once for each day of the week. The inner for loop—together with an assignment statement before and after—is reproduced here:

Using named constants to make the loop clearer

```
int sum = 0;
for (int day = MON; day <= FRI; day++)
   sum = sum + hours[day][employeeNumber - 1];
   //sum contains the sum of all the hours worked in
   //one week by the employee with number employeeNumber.
weekHours[employeeNumber - 1] = sum;</pre>
```

Note that when computing the sum of the hours for one employee, the second index, which represents the particular employee, is held constant.

The method computeDayHours works in a similar way to compute the total number of hours worked by all employees on each day of the week. However, in this case, the inner for loop cycles through the second index while the first index is held constant. Or, to phrase it another way, the roles of the employee index and the day of the week index are interchanged.

Although our class TimeBook is correct as written, it is not yet a finished piece of software ready to be saved and reused again and again. The method setHours is just a stub and needs to be replaced by a more generally applicable method that obtains hours from the user at the keyboard. The method showTable will not always produce output that is as neat as the output shown in Listing 7.14, unless all the hours have the same number of digits. Thus, the method showTable needs to be made more robust so that it will neatly display any combination of hours worked. Finally, the class TimeBook should have more methods so that it will be useful in a wide range of situations. Programming Project 5 asks you to complete the definition of the class TimeBook in all of these ways.

TimeBook needs to be completed

#### 7.6 GRAPHICS SUPPLEMENT

Write your answer in the space provided.

—WEB PAGE INSTRUCTION.

A man paints with his brains and not with his hands.

-MICHELANGELO

The first part of this section covers the FlowPane layout, which is another simple layout. Next we cover text areas and text fields, which are components that can be used for text input and output in your applications. It does not require any material from earlier in this chapter and so may be read even if you do not read the main body of this chapter. The remainder of this section shows you how to draw a very general kind of figure known as a *polygon*. It does require the basic material on arrays covered earlier in this chapter.

# **Layout Panes**

So far we've been using the VBox layout pane to vertically add components to our JavaFX applications. There are several other built-in layout panes available to us. Here, we introduce a few of these panes and demonstrate how to combine layout panes.

# The HBox Layout Pane

The HBox layout pane is the complement to the VBox layout pane. Put simply, it arranges our components, or nodes, horizontally in the pane rather than vertically. If the components take up the entire width of the pane then each node is given an equal amount of space. Listing 7.15 demonstrates the HBox pane when three buttons are added to it.

# LISTING 7.15 The HBox Layout Pane

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.HBox;
import javafx.scene.control.Button;
/**
Simple demonstration of adding buttons using the HBox layout.
These buttons do not do anything. That comes in a later version.
* /
public class HBoxDemo extends Application
   public static void main(String[] args)
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
      HBox root = new HBox();
      root.getChildren().add(new Button("This is Button 1"));
      root.getChildren().add(new Button("This is Button 2"));
      root.getChildren().add(new Button("This is Button 3"));
      Scene scene = new Scene(root, 250, 100);
      primaryStage.setTitle("HBox Demo");
      primaryStage.setScene(scene);
      primaryStage.show();
   }
}
Program Output
 HBox Demo
                                  X
 This is Button 1
            This is Button 2 This is Button 3
```

#### The StackPane Layout

The StackPane layout stacks components on top of each other. Each new node is added on top of the previous one. This provides a way to overlay text onto a shape or image or to overlay multiple shapes to create a more complex shape. Listing 7.16 demonstrates the StackPane pane when a small "c" is stacked with a large "o" to make a @ symbol.

#### LISTING 7.16 The StackPane Layout

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.StackPane;
import javafx.scene.control.Label;
import javafx.scene.text.Font;
/**
Simple demonstration of drawing two letters on top of each other
using the StackPane layout.
* /
public class StackPaneDemo extends Application
   public static void main(String[] args)
   {
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
   {
      StackPane root = new StackPane();
      Label label1 = new Label("o");
      label1.setFont(Font.font("Courier New", 54));
      Label label2 = new Label("c");
      label2.setFont(Font.font("Courier New", 24));
      root.getChildren().add(label1);
      root.getChildren().add(label2);
      Scene scene = new Scene(root, 300, 100);
      primaryStage.setTitle("StackPane Demo");
      primaryStage.setScene(scene);
      primaryStage.show();
   }
}
```

#### Program Output



#### The FlowPane Layout

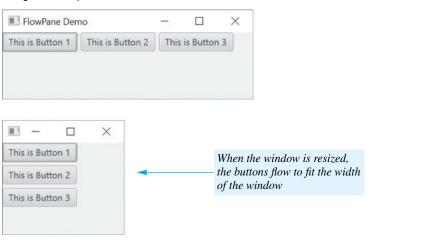
The FlowPane layout adds nodes from left to right. When nodes reach the edge of the pane, then the next node will wrap or "flow" back to the left and begin again in a new row underneath the existing nodes. This is a simple and convenient layout if you want to display items in order. If you resize the window, you will see the nodes will automatically flow to fit the available space. You can control the amount of vertical and horizontal space between elements by using the methods setVgap and setHgap. The methods set the number of pixels between vertical elements and horizontal elements, respectively. Without these methods, nodes will be displayed right next to one another. Listing 7.17 demonstrates the FlowPane pane with three buttons.

# LISTING 7.17 The FlowPane Layout (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.FlowPane;
import javafx.scene.control.Button;
Simple demonstration of adding buttons to the FlowPane layout.
public class FlowPaneDemo extends Application
   public static void main(String[] args)
   {
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
   {
     FlowPane root = new FlowPane();
     // Set a gap of 5 pixels vertically and horizontally
     // between buttons
     root.setVgap(5);
     root.setHgap(5);
     root.getChildren().add(new Button("This is Button 1"));
     root.getChildren().add(new Button("This is Button 2"));
     root.getChildren().add(new Button("This is Button 3"));
     Scene scene = new Scene(root, 500, 200);
     primaryStage.setTitle("FlowPane Demo");
     primaryStage.setScene(scene);
     primaryStage.show();
}
                                                          (continued)
```

#### LISTING 7.17 The FlowPane Layout (part 2 of 2)

#### Program Output



#### The GridPane Layout

The GridPane layout allows you to arrange nodes in a flexible grid of rows and columns. The rows and columns are accessible like a 2D array, with the upper left cell at row 0 and column 0. The HPos and VPos classes can be used to set the horizontal or vertical alignment within a grid cell. Listing 7.18 demonstrates the GridPane pane with the addition of labels in the leftmost column (cells (0,0) and (0,1)) and buttons to the right of the labels (cells (1,0) and (1,1)). An additional label is placed in cell (2,2). Note that we can add to the GridPane without invoking the getChildren() method.

# LISTING 7.18 The GridPane Layout (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.GridPane;
import javafx.geometry.HPos;
import javafx.scene.control.Button;
import javafx.scene.control.Label;
import javafx.geometry.Insets;
/**
Simple demonstration of adding buttons and labels
to the GridPane layout.
*/
```

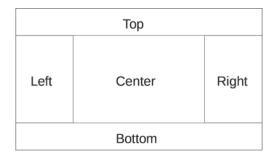
(continued)

# LISTING 7.18 The GridPane Layout (part 2 of 2)

```
public class GridPaneDemo extends Application
   public static void main(String[] args)
      launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
   {
      GridPane root = new GridPane();
        // Set a gap of 5 pixels vertically and horizontally
        // between elements
        root.setVgap(5);
        root.setHgap(5);
        // Margins around the top, right, bottom, and left
        root.setPadding(new Insets(10,10,10,10));
        // Add three nodes, by default horizontally left-aligned
        root.add(new Label("Option 1"),0,0);
        root.add(new Button("This is Button 1"),1,0);
        root.add(new Label("Option 2"),0,1);
        // Add a button that is horizontally right-aligned
        Button btn2 = new Button("Button 2");
        GridPane.setHalignment(btn2, HPos.RIGHT);
        root.add(btn2,1,1);
        // Add a label to the bottom right of the buttons
        root.add(new Label("Out there"),2,2);
        Scene scene = new Scene(root, 500, 200);
        primaryStage.setTitle("GridPane Demo");
        primaryStage.setScene(scene);
        primaryStage.show();
   }
}
Program Output
■ GridPane Demo
                                         X
 Option 1 This is Button 1
```

# GridPane Demo Option 1 This is Button 1 Option 2 Button 2 Out there

FIGURE 7.9 BorderPane Regions



#### The BorderPane Layout

The BorderPane layout places nodes within the five regions shown in Figure 7.9. The regions are named Top, Bottom, Left, Right, and Center. They correspond to a typical application with a menu or toolbar at the top, a navigation bar to the left, main content in the center, additional information to the right, and status information at the bottom.

Listing 7.19 demonstrates the BorderPane layout with buttons in each region. Note that you are not required to add to each region. If you leave a region empty then it will take no space. The center region will be resized to fill the available space in the middle. When you place items into each region, the default alignment is

Top: Pos.TOP\_LEFT
Bottom: Pos.BOTTOM\_LEFT
Left: Pos.TOP\_LEFT
Right: Pos.TOP\_RIGHT
Center: Pos.CENTER

# LISTING 7.19 The BorderPane Layout (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.BorderPane;
import javafx.scene.control.Button;
/**
Simple demonstration of adding buttons to the BorderPane layout.
*/
```

(continued)

# LISTING 7.19 The BorderPane Layout (part 2 of 2)

```
public class BorderPaneDemo extends Application
   public static void main(String[] args)
      launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
     BorderPane root = new BorderPane();
     root.setTop(new Button("Top Button"));
     root.setLeft(new Button("Left Button"));
     root.setCenter(new Button("Center Button"));
     root.setRight(new Button("Right Button"));
     root.setBottom(new Button("Bottom Button"));
     Scene scene = new Scene(root, 500, 200);
     primaryStage.setTitle("BorderPane Demo");
     primaryStage.setScene(scene);
     primaryStage.show();
   }
}
```

#### Program Output



JavaFX includes several other layout panes, such as the TitledPane, Accordion, AnchorPane, and ScrollPane. You can read about them on the Oracle website. They are used in a similar fashion as the panes we have described here, so once you understand the layout panes in the book it is relatively easy to learn how to use other layout panes. Similarly, there are many other user interface controls aside from the buttons and labels we have used so far. We will introduce text fields next, but there are many other controls that include radio buttons, sliders, scroll bars, and many more. You can also read about these UI controls on the Oracle website.

#### **RECAP Layout Panes**

JavaFX includes a number of built-in panes that control how components or nodes are displayed in a JavaFX application. Some of these panes are:

VBox	Displays nodes vertically.
HBox	Displays nodes horizontally.
FlowPane	Displays nodes left to right with a wrap-around back to the left.
StackPane	Displays nodes stack on top of each other.
GridPane	Displays nodes in a grid.
BorderPane	Displays nodes in regions top/left/right/bottom/center.

# Text Areas, Text Fields, and Combining Layouts

A **text area** is a window-like area in an application that can be used for text input and text output. A text area can have room for any number of lines and any number of characters per line. A **text field** is similar but has room for only one line of text. For example, the user can ask a question in the text area of an application. The application can then display an answer to the question in the same text area. We will write applications that lay out text fields and text areas in this chapter. In the next chapter, we will see how to make the program interact with these controls.

Text I/O can appear in a text area or a text field

To create a text area, use the TextArea class. The constructor allows you to set the initial text. You can also set the preferred width in pixels and the preferred number of rows and columns. The following sets the text area to "Default text" with a width of 200 pixels and the preference to display 4 rows and 40 columns. This is used to calculate the size of the object, although it may be overridden by the layout.

```
TextArea txtInfo = new TextArea("Default text");
txtInfo.setPrefWidth(100);
txtInfo.setPrefRowCount(4);
txtInfo.setPrefColumnCount(40);
```

A text field is created in a similar manner using the TextField class. There can only be one row in a text field. The following creates a text field with the specified default text and a preferred width of 200 pixels:

```
TextField txtOneLine = new TextField("Default text");
txtOneLine.setPrefWidth(200);
```

These UI controls are demonstrated in a FlowPane in Listing 7.20.

# LISTING 7.20 TextField and TextArea Demo (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.FlowPane;
import javafx.scene.control.TextField;
import javafx.scene.control.TextArea;
import javafx.scene.control.Label;
/ * *
Demonstration of TextField and TextArea controls.
public class TextControlDemo extends Application
   public static void main(String[] args)
      launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
      FlowPane root = new FlowPane();
      root.setVgap(5);
      root.setHgap(5);
      // Label and textfield for name
      root.getChildren().add(new Label("Name"));
      TextField txtName = new TextField("Enter name.");
      txtName.setPrefWidth(100);
      root.getChildren().add(txtName);
      // Label and textarea for info
      root.getChildren().add(new Label("Your Info"));
      TextArea txtInfo = new TextArea(
          "Enter some information\nabout yourself.");
      txtInfo.setPrefWidth(200);
      txtInfo.setPrefRowCount(4);
      txtInfo.setPrefColumnCount(40);
      root.getChildren().add(txtInfo);
      Scene scene = new Scene(root, 450, 150);
      primaryStage.setTitle("Text Control Demo");
      primaryStage.setScene(scene);
      primaryStage.show();
}
```

# LISTING 7.20 TextField and TextArea Demo (part 2 of 2)

#### Program Output



We can combine layouts to create our own custom layout. That is, the component of a layout can be another layout. This ability allows us to create a wide variety of layouts. To demonstrate this, we can insert the FlowPane from Listing 7.20 with the text field and text area into the center region of a BorderPane. We then add an HBox of buttons in the top region. The result is shown in Listing 7.21.

# LISTING 7.21 Combined Layout Demo (part 1 of 3)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.FlowPane;
import javafx.scene.layout.BorderPane;
import javafx.scene.layout.HBox;
import javafx.scene.control.TextField;
import javafx.scene.control.TextArea;
import javafx.scene.control.Label;
import javafx.scene.control.Button;
Embedding an HBox and FlowPane into a BorderPane.
public class CombinedLayout extends Application
{
   public static void main(String[] args)
      launch(args);
   }
```



(continued)

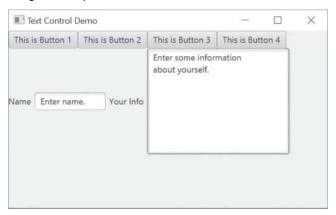
}

# LISTING 7.21 Combined Layout Demo (part 2 of 3)

```
@Override
public void start(Stage primaryStage) throws Exception
{
  BorderPane root = new BorderPane();
  // Create a FlowPane with a TextField and TextArea
  FlowPane centerPane = new FlowPane();
  centerPane.setVgap(5);
  centerPane.setHgap(5);
  // Label and textfield for name
  centerPane.getChildren().add(new Label("Name"));
  TextField txtName = new TextField("Enter name.");
  txtName.setPrefWidth(100);
  centerPane.getChildren().add(txtName);
  // Label and textarea for info
  centerPane.getChildren().add(new Label("Your Info"));
  TextArea txtInfo = new TextArea(
              "Enter some information\nabout yourself.");
  txtInfo.setPrefWidth(200);
  txtInfo.setPrefRowCount(8);
  txtInfo.setPrefColumnCount(40);
  centerPane.getChildren().add(txtInfo);
  // Create an HBox with four buttons
  HBox topPane = new HBox();
  topPane.getChildren().add(new Button("This is Button 1"));
  topPane.getChildren().add(new Button("This is Button 2"));
  topPane.getChildren().add(new Button("This is Button 3"));
  topPane.getChildren().add(new Button("This is Button 4"));
  // Add the FlowPane to the center
  root.setCenter(centerPane);
  // Add the HBox to the top
  root.setTop(topPane);
  Scene scene = new Scene(root, 450, 250);
  primaryStage.setTitle("Text Control Demo");
  primaryStage.setScene(scene);
 primaryStage.show();
```

# LISTING 7.21 Combined Layout Demo (part 3 of 3)

#### Program Output



#### **RECAP The Classes** TextArea and TextField

The classes TextArea and TextField can be used to add areas for changeable text to a JavaFX application. An object of the class TextArea has room for a specified number of lines and columns. An object of the class TextField has room for only one line that contains some specified number of characters. More text can be typed into a text area or text field than is specified in its size, but the extra text might not be visible.

#### **EXAMPLES**

```
TextField txtName = new TextField("Enter name.");
TextArea txtInfo = new TextArea("Enter information.");
txtInfo.setPrefRowCount(8);
txtInfo.setPrefColumnCount(40);
```

#### **RECAP Combing Layouts**

A node in a layout pane can contain another layout pane. By combining multiple layouts you can create your own custom layout.

#### **EXAMPLES**

```
// Add the FlowPane to the center of a BorderPane
root.setCenter(flowPane);
// Add a HBox to the top of a BorderPane
root.setTop(hBoxPane);
```



# **SELF-TEST QUESTIONS**

- 32. Suppose theText is an instance of TextArea. Write some code that will take the text currently in theText and replace it with that text written two times.
- 33. Using a BorderPane as the root, add a VBox with three buttons in the left region and a VBox with a single large text area in the center region.

# **Drawing Polygons**

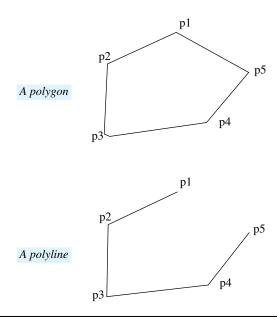
You can draw a rectangle in a JavaFX application using the GraphicsContext method strokeRect. However, a rectangle has four sides and 90-degree (right-angle) corners, and sometimes you want a figure with different angles and more or fewer sides. A **polygon** is any closed figure made up of line segments that do not cross. A rectangle is a special case of a four-sided polygon, but polygons may have any number of sides, and the angles between sides need not be 90 degrees.

You can specify a polygon by giving the locations of the corners. The polygon consists of the figure obtained by drawing lines between successive corner points. A **polyline** is similar to a polygon, but it is not closed. Figure 7.10 illustrates the difference between a polygon and a polyline. The figure shows five points labeled p1 through p5 and five lines connecting these points to form a polygon. The polyline has no line from the last point back to the first point.

A polygon is a closed figure composed of straight lines

A polyline connects points with straight lines, but is not closed

# FIGURE 7.10 A Polygon and a Polyline



The GraphicsContext method strokePolygon enables you to draw any polygon. The method requires three arguments: The first is an array of doubles specifying the x-coordinates of the points, the second is another array of doubles specifying the corresponding  $\gamma$ -coordinates of the points, and the third argument is the number of points. The two arrays contain the same number of values and can be partially filled, which is why the third argument is necessary.

The Graphics method fillPolygon is just like strokePolygon, but it fills the inside of the polygon with color. Likewise, the method strokePolyline is like strokePolygon but does not connect the last two points in the arrays with a line.

Listing 7.22 shows an application that displays a simple picture of a house. The house itself is a filled polygon drawn using strokePolygon, the window is a polygon drawn using strokePolygon, and the door is a polyline drawn using strokePolyline. Finally, strokeString labels the drawing.

# LISTING 7.22 Drawing Polygons (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.scene.Group;
import javafx.stage.Stage;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.paint.Color;
public class PolygonDemo extends Application
   private double[] xHouse = {150, 150, 200, 250, 250};
   private double[] yHouse = {100, 40, 20, 40, 100};
   private double[] xDoor = {175, 175, 200, 200};
   private double[] yDoor = {100, 60, 60, 100};
   private double[] xWindow = {220, 220, 240, 240};
   private double[] yWindow = {60, 80, 80, 60};
   public static void main(String[] args)
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
      Group root = new Group();
      Scene scene = new Scene(root);
      Canvas canvas = new Canvas (400, 150);
      GraphicsContext gc = canvas.getGraphicsContext2D();
      gc.setFill(Color.GREEN);
      gc.fillPolygon(xHouse, yHouse, xHouse.length);
```

strokePolygon, fillPolygon, and strokePolyline are in the class GraphicsContext

(continued)

# LISTING 7.22 Drawing Polygons (part 2 of 2)

```
gc.setFill(Color.BLACK);
   gc.strokePolyline(xDoor, yDoor, xDoor.length);
   gc.strokePolygon(xWindow, yWindow, xWindow.length);
   root.getChildren().add(canvas);
   primaryStage.setTitle("Home sweet home!");
   primaryStage.setScene(scene);
   primaryStage.show();
}
```

#### Program Output



# **RECAP The Methods** strokePolygon, fillPolygon, and strokePolyline

The methods strokePolygon, fillPolygon, and strokePolyline are methods in the class GraphicsContext.

#### **SYNTAX**

```
gc.strokePolygon(Array_0f_Xs, Array_0f_Ys, Number_0f_
Points);
```

Draws a polygon by connecting the points (Array\_Of\_Xs[i], Array\_Of\_ Ys[i]), for values of i ranging from 0 to Number\_Of\_Points, with line segments.

#### **EXAMPLES**

#### **SYNTAX**

```
canvas.fillPolygon(Array_Of_Xs, Array_Of_Ys, Number_Of_
Points);
```

Draws the same polygon as strokePolygon, but the inside of the polygon is filled in.

#### **EXAMPLE**

```
gc.fillPolygon(xCoord, yCoord, xCoord.length);
```

#### **SYNTAX**

Draws a polyline using the same points as specified for drawPolygon, but no line segment is drawn from the last point to the first point, so the figure is normally not closed.

#### **EXAMPLE**

```
gc.strokePolyline(xCoord, yCoord, xCoord.length);
```

# **SELF-TEST QUESTION**

34. You can draw a rectangle using the method drawRect, but you could also use strokePolygon. With gc as a calling object, write an invocation of strokePolygon that will draw a rectangle 10 pixels high and 20 pixels wide, whose upper left corner is at the point (7, 8).

#### CHAPTER SUMMARY

- An array can be thought of as a collection of variables all of the same type.
- Arrays are objects that are created using the operator new, although the syntax is slightly different from that used when creating objects of a class.
- Array elements are numbered starting with 0 and ending with 1 less than the length of the array. If a is an array, a[i] is an indexed variable of the array. The index i must have a value greater than or equal to 0 and strictly less than a.length, the array's length. If i has any other value when you run your program, an array index out-of-bounds error will occur, causing an error message.

- When an indexed variable is used as an argument to a method, it is treated just like any other argument whose data type is the same as the array's base type. In particular, if the base type is a primitive type, the method cannot change the value of the indexed variable, but if the base type is a class, the method can change the state of the object at the indexed variable.
- You can pass an entire array to a method. The method can change the values of an array of primitive values or the states of objects in the array.
- A method's return value can be an array.
- When you use only part of an array, you normally store values in an initial segment of the array and set an int variable to the number of these values. In this case, you have a partially filled array.
- An accessor method that returns an array corresponding to a private instance variable of an array type should be careful to return a copy of the array, as returning the private instance variable itself causes a privacy leak.
- The selection sort algorithm orders an array of values, such as numbers, into either increasing or decreasing order.
- Arrays can have more than one index, and so are called multidimensional. Multidimensional arrays are implemented in Java as arrays of arrays.
- A two-dimensional array can be thought of as a two-dimensional table of rows and columns. An indexed variable of such an array is an element whose row and column are indicated by its indices, where the first index designates the row, and the second index designates the column.
- Layout panes control how items are arranged in a window. You can nest different layout panes.
- You can insert text fields and text areas into a JavaFX application to provide it with text input and output.
- You can draw arbitrary polygons and polylines in a JavaFX application.

# **Exercises**

- 1. Write a program in a class EvensOddsAvg that counts the integers that are below the average. Read 15 integers from the keyboard and place them in an array. Compute the sum and count of the evens and the odds separately. Find the average of the integers, and count and display the integers that are below average.
- 2. Write a program in a class StudentCount that counts the number of students who obtained marks above 50% in a test. Read an integer *i* from the keyboard and then create an array of double values of size *i*. Read *i*

values representing the students' marks from the keyboard and place them into the array. Find the highest and the lowest among these marks. Then count the students who obtained more than 50% given as 500. Display this count and the marks of those students.

- 3. Write a program in a class RichCount that counts the number of families that are considered rich. Write and use a class Family that has the attributes
  - income—a double value that is the income for the family
  - size—the number of people in the family

and the following methods:

- Family(income, size)—a constructor that sets the attributes
- isRich(exp, sav)—a method that returns true if exp + sav \* size is greater than 60% of the family income (sav is the average savings of an individual, while exp is the expenditure done on the family)
- toString—a method that returns a string containing the information about the family

The program should read an integer k from the keyboard and then create an array of size k whose base type is Family. It should then create k objects of type Family and put them in the array, reading the income and size for each family from the keyboard. After reading an average expenditure and average savings from the keyboard, it should display the families that are rich.

- 4. Write a program in a class PastryCounter that calculates the cost of pastries sold at a bakery shop. Five flavors of pastries—pineapple, mango, chocolate, strawberry, and black forest—are stocked and cost, respectively, \$1.25, \$3.25, \$2.50, \$2.50, and \$3.75 per pastry. Create an array of strings that holds the names of these pastries. Create another array that holds the cost of each corresponding pastry. Your program should read the name of a pastry and the quantity desired by a customer. Locate the pastry in the name array and use that index to find the cost per piece in the cost array. Compute and print the total cost of the pastry sale.
- 5. Write a program in a class VowelFrequency that counts the number of times a vowel appears in a word. Your program should create an array of size 5 that will hold the count for each of the five vowels. Read a word from the keyboard as a string. Examine each vowel in the word and increment the appropriate count in the array. Display the contents of the array. Ignore the case while making checks.
- 6. Create a class Book that will record the books purchased by a person. It will have the attributes
  - booksPrices—an array of double values that are the prices of all books
  - booksPurchased—the number of books purchased so far
  - maxNumberBP—the maximum number of book purchases that can be recorded

and the following methods:

- Books (max)—a constructor that sets the maximum number of book purchases to max
- addPrice(p)—adds to an array a price whose value is p
- getNumberOfBooksPurchased—returns the number of books purchased
- getTotalBooksPrice—returns the total price of the books purchased
- 7. Define the following methods for the class Book, as described in the previous exercise:
  - getAverageBookPrice()—returns the average price of all the books purchased
  - getCountBelow(p)—returns the number of books that are less than p in value
- 8. Write a static method isStrictlyDecreasing(int[] dc) that returns true if each value in the given array is smaller than the value before it, and false otherwise.
- 9. Write a static method removeDuplicates (Character[] in) that returns a new array of the characters in the given array, but without any duplicate characters. Always keep the first copy of the character and remove subsequent ones. For example, if in contains b, d, a, b, f, a, g, a, a, and f, the method will return an array containing b, d, a, f, and g. (*Hint*: One way to solve this problem is to create a boolean array of the same size as the given array in and use it to keep track of which characters to keep. The values in the new boolean array will determine the size of the array to return.)
- 10. Write a static method remove(int v,int[] in) that will return a new array of the integers in the given array, but with the value v removed. For example, if v is 3 and in contains 0, 1, 3, 2, 3, 0, 3, and 1, the method will return an array containing 0, 1, 2, 0, and 1.
- 11. Suppose we are selling bouquets of flowers for an event. We have six kinds of flowers to sell: white rose, red rose, daisy, tulip, lily, and jasmine. We will record a customer's order as an array of six integers, representing the number of bouquets of each kind of flower. Write a static method firstOrder that takes a combined order and the second order and returns an array that represents the first order. For example, if combinedOrder contains 10, 12, 15, 20, 25, and 23, and secondOrder contains 8, 10, 5, 9, 13, and 15, then the method should return an array containing 2, 2, 10, 11, 12, and 8.
- 12. Create a class Polynomial that is used to evaluate a **polynomial** function of x:

$$P(x) = a_0 + a_1x + a_2x + \cdots + a_{n-1}x^{n-1} + a_nx^n$$

The **coefficients**  $a_i$  are floating-point numbers, the exponents of x are integers, and the largest exponent n—called the **degree** of the polynomial—is greater than or equal to 0. The class has the attributes

- ullet degree—the value of the largest exponent n
- coefficients—an array of the coefficients  $a_i$

and the following methods:

- Polynomial (max)—a constructor that creates a polynomial of degree max whose coefficients are all 0
- setConstant(i, value)—sets the coefficient  $a_i$  to value
- evaluate(x)—returns the value of the polynomial for the given value x

For example, the polynomial

$$P(x) = 3 + 5x + 2x^3$$

is of degree 3 and has coefficients  $a_0 = 3$ ,  $a_1 = 5$ ,  $a_2 = 0$ , and  $a_3 = 2$ . The invocation evaluate (7) computes  $3 + 5 \times 7 + 0 \times 7 + 2 = 7^3$ , which is 3 + 35 + 0 + 686, and returns the result 724.

- 13. Write a method beyondLastEntry(position) for the class OneWayNo-RepeatsList, as given in Listing 7.9, that returns true when position is beyond the last entry on the list.
- 14. Revise the class OneWayNoRepeatsList, as given in Listing 7.9, so that it allocates an extra element in the array entry and ignores entry [0], as suggested earlier near the end of the section entitled "More About Array Indices."
- 15. Write a static method for bubble sort that will sort an array of characters.
- 16. Overload the method selectionSort in Listing 7.10 so that it sorts an array whose indices range from first to last, where  $0 \le first \le last$ , and last is less than the length of the array.
- 17. Revise the method selectionSort that appears in Listing 7.10 so that it calls the method described in the previous exercise.
- 18. Revise the class TimeBook in Listing 7.14 to use an enumeration for the days of the week instead of named constants.
- 19. Write a sequential search of an array of integers, assuming that the array is sorted into ascending order. (*Hint*: Consider an array that contains the four integers 2, 4, 6, and 8. How can you tell that 5 is not in the array without comparing 5 to every integer in the array?)
- 20. Write a static method findFigure(picture, threshold), where picture is a two-dimensional array of double values. The method should return a new two-dimensional array whose elements are either 0.0 or 1.0. Each 1.0 in this new array indicates that the corresponding value in picture exceeds threshold times the average of all values in picture. Other elements in the new array are 0.0.

For example, if the values in picture are

1.2	1.3	4.5	6.2	2.7
1.7	3.3	4.4	10.5	17.0
1.1	4.5	2.1	25.3	9.2
1.0	9.5	8.3	2.9	2.1

the average value	is 5.55	The resulting	array for a	threshold of 1	4 would be

0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	1.0	1.0
0.0	0.0	0.0	1.0	1.0
0.0	1.0	0.0	0.0	0.0

and the resulting array for a threshold of 0.6 would be

0.0	0.0	1.0	1.0	0.0
0.0	0.0	1.0	1.0	1.0
0.0	1.0	0.0	1.0	1.0
0.0	1.0	1.0	0.0	0.0

21. Write a static method blur(double[][]picture) that you could use on a part of a picture file to obscure a detail such as a person's face or a license plate number. This method computes the weighted averages of the values in picture and returns them in a new two-dimensional array. To find a weighted average of a group of numbers, you count some of them more than others. Thus, you multiply each item by its weight, add these products together, and divide the result by the sum of the weights.

For each element in picture, compute the weighted average of the element and its immediate neighbors. Store the result in a new two-dimensional array in the same position that the element occupies in picture. This new array is the one the method returns.

The neighbors of an element in picture can be above, below, to the left of, and to the right of it, either vertically, horizontally, or diagonally. So each weighted average in the new array will be a combination of up to nine values from the array picture. A corner value will use only four values: itself and three neighbors. An edge value will use only six values: itself and five neighbors. But an interior value will use nine values: itself and eight neighbors. So you will need to treat the corners and edges separately from the other cells.

The weights to use are:

The element itself has the highest weight of 4, the horizontal and vertical neighbors have a weight of 2, and the diagonal neighbors have a weight of 1.

For example, suppose the values in picture are

1.2	1.3	4.5	6.0	2.7
1.7	3.3	4.4	10.5	17.0
1.1	4.5	2.1	25.3	9.2
1.0	9.5	8.3	2.9	2.1

and the new array is called result. In assigning weights, we will arbitrarily start with an element and consider neighbors in a clockwise direction. Thus, the interior value in result[1][1]is equal to

$$\frac{4(3.3) + 2(4.4) + 1(2.1) + 2(4.5) + 1(1.1) + 2(1.7) + 1(1.2) + 2(1.3) + 1(4.5)}{4 + 2 + 1 + 2 + 1 + 2 + 1 + 2 + 1}$$

To arrive at this equation, we started with the element at picture[1][1] and then, beginning with the neighbor to the right, we considered neighbors in a clockwise direction. The corner value in result[0][0]is equal to

$$\frac{4(1.2) + 2(1.3) + 1(3.3) + 2(1.7)}{4 + 2 + 1 + 2}$$

Note that picture[0][0] has fewer neighbors than an interior value such as picture[1][1]. The same is true for an edge value such as picture[0][1]. Thus, the edge value in result[0][1]is equal to

$$\frac{4(1.3) + 2(4.5) + 1(4.4) + 2(3.3) + 1(1.7) + 2(1.2)}{4 + 2 + 1 + 2 + 1 + 2}$$

The final array, result, would be

1.57	2.44	4.60	6.73	7.48
1.98	2.87	5.97	10.37	12.01
2.63	4.09	7.48	11.40	11.58
3.30	5.73	7.67	7.86	6.43

#### **PRACTICE PROGRAMS**

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

1. Write a program that reads integers, one per line, and displays their product. Also, display all the numbers read, each with an annotation giving its percentage contribution to the product. Use a method that takes the entire array as one argument and returns the product of the numbers in the array. (*Hint*: Ask the user for the number of integers to be entered, create an array of that length, and then fill the array with the integers read.) A possible dialogue between the program and the user follows:

```
How many numbers will you enter?

4
Enter 4 integers, one per line:

1
1
2
The product is 4.
The numbers are:
2, which is 50% of the product.
1, which is 25% of the product.
1, which is 50% of the product.
2, which is 50% of the product.
```

2. The following code creates a small phone book. An array is used to store a list of names and another array is used to store the phone numbers that go with each name. For example, Michael Myers' phone number is 333-8000 and Ash Williams' phone number is 333-2323.

Write the method lookupName so the code properly looks up and returns the phone number for the input target name. lookupName should return a blank string if the name is not in the phone book.

Programming Project 13 asks you to rewrite this program using an array of a single object. The object-based approach is more scalable than this approach, which requires a separate array to be managed for every property of the phone contact.

- 3. Write the method rotateRight that takes an array of integers and rotates the contents of the array to the right by two slots. Numbers that fall off the right should cycle back to the left. For example, if the input array is {1, 3, 5, 7} then the rotated array should be {5, 7, 1, 3}. If the input array is {1, 2, 3} then the rotated array should be {2, 3, 1}.
- 4. The following code creates a ragged 2D array. The first array has 3 slots where each entry references a second array. This second array starts with an Alaskan band name and members of the band. The length of the second array can be different for each band.

Note that band1 has six entries while band2 and band3 each have five entries. This makes alaskanBands a ragged array since its second dimension is not always the same size. Paste this code into a program and write a pair of nested loops to output the name and members of each band. Your program should work even if the array was modified to have a different number of bands or band members.

#### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

- 1. Write a program that will read a line of text that ends with a period, which serves as a sentinel value. Display all the letters that occur in the text, one per line and in alphabetical order, along with the number of times each letter occurs in the text. Use an array of base type int of length 26, so that the element at index 0 contains the number of a's, the element at index 1 contains the number of b's, and so forth. Allow both uppercase and lowercase letters as input, but treat uppercase and lowercase versions of the same letter as being equal. (Hints: Use one of the methods toUpperCase or toLowerCase in the wrapper class Character, described in Chapter 6. You will find it helpful to define a method that takes a character as an argument and returns an int value that is the correct index for that character. For example, the argument 'a' results in 0 as the return value, the argument 'b' gives 1 as the return value, and so on. Note that you can use a type cast, such as (int)letter, to change a char to an int. Of course, this will not get the number you want, but if you subtract (int)'a', you will then get the right index.) Allow the user to repeat this task until the user says she or he is through.
- 2. A **palindrome** is a word or phrase that reads the same forward and backward, ignoring blanks and considering uppercase and lowercase versions of the same letter to be equal. For example, the following are palindromes:

- warts n straw
- radar
- Able was I ere I saw Elba
- tacocat

Write a program that will accept a sequence of characters terminated by a period and will decide whether the string—without the period—is a palindrome. You may assume that the input contains only letters and blanks and is at most 80 characters long. Include a loop that allows the user to check additional strings until she or he requests that the program end. (*Hint*: Define a static method called isPalindrome that begins as follows.)

```
/**
Precondition: The array a contains letters and blanks in
positions a[0] through a[used - 1]. Returns true if the string
is a palindrome and false otherwise.
*/
public static boolean isPalindrome(char[] a, int used)
```

Your program should read the input characters into an array whose base type is char and then call the preceding method. The int variable used keeps track of how much of the array is used, as described in the section entitled "Partially Filled Arrays."

3. Add a method bubbleSort to the class ArraySorter, as given in Listing 7.10, that performs a **bubble sort** of an array. The bubble sort algorithm examines all adjacent pairs of elements in the array from the beginning to the end and interchanges any two elements that are out of order. Each interchange makes the array more sorted than it was, until it is entirely sorted. The algorithm in pseudocode follows:

# Bubble sort algorithm to sort an array a

Repeat the following until the array a is sorted:

```
for (index = 0; index <a.length - 1; index++)
   if (a[index] > a[index + 1])
        Interchange the values of a[index] and a[index + 1].
```

The bubble sort algorithm usually requires more time than other sorting methods

4. Add a method insertionSort to the class ArraySorter, as given in Listing 7.10, that performs an **insertion sort** of an array. To simplify this project, our insertion sort algorithm will use an additional array. It copies elements from the original given array to this other array, inserting each element into its correct position in the second array. This will usually require moving a number of elements in the array receiving the new elements. The algorithm in pseudocode is as follows:



#### Insertion sort algorithm to sort an array a

for (index = 0; index <a.length; index++)
 Insert the value of a[index] into its correct position in the array
 temp, so that all the elements copied into the array temp so far
 are sorted.</pre>

Copy all the elements from temp back to a.

The array temp is partially filled and is a local variable in the method sort.

- 5. The class TimeBook in Listing 7.14 is not really finished. Complete the definition of this class in the way described in the text. In particular, be sure to add a default constructor, as well as set and get methods that change or retrieve each of the instance variables and each indexed variable of each array instance variable. Be sure you replace the stub setHours with a method that obtains values from the keyboard. You should also define a private method having two int parameters that displays the first parameter in the number of spaces given by a second parameter. The extra spaces not filled by the first parameter are to be filled with blanks. This will let you write each array element in exactly four spaces, for example, and so will allow you to display a neat rectangular arrangement of array elements. Be sure that the main method in Listing 7.14 works correctly with these new methods. Also, write a separate test program to test all the new methods. (*Hint*: To display an int value n in a fixed number of spaces, use Integer. toString(n) to convert the number to a string value, and then work with the string value. This method is discussed in Chapter 6 in the section "Wrapper Classes.")
- 6. Define a class called TicTacToe. An object of type TicTacToe is a single game of tic-tac-toe. Store the game board as a single two-dimensional array of base type char that has three rows and three columns. Include methods to add a move, to display the board, to tell whose turn it is (X or O), to tell whether there is a winner, to say who the winner is, and to reinitialize the game to the beginning. Write a main method for the class that will allow two players to enter their moves in turn at the same keyboard.
- 7. Repeat Programming Project 10 from Chapter 5 but use an array to store the movie ratings instead of separate variables. All changes should be internal to the class, so the main method to test the class should run identically with either the old Movie class or the new Movie class using arrays.
- 8. Traditional password entry schemes are susceptible to "shoulder surfing" in which an attacker watches an unsuspecting user enter his or her password or PIN number and uses it later to gain access to the account. One way to combat this problem is with a randomized challenge-response system. In these systems the user enters different information every time based on a secret in response to a randomly generated challenge. Consider



the following scheme in which the password consists of a five-digit PIN number (00000 to 99999). Each digit is assigned a random number that is 1, 2, or 3. The user enters the random numbers that correspond to their PIN instead of their actual PIN numbers.

For example, consider an actual PIN number of 12345. To authenticate the user would be presented with a screen such as:

PIN: 0 1 2 3 4 5 6 7 8 9 NUM: 3 2 3 1 1 3 2 2 1 3

The user would enter 23113 instead of 12345. This doesn't divulge the password even if an attacker intercepts the entry because 23113 could correspond to other PIN numbers, such as 69440 or 70439. The next time the user logs in, a different sequence of random numbers would be generated, such as:

PIN: 0 1 2 3 4 5 6 7 8 9 NUM: 1 1 2 3 1 2 2 3 3 3

Write a program to simulate the authentication process. Store an actual PIN number in your program. The program should use an array to assign random numbers to the digits from 0 to 9. Output the random digits to the screen, input the response from the user, and output whether or not the user's response correctly matches the PIN number.

- 9. Write a GUI application that displays a picture of a pine tree formed by drawing a triangle on top of a small rectangle that makes up the visible trunk. The tree should be green and have a gray trunk.
- 10. ELIZA was a program written in 1966 that parodied a psychotherapist session. The user typed sentences and the program used those words to compose a question.

Create a simple GUI application based on this idea. The program will use a label to hold the program's question, a text field into which the user can type an answer, a button for the user to signal that the answer is complete, and a quit button.

The initial text for the question label should read: "What would you like to talk about?" When the user presses a button, get the text from the text field. Now extract the words from the text one at a time and find the largest word of length 4 or more. Let's call this largest word X for now. In response, create a question based on the length of the word. If the word is length 4, the new question is: "Tell me more about X." If the word is length 5, the new question is: "Why do you think X is important?" If the word is length 6 or more, the new question is: "Now we are getting somewhere. How does X affect you the most?" If there is no word of length 4, the new question is: "Maybe we should move on. Is there something else you would like to talk about?" (Hint: You can use the class Scanner to extract the words from a string, assuming blanks separate the words. For example, the following statements

Graphics

Graphics

```
String text = " one potato two potato ";
Scanner parser = new Scanner(text);
System.out.println(parser.next());
System.out.println(parser.next());
display one and potato on separate lines.)
```

11. Sudoku is a popular logic puzzle that uses a 9 by 9 array of squares that are organized into 3 by 3 subarrays. The puzzle solver must fill in the squares with the digits 1 to 9 such that no digit is repeated in any row, any column, or any of the nine 3 by 3 subgroups of squares. Initially, some squares are filled in already and cannot be changed. For example, the following might be a starting configuration for a Sudoku puzzle:

1	2	3	4	9	7	8	6	5
4	5	9						
6	7	8						
3				1				
2								
9					5			
8								
7								
5			9					

#### Create a class SudokuPuzzle that has the attributes

- board—a 9 by 9 array of integers that represents the current state of the puzzle, where 0 indicates a blank square
- start—a 9 by 9 array of boolean values that indicates which squares in board are given values that cannot be changed

## and the following methods:

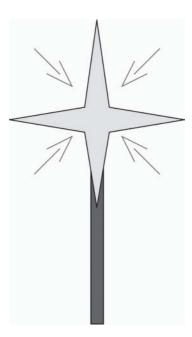
- SudokuPuzzle—a constructor that creates an empty puzzle
- toString—returns a string representation of the puzzle that can be printed
- addInitial(row, col, value)—sets the given square to the given value as an initial value that cannot be changed by the puzzle solver
- addGuess(row, col, value)—sets the given square to the given value; the value can be changed later by another call to addGuess
- checkPuzzle—returns true if the values in the puzzle do not violate the restrictions
- getValueIn(row, col)—returns the value in the given square

- getAllowedValues(row, col)—returns a one-dimensional array of nine booleans, each of which corresponds to a digit and is true if the digit can be placed in the given square without violating the restrictions
- isFull—returns true if every square has a value
- reset—changes all of the nonpermanent squares back to blanks (0s)

Write a main method in the class Sudoku that creates a SudokuPuzzle object and sets its initial configuration. Then use a loop to allow someone to play Sudoku. Display the current configuration and ask for a row, column, and value. Update the game board and display it again. If the configuration does not satisfy the restrictions, let the user know. Indicate when the puzzle has been solved correctly. In that case, both checkPuzzle and isFull would return true. You should also allow options for resetting the puzzle and displaying the values that can be placed in a given square.

Graphics

12. Create a GUI application that draws the following picture of a magic wand, using polygons and polylines:



13. Practice Program 2 used two arrays to implement a simple phone book. A more scalable solution is to make an array of an object that stores the name and corresponding phone number. Modify the program to use a single array of an object. The output should remain the same.

- 14. Practice Program 5.4 asked you to define a Trivia class that contained strings representing a trivia question and answer to that question. Add an integer for the number of points that the question is worth if the player gets the question right. Create constructor, accessor, and mutator methods. Use this class in a program that creates an array of 10 Trivia objects. You can select questions, answers, and point values of your choice. Make a loop that asks each trivia question to the player, input an answer, output whether the answer is correct or incorrect (if incorrect also output the correct answer), and after all questions have been asked output the user's score.
- 15. Write a program that manages a list of up to 10 players and their high scores in the computer's memory. Use two arrays to manage the list. One array should store the player's name and the other array should store the player's high score. Use the index of the arrays to correlate the name with the score. In the next Programming Project, we ask you to do the same thing, but using an array of a class. Your program should start with zero players in the list and support the following features:
  - a. Add a new player and score. If it is one of the top 10 scores then add it to the list of scores. The same name and score can appear multiple times. For example, if Bill played 3 times and scored 100,100, and 99, and Bob played once and scored 50, then the top scores would be Bill 100, Bill 100, Bill 99, Bob 50.
  - b. Print the top 10 names and scores to the screen sorted by score (highest at the top).
  - c. Allow the user to enter a player name and output that player's highest score if it is on the top 10 list or a message if the player's name has not been input or is not in the top 10.
  - d. Allow the user to enter a player name and remove the highest score for that player from the list.

Create a menu system that allows the user to select which option to invoke.

- 16. Do Programming Project 15 except use a class named Player to store a player's name and score. Use a single array of type Player. Be sure to include a constructor with this class that sets the name and score.
- 17. Create a JavaFX application to create the interface for a calculator. Use a BorderPane in the stage with a TextField at the top. The text field would be used to store the number being entered in the calculator as digits are entered. Create buttons for digits 0–9 in a GridPane in the center of the BorderPane. Create buttons for the operators \*, /, +, on the left. Create a button for = on the right.

Your application won't actually function as a calculator at this point. You are just designing the interface.

## **Answers to Self-Test Questions**

```
1. 0 2 4 6 8 10 12 14 16 18
2. a
e
i
o
u
3. Tide 1 is -7.3|
Tide 2 is 14.2
```

- 4. The last index of a is 9. The value of a.length is 10.
- 5. The for loop references elements b[1] through b[10], but there is no element indexed by 10. The array elements are b[0] through b[9]. If included in a complete class or program, the code would compile without any error messages, but when it is run, you would get an error message saying that an array index is out of bounds.

```
6. import java.util.Scanner;
  public class Question6
  {
      public static void main(String[] args)
           double[] array = new double[20];
           Scanner keyboard = new Scanner(System.in);
           System.out.println("Enter 20 numbers:");
           for (int index = 0; index <array.length; index++)</pre>
           array[index] = keyboard.nextDouble();
           double lastNumber = array[array.length - 1];
           System.out.println("The last number read is " +
                               lastNumber + ".");
           System.out.println("The numbers read and their " +
                               "differences from last number are:");
           for (int index = 0; index <array.length; index++)</pre>
           System.out.println(array[index] +
           " differs from the last number by " +
                               (array[index] - lastNumber));
      }
  }
7. SalesAssociate[] entry = new SalesAssociate[3];
  for (int i = 0; i <entry.length; i++)</pre>
      entry[i] = new SalesAssociate("Jane Doe", 5000);
```

8. The lines that are changed are shown in highlight in the following code. Note that you should also change the definition of the method writeOutput in the class SalesAssociate. We have also shown this method in the following code. Remember that you must make the class

DollarFormat available, either by placing it in the same directory or by putting it in a package and importing the package.

```
/**
Displays sales report on the screen.
public void displayResults()
    System.out.print("Average sales per associate is ");
    DollarFormat.writeln(averageSales);
    System.out.print("The highest sales figure is ");
    DollarFormat.writeln(highest);
   System.out.println();
    System.out.println("The following had the highest sales:");
    for (int i = 1; i <= numberOfAssociates; i++)</pre>
         double nextSales = team[i].getSales();
         if (nextSales == highest)
         {
             team[i].writeOutput();
             DollarFormat.write(nextSales - averageSales);
             System.out.println(" above the average.");
             System.out.println();
         }
    }
   System.out.println("The rest performed as follows:");
    for (i = 1; i <= numberOfAssociates; i++)</pre>
    {
         double nextSales = team[i].getSales();
         if (team[i].getSales() != highest)
            team[i].writeOutput();
            if (nextSales >= averageSales)
                DollarFormat.write(nextSales - averageSales);
                System.out.println(" above the average.");
            }
            else
            {
                DollarFormat.write(averageSales - nextSales);
                System.out.println(" below the average.");
            System.out.println();
        }
   }
}
```

The following is the rewritten version of the method writeOutput of the class SalesAssociate, with the changes shown in highlight:

```
public void writeOutput()
   {
       System.out.println("Sales associates: " + name);
       System.out.print("Sales: ");
       DollarFormat.writeln(sales);
   }
9. a[1] = a, b[1] = a
   a[2] = a, b[2] = a
   a[1] = a, b[1] = a
   a[2] = b, b[2] = b
10. Here are two possible answers:
   public static void showArray(char[] a)
       for (int i = 0; i <a.length; i++)</pre>
           System.out.print(a[i]);
       System.out.println();
   public static void showArray(char[] line)
   {
       for (char character : line)
           System.out.print(character);
       System.out.println();
11. public s tatic double[] getArrayOfHalves(double[] a)
       double[] temp = new double[a.length];
       for (int i = 0; i < a.length; i++)</pre>
           temp[i] = a[i] / 2.0;
       return temp;
   }
```

12. The method does not return an array distinct from the given argument array. Rather, it returns a reference to the array it is given. To make a duplicate array, you would replace the statement

```
temp = anArray;
with
for (int i = 0; i <anArray.length; i++)
   temp[i] = anArray[i];</pre>
```

13. If b is an array of length 10, the invocation

```
doubleSize(b);
```

will run with no error messages, but the length of b will not change. In fact, nothing about b will change. The parameter a is a local variable that is initialized with a reference to b. The local variable a is changed so that it

contains a reference to an array that is twice the size of b, but that reference goes away as soon as the invocation ends.

14. The method compiles and executes correctly. It returns a reference to the instance variable team, which is an array of SalesAssociate objects. However, this method causes a privacy leak. Once you have a reference to the array team, you could change the data in the array. For example, you could change your competitor's sales to zero by using the SalesAssociate method set.

```
15. int count = toDoList.getNumberOfEntries();
   for (int pos = toDoList.START_POSITION;
       pos <= count; pos++)</pre>
       System.out.println(toDoList.getEntryAt(position));
16. if (!toDoList.isEmpty())
       int position = toDoList.START_POSITION;
       while (!toDoList.atLastEntry(position))
           System.out.println(toDoList.getEntryAt(position));
           position++;
       System.out.println(toDoList.getEntryAt(position));
   }
17. One answer is
   for (int i = 0; i < a.length; i++)
       System.out.println(a[i]);
   Another answer is
   for (double element : a)
       System.out.println(element);
18. for (int i = 0; i < numberUsed; i++)
       System.out.println(a[i]);
   A for-each loop is not possible here.
19. a[0], a[1], and a[2].
   numberUsed is 3.
20. a[numberUsed] = 42;
   numberUsed++:
21. if (numberUsed == a.length)
   System.out.println("Array is full.
       Cannot add to it.");
   else
       a[numberUsed] = 42;
       numberUsed++:
   }
```

- 24. ArraySorter.selectionSort(myArray);
- 25. Change the base type of the array from int to double. You can simply replace all occurrences of int with double, except for those occurrences of int that give the type of an index. For example, you would replace

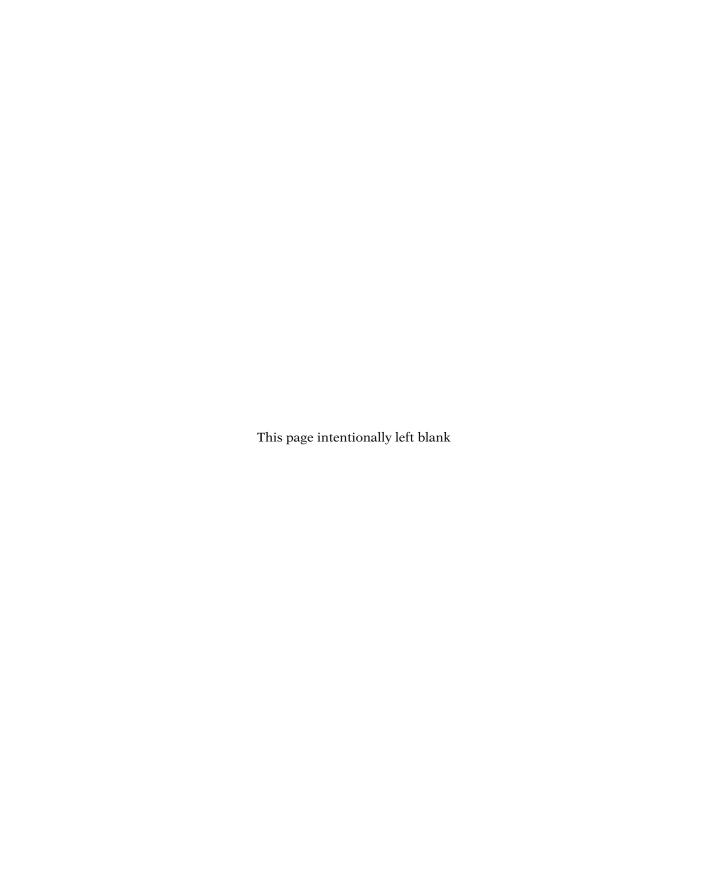
```
private static void interchange(int i, int j, int[] a)
with
private static void interchange(int i, int j, double[] a)
Note that i and j are indices, and so they are still of type int.
```

26. Replace the < with > in the following line of the definition of getIndexOfSmallest:

```
if (a[index] < min)</pre>
```

However, to make your code more readable, you should rename the method to something like getIndexOfLargest, rename the variable min to something like max, and rename the variable indexOfMin to something like indexOfMax. You should also rewrite some of the comments.

```
for (int column = 0; column <anArray[row].length;</pre>
                column++)
                System.out.print("$"+anArray[row][column]
                                + " ");
            System.out.println();
       }
   }
   This method can be seen within the class InterestTable3 in the code
   available on the Web.
30. int[][] a = new int [4][5];
   System.out.println("Enter numbers:");
   Scanner keyboard = new Scanner(System.in);
        for (int row = 0; row < 4; row++)
        for (int column = 0; column < 5; column++)</pre>
            a[row][column] = keyboard.nextInt();
   Alternatively, you could begin the for statements as
   for (int row = 0; row < a.length; row++)</pre>
        for (int column = 0; column < a[row].length;</pre>
            column++)
31. public static void display(int[][] anArray)
        for (int row = 0; row < anArray.length; row++)</pre>
            for (int column = 0; column <</pre>
               anArray[row].length; column++)
            System.out.print(anArray[row][column] +" ");
            System.out.println();
        }
   }
32. BorderPane root = new BorderPane();
   VBox centerPane = new VBox();
   centerPane.getChildren().add(new TextAra());
   VBox leftPane = new VBox();
   leftPane.getChildren().add(new Button("Button 1"));
   leftPane.getChildren().add(new Button("Button 2"));
   leftPane.getChildren().add(new Button("Button 3"));
   root.setCenter(centerPane);
   root.setLeft(leftPane);
33. private int[] xCoord = {7, 27, 27, 7};
   private int[] yCoord = {8, 8, 18, 18};
   gc.strokePolygon(xCoord, yCoord, xCoord.length);
```



# Inheritance, Polymorphism, and Interfaces

### **8.1 INHERITANCE BASICS** 622

Derived Classes 624
Overriding Method Definitions 628
Overriding Versus Overloading 629
The final Modifier 629
Private Instance Variables and Private Methods of a Base Class 630
UML Inheritance Diagrams 632

# **8.2 PROGRAMMING WITH INHERITANCE** 635

Constructors in Derived Classes 635
The this Method—Again 637
Calling an Overridden Method 637
Programming Example: A Derived Class of a Derived Class 638
Another Way to Define the equals Method in Undergraduate 643
Type Compatibility 643
The Class Object 648
A Better equals Method 650

### **8.3 POLYMORPHISM** 652

Dynamic Binding and Inheritance 652
Dynamic Binding with toString 655

# 8.4 INTERFACES AND ABSTRACT CLASSES 657

Class Interfaces 657
Java Interfaces 658
Implementing an Interface 659
An Interface as a Type 661
Extending an Interface 664
Case Study: Character Graphics 665
Case Study: The Comparable Interface 678
Abstract Classes 682

## **8.5 GRAPHICS SUPPLEMENT** 684

Event-Driven Programming 685
Event Handling in a Separate Class 686
Event Handling in the Main GUI Application
Class 689
Event Handling in an Anonymous Inner Class 691
Programming Example: Adding Numbers 694

To understand a name you must be acquainted with the particular of which it is a name.

-BERTRAND RUSSELL

Like mother, like daughter

-COMMON SAYING

This chapter covers inheritance, polymorphism, and interfaces, three key concepts in object-oriented programming. These concepts are also needed in order to use many of the libraries that come with the Java programming language. Polymorphism makes objects behave as you expect them to and allows you to focus on the specifications of those behaviors. Inheritance will enable you to use an existing class to define new classes, making it easier to reuse software. Finally, interfaces allow you to specify the methods that a class must implement.

## **OBJECTIVES**

After studying this chapter, you should be able to

- Describe polymorphism and inheritance in general
- Define interfaces to specify methods
- Describe dynamic binding
- Define and use derived classes in Java
- Understand the role of event handling in a JavaFX application

## **PREREOUISITES**

You need to have read the material in Chapters 1 through 6 before you can understand the material in this chapter. Chapter 7 is needed to understand some of the examples presented in Sections 8.3 and 8.4.

## **8.1** INHERITANCE BASICS

Socrates is a person.

All people are mortal.

Therefore socrates is mortal.

—TYPICAL SYLLOGISM

Suppose we define a class for vehicles that has instance variables to record the vehicle's number of wheels and maximum number of occupants. The class also has accessor and mutator methods. Imagine that we then define a class for

automobiles that has instance variables and methods just like the ones in the class of vehicles. In addition, our automobile class would have added instance variables for such things as the amount of fuel in the fuel tank and the license plate number and would also have some added methods. Instead of repeating the definitions of the instance variables and methods of the class of vehicles within the class of automobiles, we could use Java's inheritance mechanism, and let the automobile class inherit all the instance variables and methods of the class for vehicles.

**Inheritance** allows you to define a very general class and then later define more specialized classes that add some new details to the existing general class definition. This saves work, because the more specialized class *inherits* all the properties of the general class and you, the programmer, need only program the new features.

Before we construct an example of inheritance within Java, we first need to set the stage. We'll do so by defining a simple class called Person. This class—shown in Listing 8.1—is so simple that the only attribute it gives a person is a

Inheritance lets you define specialized classes from a general

## LISTING 8.1 The Class Person

```
public class Person
{
    private String name;
    public Person()
    {
        name = "No name yet";
    }
    public Person(String initialName)
    {
        name = initialName;
    }
    public void setName(String newName)
    {
        name = newName;
    }
    public String getName()
    {
        return name;
    }
    public void writeOutput()
    {
        System.out.println("Name: " + name);
    }
    public boolean hasSameName(Person otherPerson)
    {
        return this.name.equalsIgnoreCase(otherPerson.name);
    }
}
```

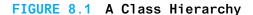
name. We will not have much use for the class Person by itself, but we will use it when defining other classes.

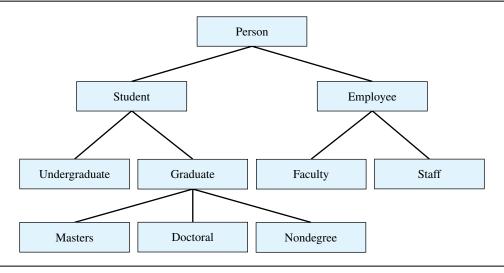
Most of the methods for the class Person are straightforward. For example, the method hasSameName is similar to the equals methods we've seen, but note that it considers uppercase and lowercase versions of a letter to be the same when comparing names.

## **Derived Classes**

Suppose we are designing a college record-keeping program that has records for students, faculty, and other staff. There is a natural hierarchy for grouping these record types: They are all records of people. Students are one subclass of people. Another subclass is employees, which includes both faculty and staff. Students divide into two smaller subclasses: undergraduate students and graduate students. These subclasses may further subdivide into still smaller subclasses.

Figure 8.1 depicts a part of this hierarchical arrangement. Although your program may not need any class corresponding to people or employees, thinking in terms of such classes can be useful. For example, all people have names, and the methods of initializing, displaying, and changing a name will be the same for student, staff, and faculty records. In Java, you can define a class called Person that includes instance variables for the properties that belong to all subclasses of people. The class definition can also contain all the methods that manipulate the instance variables for the class Person. In fact, we have already defined such a Person class in Listing 8.1.





Listing 8.2 contains the definition of a class for students. A student is a person, so we define the class Student to be a **derived class**, or **subclass**, of the class Person. A derived class is a class defined by adding instance variables and methods to an existing class. We say that the derived class **extends** the existing class. The existing class that the derived class is built upon is called the **base class**, or **superclass**. In our example, Person is the base class and Student is the derived class. We indicated this in the definition of Student in Listing 8.2 by including the phrase extends Person on the first line of the class definition, so that the class definition of Student begins

A derived class extends a base class and inherits the base class's public members

public class Student extends Person

## LISTING 8.2 A Derived Class (part 1 of 2)

```
public class Student extends Person
                                        super is explained in a later section.
    private int studentNumber;
                                        Do not worry about it until you reach
    public Student()
                                        the discussion of it in the text.
        super();
        studentNumber = 0;//Indicating no number yet
    public Student(String initialName, int initialStudentNumber)
        super(initialName);
        studentNumber = initialNumber;
    public void reset(String newName, int newStudentNumber)
        setName(newName);
        studentNumber = newStudentNumber;
    public int getStudentNumber()
        return studentNumber;
    public void setStudentNumber(int newStudentNumber)
        studentNumber = newStudentNumber;
    public void writeOutput()
        System.out.println("Name: " + getName());
        System.out.println("Student Number: " + studentNumber);
    }
```

(continued)

## LISTING 8.2 A Derived Class (part 2 of 2)

The class Student—like any other derived class—is said to inherit the public instance variables and public methods of the base class that it extends. When you define a derived class, you give only the added instance variables and the added methods. Even though the class Student has all the public instance variables and all the public methods of the class Person, we do not declare or define them in the definition of Student. For example, every object of the class Student has the method getName, but we do not define getName in the definition of the class Student.

A derived class, such as Student, can also add some instance variables or methods to those it inherits from its base class. For example, Student defines the instance variable studentNumber and the methods reset, getStudentNumber, setStudentNumber, writeOutput, and equals, as well as some constructors. (We will postpone the discussion of constructors until we finish explaining the other parts of these class definitions.)

Notice that although Student does not inherit the private instance variable name from Person, it does inherit the method setName and all the other public methods of the base class. Thus, Student has indirect access to name and so has no need to define its own version. If s is a new object of the class Student, defined as

```
Student s = new Student();
we could write
s.setName("Warren Peace");
```

Because name is a private instance variable of Person, however, you cannot write s.name outside of the definition of the class Person, not even within the definition of Student. The instance variable exists, however, and it can be accessed and changed using methods defined within Person. Listing 8.3 contains a very small demonstration program to illustrate inheritance.

An object of Student has all of the methods of Person in addition to all of the methods of Student. Earlier, we noted that a student is a person. The classes Student and Person model this real-world relationship in that Student has all the behaviors of Person. We call this relationship an **is-a relationship**. You should use inheritance only if an is-a relationship exists between a class and a proposed derived class.

Inheritance should define a natural is-a relationship between two classes

# LISTING 8.3 A Demonstration of Inheritance Using Student

```
public class InheritanceDemo
{
    public static void main(String[] args)
    {
        Student s = new Student();
        s.setName("Warren Peace")
        s.setStudentNumber(1234);
        s.writeOutput();
    }
}

    setName is inherited
    from the class Person.
    s.writeOutput();
}
```

## Screen Output

Name: Warren Peace Student Number: 1234

# PROGRAMMING TIP Use Inheritance Only to Model Is-a Relationships

If an is-a relationship does not exist between two proposed classes, do not use inheritance to derive one class from the other. Instead, consider defining an object of one class as an instance variable within the other class. That relationship is called has-a. The programming tip titled "Is-a and Has-a Relationships" talks more about these two relationships.

When discussing derived classes, it is common to use terminology derived from family relationships. A base class is often called a **parent class**. A derived class is then called a **child class**. This makes the language of inheritance very smooth. For example, we can say that a child class inherits public instance variables and public methods from its parent class.

This analogy is often carried one step further. A class that is a parent of a parent of a parent of another class (or some other number of "parent of" iterations) is often called an **ancestor class**. If class A is an ancestor of class B, then class B is often called a **descendant** of class A.

A base class is also called a superclass, a parent class, and an ancestor class

#### **RECAP Derived Class**

You define a derived class, or subclass, by starting with another already defined class and adding (or changing) methods and instance variables. The class you start with is called the base class, or superclass. The derived (continued)

class inherits all of the public methods and public instance variables from the base class and can add more instance variables and methods.

#### **SYNTAX**

```
public class Derived_Class_Name extends Base_Class_Name
{
    Declarations_of_Added_Instance_Variables
    Definitions_of_Added__And_Changed_Methods
}
```

#### **EXAMPLE:**

See Listing 8.2.

As you will see in the next section, changed methods are said to be overridden.

A derived class is also called a subclass, a child class, and a descendant class

Overriding a

class

method redefines

it in a descendant

# **Overriding Method Definitions**

The class Student in Listing 8.2 defines a method named writeOutput that has no parameters. But the class Person also has a method by the same name that has no parameters. If the class Student were to inherit the method writeOutput from the base class Person, Student would contain two methods with the name writeOutput, both of which have no parameters. Java has a rule to avoid this problem. If a derived class defines a method with the same name, the same number and types of parameters, and the same return type as a method in the base class, the definition in the derived class is said to **override** the definition in the base class. In other words, the definition in the derived class is the one that is used for objects of the derived class. For example, the invocation

```
s.writeOutput();
```

in Listing 8.3 will use the definition of writeOutput in the class Student, not the definition in the class Person, since s is an object of the class Student.

When overriding a method, you can change the body of the method definition to anything you wish, but you cannot make any changes in the method's heading, including its return type.

A method overrides another if both have the same name, return type, and parameter list

## **RECAP Overriding Method Definitions**

In a derived class, if you include a method definition that has the same name, the *exact* same number and types of parameters, and the same return type as a method already in the base class, this new definition

(continued)

replaces the old definition of the method when objects of the derived class receive a call to the method.

When overriding a method definition, you cannot change the return type of the method. Since the signature of a method does not include the return type, you can say that when one method overrides another, both methods must have the same signature and return type.

# **Overriding Versus Overloading**

Do not confuse *overriding* a method with *overloading* a method. When you override a method definition, the new method definition given in the derived class has the same name, the same return type, and the exact same number and types of parameters. On the other hand, if the method in the derived class were to have the same name and the same return type but a different number of parameters or a parameter of a different type from the method in the base class, the method names would be overloaded. In such cases, the derived class would have both methods.

A method overloads another if both have the same name and return type but different parameter lists

For example, suppose we added the following method to the definition of the class Student in Listing 8.2:

```
public String getName(String title)
{
    return title + getName();
}
```

In this case, the class Student would have two methods named getName: It would inherit the method getName, with no parameters, from the base class Person (Listing 8.1), and it would also have the method named getName, with one parameter, that we just defined. This is because the two getName methods have different numbers of parameters, and thus the methods use overloading.

If you get overloading and overriding confused, remember this: Overloading places an additional "load" on a method name by using it for another method, whereas overriding replaces a method's definition.

## The final Modifier

If you want to specify that a method definition cannot be overridden by a new definition within a derived class, you can add the final modifier to the method heading, as in the following sample heading:

A final method cannot be overridden

```
public final void specialMethod()
```

When a method is declared as final, the compiler knows more about how it will be used, and so the compiler can generate more efficient code for the method.

A final class cannot be a base class

An entire class can be declared final, in which case you cannot use it as a base class to derive any other class. You are not very likely to need the final modifier right now, but you will see it in the specifications of some methods in the standard Java libraries.

## PROGRAMMING TIP Constructors That Call Methods

If a constructor calls a public method, a derived class could override that method, thereby affecting the behavior of the constructor. To prevent that from happening, declare such public methods as final.

# Private Instance Variables and Private Methods of a Base Class

An object of the derived class Student (Listing 8.2) does not inherit the instance variable name from the base class Person (Listing 8.1), but it can access or change name's value via the public methods of Person. For example, the following statements create a Student object and set the values of the instance variables name and studentNumber:

```
Student joe = new Student();
joe.reset("Joesy", 9892);
```

Since the instance variable name is a private instance variable in the definition of the class Person, it cannot be directly accessed by name within the definition of the class Student. Thus, the definition of the method reset in the class Student is

It cannot be as follows:

As the comment indicates, this assignment will not work, because a derived class does not inherit private instance variables from its base class. Thus, the definition of reset in the class Student uses the method setName to set the name instance variable.



Private instance variables in a base class are not inherited by a derived class; they cannot be referenced directly by name within a derived class

# **GOTCHA** Private Instance Variables Are Not Directly Accessible from Derived Classes

A derived class cannot access the private instance variables of its base class directly by name. It knows only about the public behavior of the base class. The derived class is not supposed to know—or care—how its base class stores data. However, an inherited public method may contain a reference to a private instance variable.

The fact that a private instance variable of a base class cannot be accessed by name within the definition of a method of a derived class often seems wrong to people. After all, students should be able to change their own names, rather than being told "Sorry, name is a private instance variable of the class Person." If you are a student, you are also a person. In Java, this is also true; an object of the class Student is also an object of the class Person. However, the rules regarding the use of private instance variables must be as we have described, or else the private designation would be pointless. If private instance variables of a class were accessible in method definitions of a derived class, whenever you wanted to access a private instance variable, you could simply create a derived class and access it in a method of that class. This would mean that all private instance variables would be accessible to anybody who wanted to put in a little extra effort.

Similarly, private methods in a base class are not directly accessible by name within any other class, not even a derived class. The private methods still exist, however. If a derived class calls an inherited *public* method that contains an invocation of a private method, that invocation still works. However, a derived class cannot define a method that invokes a private method of the base class. This should not be a problem. Private methods should serve only as helping methods, and so their use should be limited to the class in which they are defined. If you want a method to serve as a helping method in a number of derived classes, it is more than just a helping method, and you should make the method public.

Private methods in a base class are not inherited by a derived class; they cannot be called directly by name from a derived class

# **GOTCHA** Private Methods Are Not Directly Accessible from Derived Classes

A derived class cannot call a private method defined within the base class. However, the derived class can call a public method that in turn calls a private method when both methods are in the base class.

# PROGRAMMING TIP Assume That Your Coworkers Are Malicious

The reason private instance variables cannot be accessed by name in a derived class is that otherwise a malicious programmer could access them by using a trick. You may argue that your coworkers are not malicious. In fact, in a

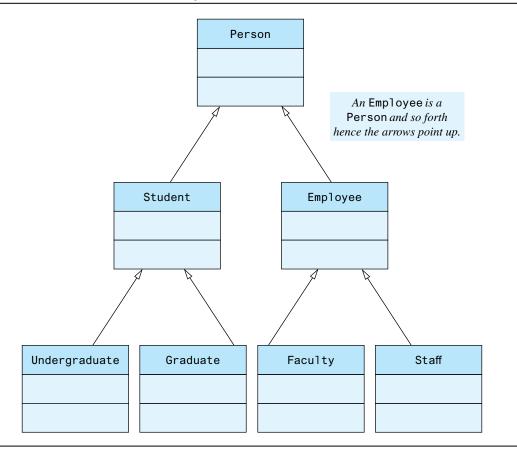
beginning course you may sometimes be the only programmer on an assignment, and you certainly are not trying to sabotage your own work. Those are good points. However, your coworkers—or even you yourself—might inadvertently do something that, although not intended to be malicious, still creates a problem. We think in terms of a malicious programmer not because we think our coworkers are malicious, but because that is the best way to protect against honest mistakes by well-meaning programmers—including you!

An arrow points up from a derived class to a base class in a UML diagram

# **UML Inheritance Diagrams**

Figure 8.2 shows a portion of the class hierarchy given in Figure 8.1, but uses UML notation. Note that the class diagrams are incomplete. You normally show only as much of the class diagram as you need for the design task at hand.

FIGURE 8.2 A Class Hierarchy in UML Notation



The only significant difference between the notation in Figure 8.2 and that in Figure 8.1 is that the lines indicating inheritance in Figure 8.2 have unfilled arrowheads. Note that the arrowheads point up from the derived class to the base class. These arrows show the is-a relationship. For example, a Student is a Person. In Java terms, an object of type Student is also of type Person.

The arrows also help in locating method definitions. If you are looking for a method definition for some class, the arrows show the path you (or the computer) should follow. If you are looking for the definition of a method used by an object of the class Undergraduate, you first look in the definition of the class Undergraduate; if it is not there, you look in the definition of Student; if it is not there, you look in the class Person.

Figure 8.3 shows more details of the inheritance hierarchy for two classes: Person and one of its derived classes, Student. Suppose s references an object

FIGURE 8.3 Some Details of the UML Class Hierarchy Shown in Figure 8.2

```
Person

- name: String

+ setName(String newName): void
+ getName(): String
+ writeOutput(): void
+ hasSameName(Person otherPerson)): boolean

Student

- studentNumber: int

+ reset(String newName, int newStudentNumber): void
+ getStudentNumber(): int
+ setStudentNumber(int newStudentNumber): void
+ writeOutput(): void
+ equals(Student otherStudent): boolean
```

of the class Student. The diagram in Figure 8.3 tells you that definition of the method getStudentNumber in the call

```
int num = s.getStudentNumber();
```

is found within the class Student, but that the definition of setName in

```
s.setName("Joe Student");
```

is in the class Person.



## **SELF-TEST QUESTIONS**

- 1. What is the difference between overriding a method and overloading a method name?
- 2. Suppose the class SportsCar is a derived class of a class Automobile. Suppose also that the class Automobile has private instance variables named speed, manufacturer, and numberOfCylinders. Will an object of the class SportsCar have instance variables named speed, manufacturer, and numberOfCylinders?
- 3. Suppose the class SportsCar is a derived class of a class Automobile, and suppose also that the class Automobile has public methods named accelerate and addGas. Will an object of the class SportsCar have methods named accelerate and addGas? If so, do these methods have to perform the exact same actions in the class SportsCar as in the class Automobile?
- 4. Can a derived class directly access by name a private instance variable of the base class?
- 5. Can a derived class directly invoke a private method of the base class?
- 6. Suppose s is an object of the class Student. Based on the inheritance diagram in Figure 8.3, where will you find the definition of the method hasSameName, used in the following invocation? Explain your answer.

```
Student other = new Student("Joe Student", 777);
if (s.hasSameName(other))
    System.out.println("Wow!");
```

7. Suppose s is an object of the class Student. Based on the inheritance diagram in Figure 8.3, where will you find the definition of the method used in the following invocation? Explain your answer.

```
s.setStudentNumber(1234);
```

## **8.2** PROGRAMMING WITH INHERITANCE

You do not have to die in order to pass along your inheritance.

```
—AD FOR AN ESTATE PLANNING SEMINAR
```

This section presents some basic programming techniques you need when defining or using derived classes.

## Constructors in Derived Classes

A derived class, such as the class Student in Listing 8.2, has its own constructors. It does not inherit any constructors from the base class. A base class, such as Person, also has its own constructors. In the definition of a constructor for the derived class, the typical first action is to call a constructor of the base class. For example, consider defining a constructor for the class Student. One thing that needs to be initialized is the student's name. Since the instance variable name is defined in the definition of Person, it is normally initialized by the constructors for the base class Person.

A derived class does not inherit constructors from its base class

Consider the following constructor definition in the derived class Student (Listing 8.2):

```
public Student(String initialName, int initialStudentNumber)
{
    super(initialName);
    studentNumber = initialStudentNumber;
}
```

Constructors in a derived class invoke constructors from the base class

This constructor uses the reserved word super as a method name to call a constructor of the base class. Although the base class Person defines two constructors, the invocation

```
super(initialName);
```

is a call to the constructor in that class that has one parameter, a string. Notice that you use the keyword super, not the name of the constructor. That is, you do *not* use

Use super within a derived class as the name of a constructor in the base class (superclass)

Person(initialName); //ILLEGAL

FAQ How can I remember that super invokes a constructor in the base class instead of in a derived class?

Recall that another name for a base class is superclass. So super invokes the constructor in a class's superclass.

The use of super involves some details: It must always be the first action taken in a constructor definition. You cannot use super later in the definition.

Any call to super must be first within a constructor If you do not include an explicit call to the base-class constructor in any constructor for a derived class, Java will automatically include a call to the base class's default constructor. For example, the definition of the default constructor for the class Student given in Listing 8.2,

```
public Student()
{
    super();
    studentNumber = 0;//Indicating no number yet
}
```

Without super, a constructor invokes the default constructor in the base class

is completely equivalent to the following definition:

```
public Student()
{
    studentNumber = 0;//Indicating no number yet
}
```

## **RECAP** Calling a Base-Class Constructor

When defining a constructor for a derived class, you can use super as a name for the constructor of the base class. Any call to super must be the first action taken by the constructor.

#### **EXAMPLE**

```
public Student(String initialName, int initialStudentNumber)
{
    super(initialName);
    studentNumber = initialStudentNumber;
}
```

# **GOTCHA** Omitting a Call to super in a Constructor

When you omit a call to the base-class constructor in any derived-class constructor, the default constructor of the base class is called as the first action in the new constructor. This default constructor—the one without parameters—might not be the one that should be called. Thus, including your own call to the base-class constructor is often a good idea.

For example, omitting super(initialName) from the second constructor in the class Student would cause Person's default constructor to be invoked. This action would set the student's name to "No name yet" instead of to the string initialName.

## The this Method—Again

Another common action when defining a constructor is to call another constructor in the same class. Chapter 6 introduced you to this idea, using the keyword this. Now that you know about super, it's clear that you can use this and super in similar ways.

You can use both this and super to call a constructor

We can revise the default constructor in the class Person (Listing 8.1) to call another constructor in that class by using this, as follows:

```
public Person()
{
    this("No name yet");
}
```

In this way, the default constructor calls the constructor

```
public Person(String initialName)
{
    name = initialName;
}
```

thereby setting the instance variable name to the string "No name yet".

As with super, any use of this must be the first action in a constructor definition. Thus, a constructor definition cannot contain both a call using super and a call using this. What if you want to include both calls? In that case, use this to call a constructor that has super as its first action.

## **REMEMBER** this and super Within a Constructor

When used in a constructor, this calls a constructor of the same class, but super invokes a constructor of the base class.

# Calling an Overridden Method

We just saw how a constructor of a derived class can use super as a name for a constructor of the base class. A method of a derived class that overrides (redefines) a method in the base class can use super to call the overridden method, but in a slightly different way.

For example, consider the method writeOutput for the class Student in Listing 8.2. It contains the statement

```
System.out.println("Name: " + getName());
```

to display the name of the Student. Alternatively, you could display the name by calling the method writeOutput of the class Person in Listing 8.1, since the writeOutput method for the class Person will display the person's name. The only problem is that if you use the method name writeOutput within the class

Student, it will invoke the method named writeOutput in the class Student. What you need is a way to say "writeOutput() as it is defined in the base class." The way you say that is super.writeOutput(). So an alternative definition of the writeOutput method for the class Student is the following:

Using super as an object calls a base-class method

```
public void writeOutput()
{
    super.writeOutput(); //Display the name
    System.out.println("Student Number: " + studentNumber);
}
```

If you replace the definition of writeOutput in the definition of Student (Listing 8.2) with the preceding definition, the class Student will behave exactly the same as it did before.

## **RECAP** Calling an Overridden Method

Within the definition of a method of a derived class, you can call an overridden method of the base class by prefacing the method name with super and a dot.

#### **SYNTAX**

```
super.Overridden_Method_Name(Argument_List)
```

#### **EXAMPLE**

# PROGRAMMING EXAMPLE

A Derived Class of a Derived Class

You can form a derived class from a derived class. In fact, this is common. For example, we previously derived the class Student (Listing 8.2) from the class Person (Listing 8.1). We now derive a class Undergraduate from Student, as shown in Listing 8.4. Figure 8.4 contains a UML diagram showing the relationship among the classes Person, Student, and Undergraduate.

## LISTING 8.4 A Derived Class of a Derived Class

```
public class Undergradute extends Student
    private int level; //1 for freshman, 2 for sophomore
                       //3 for junior, or 4 for senior.
    public Undergraduate()
        super();
        level = 1
    public Undergraduate(String initialName,
                    int initialStudentNumber, int initialLevel)
    {
        super(initialName, initialStudentNumber);
        setLevel(initialLevel); //checks 1 <= initialLevel <= 4</pre>
    public void reset(String newName, int newStudentNumber,
                      int newLevel)
    {
        reset(newName, newStudentNumber); //Student's reset
        setLevel(newLevel); //Checks 1 <= newLevel <= 4
    }
    public int getLevel()
        return level;
    public void setLevel(int newLevel)
        if ((1 <= newLevel) && (newLevel <= 4))</pre>
            level = newLevel:
        else
            System.out.println("Illegal level!");
            System.exit(0);
        }
    public void writeOutput()
        super.writeOutput();
        System.out.println("StudentLevel: " + level);
    public boolean equals(Undergraduate otherUndergraduate)
        return equals(Student)otherUndergraduate) &&
               (this.level == otherUndergraduate.level);
}
```

FIGURE 8.4 More Details of the UML Class Hierarchy Shown in Figure 8.2

```
Person
- name: String
+ setName(String newName): void
+ getName( ): String
+ writeOutput( ): void
+ hasSameName(Person otherPerson)): boolean
                       Student
- studentNumber: int
+ reset(String newName, int newStudentNumber): void
+ getStudentNumber( ): int
+ setStudentNumber(int newStudentNumber): void
+ writeOutput( ): void
+ equals(Student otherStudent): boolean
                    Undergraduate
- level: int
+ reset(String newName, int newStudentNumber,
        int newlevel): void
+ getLevel(): int
+ setLevel(int newLevel): void
+ writeOutput( ): void
+ equals(Undergraduate otherUndergraduate): boolean
```

An object of the class Undergraduate has all the public members of the class Student. But Student is already a derived class of Person. This means that an object of the class Undergraduate also has all the public members of the class Person. An object of the class Person has the instance variable name. An object of the class Student has the instance variable studentNumber, and an object of the class Undergraduate has the instance variable level. Although an object of the class Undergraduate does not inherit the instance variables name and studentNumber, since they are private, it can use its inherited accessor and mutator methods to access and change them. In effect, the classes Student and Undergraduate—as well as any other classes derived from either of them—reuse the code given in the definition of the class Person, because they inherit all the public methods of the class Person.

Each of the constructors in the class Undergraduate begins with an invocation of super, which in this context stands for a constructor of the base class Student. But the constructors for the class Student also begin with an invocation of super, which in this case stands for a constructor of the base class Person. Thus, when we use new to invoke a constructor in Undergraduate, constructors for Person and Student are invoked, and then all the code following super in the constructor for Undergraduate is executed.

The classes Student and Undergraduate both define a method named reset. In Student, reset has two parameters, while in Undergraduate, reset has three parameters, so reset is an overloaded name. The reset method in the class Undergraduate, which we reproduce here, begins by invoking reset, passing it only two arguments:

reset is an overloaded method

```
public void reset(String newName, int newStudentNumber, int
newLevel)
{
    reset(newName, newStudentNumber); //Student's reset
    setLevel(newLevel); //Checks 1 <= newLevel <= 4
}</pre>
```

Thus, this invocation is to the method named reset defined in the base class Student, which changes the values of the instance variables name and studentNumber. The Undergraduate reset method then changes the value of the new instance variable level by calling setLevel.

Remember that within the definition of the class Undergraduate, the private instance variables name and studentNumber—of the base classes Person and Student, respectively—cannot be referenced by name, and so a mutator method is needed to change them. The reset method of the class Student is perfect for this purpose.

Because the version of reset defined in the class Undergraduate has a different number of parameters than the version of reset defined in the class Student, there is no conflict in having both versions of reset in the derived

class Undergraduate. In other words, we can overload the reset method. In contrast, the definition of the method writeOutput in Undergraduate, which we reproduce here, has exactly the same parameter list as the version of writeOutput in the base class Student:

writeOutput overrides the base-class method having the same signature

```
public void writeOutput()
{
    super.writeOutput();
    System.out.println("StudentLevel: " + level);
}
```

Thus, when writeOutput is invoked, Java must decide which definition of writeOutput to use. For an object of the derived class Undergraduate, it uses the version of writeOutput given in the definition of the class Undergraduate. The version in Undergraduate overrides the definition given in the base class Student. To invoke the version of writeOutput defined in Student within the definition of the derived class Undergraduate, you must place super and a dot in front of the method name writeOutput, as shown previously.

Now consider the methods named equals in the classes Student and Undergraduate. They have different parameter lists. The one in the class Student has a parameter of type Student, while the one in the class Undergraduate has a parameter of type Undergraduate. They have the same number of parameters—namely, one—but that one parameter is of a different type in each of the two definitions. Recall that a difference in type is enough to qualify for overloading. To help us analyze the situation, we reproduce the definition of equals within the derived class Undergraduate here:

```
public boolean equals(Undergraduate otherUndergraduate)
{
    return equals((Student)otherUndergraduate) &&
        (this.level == otherUndergraduate.level);
}
```



Why did we cast otherUndergraduate to Student in the invocation of equals? Because otherwise Java would invoke the definition of equals in the class Undergraduate. That is, this equals method would invoke itself. While a method that invokes itself is perfectly acceptable under certain conditions—as you will see in Chapter 11—it isn't what we want to happen here. By casting the argument from Undergraduate to Student, we cause Java to call Student's equals method. Notice that otherUndergraduate, as an Undergraduate object, has all the behaviors of a Student object, and so will act correctly within Student's equals method. We will elaborate this point in the next section.

Extra code on the Web

There is nothing unusual about how the class Undergraduate is used, but we have included a simple demonstration program for this class in the file

UndergraduateDemo.java as part of the source code for this book that is available on the Web.

## Another Way to Define the equals Method in Undergraduate

The equals method in the class Undergraduate casts its parameter otherUndergraduate from Undergraduate to its base class Student when it passes it to Student's equals method. Another way to force Java to call the definition of equals in Student is to use super and a dot, as follows:

## **GOTCHA** You Cannot Use Repeated supers

As we already noted, within the definition of a method of a derived class, you can call an overridden method of the base class by prefacing the method name with super and a dot. However, you cannot repeat the use of super to invoke an overridden method from some ancestor class other than a direct parent. Suppose that the class Student is derived from the class Person, and the class Undergraduate is derived from the class Student. You might think that you can invoke a method of the class Person within the definition of the class Undergraduate by using super.super, as in

```
super.super.writeOutput();//ILLEGAL!
```

However, as the comment indicates, it is illegal to have such a train of supers in Java.

# **Type Compatibility**

Consider the class Undergraduate in Listing 8.4. It is a derived class of the class Student. In the real world, every undergraduate is also a student. This relationship holds true in our Java example as well. Every object of the class Undergraduate is also an object of the class Student. Thus, if you have a method that has a formal parameter of type Student, the argument in an invocation of this method can be an object of type Undergraduate. In this case, the method could use only methods defined in the class Student, but every object of the class Undergraduate has all these methods.

For example, suppose that the classes Student and Undergraduate are defined as in Listings 8.2 and 8.4, and consider the following method definition that might occur in some class:

An object of a derived class can serve as an object of the base class

A program that uses SomeClass might contain the following code:

```
Student studentObject = new Student("Jane Doe", 1234);
Undergraduate undergradObject =
    new Undergraduate("Jack Buck", 1234, 1);
SomeClass.compareNumbers(studentObject, undergradObject);
```

If you look at the heading for the method compareNumbers, you will see that both parameters are of type Student. However, the invocation

```
SomeClass.compareNumbers(studentObject, undergradObject);
```

uses one argument of type Student and one object of type Undergraduate. How can we use an object of type Undergraduate where an argument of type Student is required? The answer is that every object of type Undergraduate is also of type Student. To make the point a little more dramatically, notice that you can reverse the two arguments and the method invocation will still be valid, as shown below:

```
SomeClass.compareNumbers(undergradObject, studentObject);
```

Note that there is no automatic type casting here. An object of the class Undergraduate *is* an object of the class Student, and so it *is* of type Student. It need not be, and is not, type cast to an object of the class Student.

An object can actually behave as if it has more than two types as a result of inheritance. Recall that the class Undergraduate is a derived class of the class Student and that Student is a derived class of the class Person in Listing 8.1. This means that every object of the class Undergraduate is also an object of type Student as well as an object of type Person. Thus, everything that works for objects of the class Person also works for objects of the class Undergraduate.

For example, suppose that the classes Person and Undergraduate are defined as in Listings 8.1 and 8.4, and consider the following code, which might occur in a program:

An object can have several types because of inheritance

```
Person joePerson = new Person("Josephine Student");
System.out.println("Enter name:");
Scanner keyboard = new Scanner(System.in);
String newName = keyboard.nextLine();
Undergraduate someUndergrad =
    new Undergraduate(newName, 222, 3);
if (joePerson.hasSameName(someUndergrad))
    System.out.println("Wow, same names!");
else
    System.out.println("Different names");
```

If you look at the heading for the method hasSameName in Listing 8.1, you will see that it has one parameter, and that parameter is of type Person. However, the call in the preceding if-else statement,

```
joePerson.hasSameName(someUndergrad)
```

is perfectly valid, even though the argument someUndergrad is an object of the class Undergraduate—that is, its type is Undergraduate—but the corresponding parameter in hasSameName is of type Person. Every object of the class Undergraduate is also an object of the class Person.

Even the following invocation is valid:

```
someUndergrad.hasSameName(joePerson)
```

The method hasSameName belongs to Person, but it is inherited by the class Undergraduate. So the Undergraduate object someUndergrad has this method. An object of type Undergraduate is also of type Person. Everything that works for objects of an ancestor class also works for objects of any descendant class. Or, to say this another way, an object of a descendant class can do the same things as an object of an ancestor class. As we have already seen, if class A is derived from class B, and class B is derived from class C, then an object of class A is of type A. It is also of type B, and it is also of type C. This works for any chain of derived classes, no matter how long the chain is.

Because an object of a derived class has the types of all of its ancestor classes in addition to its "own" type, you can assign an object of a class to a variable of any ancestor type, but not the other way around. For example, because Student is a derived class of Person, and Undergraduate is a derived class of Student, the following code is valid:

```
Student s = new Student();
Undergraduate ug = new Undergraduate();
Person p1 = s;
Person p2 = ug;
```

An object of a class can be referenced by a variable of any ancestor type

You can even bypass the variables s and ug and place the new objects directly into the variables p1 and p2, as follows:

```
Person p1 = new Student();
Person p2 = new Undergraduate();
```

However, the following statements are all illegal:

```
Student s = new Person(); //ILLEGAL!
Undergraduate ug = new Person(); //ILLEGAL!
Undergraduate ug2 = new Student(); //ILLEGAL!
```

And if we define p and s as follows:

```
Person p = new Person(); //valid
Student s = new Student(); //valid
```

even the following statements, which may look more innocent, are similarly illegal:

```
Undergraduate ug = p; //ILLEGAL!
Undergraduate ug2 = s; //ILLEGAL!
```

This all makes perfectly good sense. For example, a Student is a Person, but a Person is not necessarily a Student. Some programmers find the phrase "is a" to be useful in deciding what types an object can have and what assignments to variables are valid. As another example, if Employee is a derived class of Person, an Employee is a Person, so you can assign an Employee object to a variable of type Person. However, a Person is not necessarily an Employee, so you cannot assign an object created as just a plain Person to a variable of type Employee.

A Student "is a" Person, but the converse might not be true

## **REMEMBER** Assignment Compatibilities

An object of a derived class has the type of the derived class, but it can be referenced by a variable whose type is any one of its ancestor classes. Thus, you can assign an object of a derived class to a variable of any ancestor type, but not the other way around.

# ■ PROGRAMMING TIP Is-a and Has-a Relationships

As we just noted, a Student is a Person, so we made the Student class a derived class of the Person class. This is an example of an is-a relationship between classes. It is one way to make a more complex class out of a simpler class.

Another way is known as the has-a relationship. For example, you have a class Date that records a date; you might add a date of enrollment to the Student class by adding an instance variable of type Date to the Student class. In this case we say a Student "has a" Date. As another example, if we have a class MechanicalArm and we are defining a class to simulate a robot, we can give the Robot class an instance variable of type MechanicalArm. In this case we say that a Robot "has a" MechanicalArm.

In most situations you can make your code work with either an "is-a" relationship or a "has-a" relationship. Often, a "has-a" relationship is the better choice. It seems silly to make the Robot class a derived class of the Mechanical Arm class, but it can be done. The result would be a poor design, however.

Fortunately, the best programming technique is usually to simply follow what sounds most natural in English. It makes more sense to say "A Robot has a MechanicalArm" than it does to say "A Robot is a MechanicalArm." So it makes better programming sense to have a MechanicalArm as an instance variable of a Robot class.

You will often encounter the terms *is-a* and *has-a* in the literature on programming techniques.

If class A has an object of class B as an instance variable, the relationship between A and B is "has a"

### **SELF-TEST QUESTIONS**

- 8. Give a complete definition of a class called TitledPerson, which you derive from the class Person in Listing 8.1. The class TitledPerson has one additional String instance variable for a title, such as Ms., Mr., or The Honorable. The class TitledPerson has two constructors: a default constructor and one that sets both the name and the title. It has a writeOutput method, a reset method, an equals method, an accessor method getTitle that returns the title, and a mutator method setTitle that changes the person's title. For two titled people to be equal, they must have the same name and the same title. You may want to use the class Student in Listing 8.2 as a model.
- 9. Add a constructor to the class Student that sets the student's name to a given argument string and sets the student's number to zero. Your constructor should invoke another constructor in Student to accomplish this.
- 10. Rewrite the definition of the method writeOutput for the class Undergraduate in Listing 8.4, using getName and getStudentNumber instead of super.writeOutput. (Most programmers would use the version in Listing 8.4, but you should be able to write either version.)
- 11. Rewrite the definition of the method reset for the class Undergraduate in Listing 8.4, using setName and setStudentNumber instead of the overloaded reset method name. (Most programmers would use the version in Listing 8.4, but you should be able to write either version.)
- 12. Can an object be referenced by variables of several different data types?
- 13. What is the type or types of the variable(s) that can reference the object created in the following statement? (The definition of the class Undergraduate is given in Listing 8.4.)

Undergraduate ug = new Undergraduate();

- 14. Describe two uses for the keyword super.
- 15. What is the difference between this and super when these words are used within a constructor definition as the names of methods that are called?

## The Class Object

The class Object is the ultimate ancestor of all classes

Java has an "Eve" class—that is, a class that is an ancestor of every class. In Java, every class is derived from the class Object. If a class C has a different base class B, this base class is derived from Object, and so C is a derived class of Object. Thus, every object of every class is of type Object, as well as being of the type of its class and all its ancestor classes. Even classes that you define yourself without using inheritance are descendant classes of the class Object. If you do not make your class a derived class of some class, Java will automatically make it a derived class of Object.

The class Object allows Java programmers to write Java methods that have a parameter of type Object that represents an object of any class whatsoever. You will eventually encounter library methods that accept an argument of type Object and hence can be used with an argument that is an object of absolutely any class.

The class Object does have some methods that every Java class inherits. For example, every class inherits the methods equals and toString from some ancestor class, either directly from the class Object or from a class that ultimately inherited the methods from the class Object. However, the methods equals and toString inherited from Object will not work correctly for almost any class you define. Thus, you need to override the inherited method definitions with new, more appropriate definitions.

Writing a correct version of equals is a bit complicated for beginning programmers. The equals methods we present in this book will work well in most situations. The next section shows how to write a fully complete and correct definition of equals.

The inherited method toString takes no arguments. The method toString is supposed to return all the data in an object, packaged into a string. However, the inherited version of toString is almost always useless, because it will not produce a nice string representation of the data. You need to override the definition of toString so it produces an appropriate string for the data in objects of the class being defined.

For example, the following definition of toString could be added to the class Student in Listing 8.2:

Every class inherits the methods toString and equals from Object

The version of the class Student included with the source code for this book, which is available on the Web, includes this toString method, so you can easily try it out.

After adding this toString method to the class Student, we can use it to display output in the following way:

```
Student joe = new Student("Joe Student", 2001);
System.out.println(joe.toString());
```

The output produced would be

```
Name: Joe Student
Student number: 2001
```

The method println that is invoked here has a parameter of type String.

The object System.out has several definitions of println—in other words, println is overloaded. One of these println methods has a parameter of type Object. The definition is equivalent to the following one:

```
public void println(Object theObject)
{
    System.out.println(theObject.toString());
}
```

println is an example of a reallife overloaded method

# **PROGRAMMING TIP** Define Your Own toString Method Within Typical Classes

Object's toString method will not display any data related to your class. You usually should override toString in the classes that you write.

Another method inherited from the class Object is the method clone. This method takes no arguments and returns a copy of the calling object. The returned object is supposed to have data identical to that of the calling object, but it is a different object—an identical twin or a "clone." Like other methods inherited from the class Object, the method clone needs to be redefined (overridden) before it will function properly. However, in the case of the method clone, there are other things you must do as well. A thorough discussion of the method clone is beyond the scope of this text, but some information on this method is given in the section "Privacy Leaks" in Chapter 6 and in Appendix 10 (on the book's Web site).

clone is another method in object

## **SELF-TEST QUESTIONS**

16. Consider the code below, which was discussed in the previous section:

```
Student joe = new Student("Joe Student", 2001);
System.out.println(joe.toString());
```

Why is the output on two lines instead of being all on one line?

17. Which of the following lines are legal and which are illegal? The class Undergraduate is a derived class of Student, and Student is a derived class of Person.

```
a. Person p1 = new Student();
b. Person p2 = new Undergraduate();
c. Student s1 = new Person();
d. Student s2 = new Undergraduate();
e. Undergraduate ug1 = new Person();
f. Undergraduate ug2 = new Student();
g. Object ob = new Student();
h. Student s3 = new Object();
```

### A Better equals Method

As we mentioned in the previous section, the class Object defines an equals method that every class inherits. But most of the time, if you want your class to have an equals method that works correctly, you should override Object's definition of equals and define your own version. However, we did not, strictly speaking, follow our own advice. The heading for the method equals in our definition of the class Student given in Listing 8.2 is

```
public boolean equals(Student otherStudent)
```

but the heading for the method equals in the class Object is

```
public boolean equals(Object otherObject)
```

These two equals methods have different parameter types, so we actually have not overridden the definition of equals. We have merely overloaded the method. In other words, the class Student has both of these methods. For most situations, this will not matter. However, there are cases in which it does matter.

Suppose we use some method—either predefined or programmer defined—that has a parameter of type Object named objectParam and another parameter studentParam of type Student. Now suppose the body of this method contains the invocation

```
studentParam.equals(objectParam)
```

If you plug in two arguments of type Student for the parameters objectParam and studentParam, Java will use the definition of equals inherited from the class Object, not the one we defined for the class Student. This means that in some cases, the method equals will return the wrong answer.

To fix this problem, we need to change the type of the parameter for the equals method in the Student class from Student to Object. A first try might be the following:

An equals method that works in most cases

```
//First try at an improved equals method
public boolean equals(Object otherObject)
   Student otherStudent = (Student)otherObject;
   return this.hasSameName(otherStudent) &&
     (this.studentNumber == otherStudent.studentNumber);
}
```

Note that we need to type cast the parameter other 0 bject from type 0 bject to type Student. Without the type cast and the variable other Student, we would receive a syntax error when we write

```
otherObject.studentNumber
```

because the class Object does not have an instance variable named studentNumber. (Actually, the invocation of hasSameName would likely also cause a syntax error.)

This first try at an improved equals method does override the definition of equals given in the class Object and will work well in almost all cases. However, it still has a shortcoming: Our new definition of equals now allows an argument that can be any object at all. What happens if the method equals is used with an argument that is not a Student? The answer is that a run-time error will occur when the type cast to Student is executed.

We should make our definition work for any object. If the object is not a Student, we simply return false. After all, the method belongs to a Student object, and so if the argument is not a Student, the two objects cannot be considered equal. But how can we tell when the parameter is not of type Student?

We can use the instanceof operator to check whether an object is of type Student. The syntax is

#### Object instanceof Class\_Name

This expression returns true if Object is of type Class\_Name; otherwise it returns false. So the following will return true if otherObject is of type Student:

```
otherObject instanceof Student
```

Therefore, the equals method should return false if the preceding boolean expression is false.

Our final version of the method equals is shown in Listing 8.5. Note that we have also taken care of one more possible case. The predefined constant

#### **ASIDE** Multiple Inheritance

Some programming languages—such as C++ allow one class to be derived from two different base classes. That is, you can derive class C from classes A and B. This feature, known as multiple inheritance, is not allowed in Java. In Java, a derived class can have only one base class. You can, however, derive class B from class A and then derive class C from class B, since this is not multiple inheritance.

A derived class can implement any number of interfaces in addition to extending any one base class. Interfaces are discussed later in this chapter. This capability gives Java an approximation to multiple inheritance without the complications that arise with multiple base classes.

> The instanceof operator checks an object's class

## LISTING 8.5 A Better equals Method for the Class Student

null can be plugged in for a parameter of type Object. The Java documentation says that an equals method should return false when comparing an object and the value null. So that is what we have done.

### 8.3 POLYMORPHISM

What's in a name? That which we call a rose By any other name would smell as sweet.

-WILLIAM SHAKESPEARE, Romeo and Juliet

Inheritance allows you to define a base class and derive classes from the base class. **Polymorphism** allows you to make changes in the method definition for the derived classes and have those changes apply to the methods written *in the base class*. This all happens automatically in Java, but it is important to understand the process.



Consider a program that uses the Person, Student, and Undergraduate classes as depicted in Figure 8.4. Let's say that we would like to set up a committee that consists of four people who are either students or employees. If we use an array to store the list of committee members, then it makes sense to make the array of type Person so it can accommodate any class derived from it. Here is a possible array declaration:

```
Person[] people = new Person[4];
```



Next we might add objects to the array that represent members of the committee. In the example below we have added three objects of type Undergraduate and one object of type Student (perhaps we don't know if this person is an undergraduate or graduate):

```
people[0] = new Undergraduate("Cotty, Manny", 4910, 1);
people[1] = new Undergraduate("Kick, Anita", 9931, 2);
people[2] = new Student("DeBanque, Robin", 8812);
people[3] = new Undergraduate("Bugg, June", 9901, 4);
```

In this case we are assigning an object of a derived class (either Student or Undergraduate) to a variable defined as an ancestor of the derived class (Person). This is valid because Person encompasses the derived classes. In other words, Student "is-a" Person and Undergraduate "is-a" Person, so we can assign either one to a variable of type Person.

Next, let's output a report containing information about all of the committee members. The report should be as detailed as possible. For example, if a student is an undergraduate, then the report should contain the student's name, student number, and student level. If the student is of type Student, then the report should contain the name and student number. Similar details would be expected for employees. The writeOutput method contains this detail, but which one is invoked? There are three of them, one defined for Undergraduate, Student, and Person.

If we focus on just people[0], then we can see that it is declared to be an object of type Person. If we invoke:

```
people[0].writeOutput();
```

then it is logical to assume that the writeOutput method defined in the Person object will be invoked. But that is not what happens! Instead, Java recognizes that an object of type Undergraduate is stored in people[0]. As a result, even though people[0] is declared to be of type Person, the method associated with the class used to create the object is invoked. This is called **dynamic binding** or **late binding**.

More precisely, when an overridden method is invoked, its action is the one defined in the class used to create the object using the new operator. It is not determined by the type of the variable naming the object. A variable of any ancestor class can reference an object of a descendant class, but the object always remembers which method actions to use for every method name. The type of the variable does not matter. What matters is the class name when the object was created.

Returning to our report, the code below could be used to generate it:

```
for (Person p : people)
{
    p.writeOutput();
    System.out.println();
}
```

#### This code would output:

```
Name: Cotty, Manny
Student Number: 4910
Student Level: 1
Name: Kick, Anita
Student Number: 9931
Student Level: 2
Name: DeBanque, Robin
Student Number: 8812
Name: Bugg, June
Student Number: 9901
Student Level: 4
```

A complete program is given in Listing 8.6.

#### LISTING 8.6 A Demo of Polymorphism (part 1 of 2)

```
public class PolymorphismDemo
    public static void main(String[] args)
    {
        Person[] people = new Person[4];
        people[0] = new Undergraduate("Cotty, Manny", 4910, 1);
        people[1] = new Undergraduate("Kick, Anita", 9931, 2);
        people[2] = new Student("DeBanque, Robin", 8812);
        people[3] = new Undergraduate("Bugg, June", 9901, 4);
        for (Person p : people)
         {
                                           Even though p is of type Person, the
             p.writeOutput();
                                           writeOutput method associated
             System.out.println();
                                           with Undergraduate or Student
                                           is invoked depending upon which class
    }
                                           was used to create the object.
}
```

#### Screen Output

```
Name: Cotty, Manny
Student Number: 4910
Student Level: 1
Name: Kick, Anita
Student Number: 9931
Student Level: 2
```

(continued)

#### LISTING 8.6 A Demo of Polymorphism (part 2 of 2)

```
Name: DeBanque, Robin
Student Number: 8812
Name: Bugg, June
Student Number: 9901
Student Level: 4
```

One of the amazing things about polymorphism is it lets us invoke methods that might not even exist yet! For example, assume the program in Listing 8.6 exists and runs with only the Person, Student, and Undergraduate classes defined. At some later date we could write the Employee, Faculty, and

Staff classes as depicted in Figure 8.1. Since all of these classes would be derived from the Person class, as long as each implements a writeOutput method then we could add one of these objects to the array and its writeOutput method would be invoked in the for loop. We wouldn't even need to recompile the PolymorphismDemo class in Listing 8.6 to invoke the new methods via dynamic binding.

#### **ASIDE** Java Assumes Dynamic Binding

In many other languages, you must specify in advance what methods may need dynamic binding. Java always assumes that dynamic binding will occur. Although making this assumption is less efficient, Java is easier to program and less prone to errors as a result.

#### **REMEMBER** Objects Know How They Are Supposed to Act

When an overridden method is invoked, its action is the one defined in the class used to create the object using the new operator. It is not determined by the type of the variable naming the object. A variable of any ancestor class can reference an object of a descendant class, but the object always remembers which method actions to use for every method name. The type of the variable does not matter. What matters is the class name when the object was created. This is because Java uses dynamic binding.

## Dynamic Binding with toString

If you include an appropriate toString method in the definition of a class, then you can output an object of the class using System.out.println. For example, in the previous section we described adding a toString method to the Student class:

For the Student object joe, we can invoke the method with the statement

```
System.out.println(joe.toString());
```

However, we can get the exact same result without the toString:

```
System.out.println(joe);
```

This happens because Java uses dynamic binding with the toString method. The various println methods that belong to the object System.out were written long before we defined the class Student. Yet the invocation calls the definition of toString in the class Student, not the definition of toString in the class Object, because joe references an object of type Student. Dynamic binding is what makes this work. Because System.out.println invokes toString in this manner, always defining a suitable toString method for your classes is a good idea.

### **RECAP** Dynamic Binding and Polymorphism

With dynamic, or late, binding the definition of a method is not bound to an invocation of the method until run time when the method is called. Polymorphism refers to the ability to associate many meanings to one method name through the dynamic binding mechanism. Thus, polymorphism and dynamic binding are really the same topic.

## **SELF-TEST QUESTIONS**

- 18. What is polymorphism?
- 19. What is dynamic binding? What is late binding? Give an example of each.
- 20. Is overloading a method name an example of polymorphism?
- 21. In the following code, will the two invocations of writeOutput produce the same output on the screen or not? (The relevant classes are defined in Listings 8.1, 8.2, and 8.4.)

```
Person person = new Student("Sam", 999);
person.writeOutput();
person = new Undergraduate("Sam", 999, 1);
person.writeOutput();
```

22. In the following code, which definition of writeOutput is invoked? (The classes are defined in the previous case study.)

```
Undergraduate ug = new Undergraduate("Sam", 999, 1);
Personp = (Person) ug;
p.writeOutput();
```

#### **8.4** INTERFACES AND ABSTRACT CLASSES

Art, it seems to me, should simplify. That, indeed, is very nearly the whole of the higher artistic process; finding what conventions of form and what details one can do without and yet preserve the spirit of the whole . . .

—WILLA CATHER, ON The Art of Fiction

Chapter 5 defined a class interface as the portion of a class that tells a programmer how to use it. In particular, a class interface consists of the headings for the public methods and public named constants of the class, along with any explanatory comments. Knowing only a class's interface—that is, the specifications of its public methods—a programmer can write code that uses the class. The programmer does not need to know anything about the class's implementation.

Until now, we have integrated a class's interface into its definition. Java, however, enables you to write an interface and to store it in its own file, separate from the implementation file. Let's further examine the idea of a class interface and see how this concept translates to a Java interface.

#### **Class Interfaces**

In Chapter 1, we imagined a person calling her pets to dinner by whistling. Each animal responded in its own way: Some ran, some flew, and some swam. Let's specify some behaviors for these pets. For example, suppose our pets are able to

- Be named
- Eat
- Respond to a command

We could specify the following method headings for these behaviors:

```
    /** Sets a pets name to petName. */
        public void setName(String petName)
    /** Returns true if a pet eats the given food.*/
        public boolean eat(String food)
    /** Returns a description of a pet's response to the given command. */
        public String respond(String command)
```

These method headings can form a class interface.

Now imagine that each of the three classes Dog, Bird, and Fish implements all of these methods. The objects of these classes then have the same behaviors—that is, each object can be named, can eat, and can respond. The nature of these behaviors, however, can be different among the objects.

An example of a class interface

Although dogs, birds, and fish respond to a command, for example, the way they respond differs.

Imagine a Java statement such as

```
String response = myPet.respond("Come!");
```

This statement is legal regardless of whether myPet names a Dog object, a Bird object, or a Fish object. The value of the string response, however, differs according to the type of object that myPet names. We can substitute one type of object for the other with no problem, as long as each of the three classes implements the method respond in its own way. How can we be sure that a class implements certain methods? Read on.

### **Java Interfaces**

A Java interface is a program component that contains the headings for a number of public methods. Some interfaces describe all the public methods in a class, while others specify only certain methods. An interface also can define public named constants. In addition, an interface should include comments that describe the methods, so a programmer will have the necessary information to implement them. In this way, a class designer can specify methods for other programmers. In fact, the Java Class Library contains interfaces that are already written for your use, but you can also define your own.

The class interface that we wrote in the previous section is almost in the form necessary for a Java interface. A Java interface begins like a class definition, except that you use the reserved word interface instead of class. That is, an interface begins with

```
public interface Interface_Name
```

rather than

```
public class Class_Name
```

The interface can contain any number of public method headings, each followed by a semicolon. For example, Listing 8.7 contains a Java interface for objects whose methods return their perimeters and areas.

By convention, an interface name begins with an uppercase letter, just as class names do. You store an interface in its own file, using a name that begins with the name of the interface, followed by .java. For example, the interface in Listing 8.7 is in the file Measurable.java. This interface provides a programmer with a handy summary of the methods' specifications. The programmer should be able to use these methods given only the information in the interface, without looking at the method bodies.

An interface does not declare any constructors for a class. Methods within an interface must be public, so you can omit public from their headings. An interface can also define any number of public named constants. It contains no instance variables, however, nor any complete method definitions—that is, methods cannot have bodies.

You name and store an interface as you would a class

An interface has no instance variables, constructors, or method definitions

#### LISTING 8.7 A Java Interface

```
/**
An interface for methods that return
the perimeter and area of an object.

*/
public interface Measurable
{
    /** Returns the perimeter. */
    public double getPerimeter();
    /** Returns the area. */
    public double getArea();

/** Do not forget the semicolons at the end of the method headings.
}
```

```
RECAP Java Interfaces
SYNTAX
   public interface Interface_Name
       Public_Named_Constant_Definitions
       Public_Method_Heading_1;
       Public_Method_Heading_n;
   }
EXAMPLE
   / * *
   An interface of static methods to convert measurements
   between feet and inches.
   public interface Convertible
       public static final int INCHES_PER_FOOT = 12;
       public static double convertToInches(double feet);
       public static double convertToFeet(double inches);
   }
```

## Implementing an Interface

When you write a class that defines the methods declared in an interface, we say that the class **implements the interface**. A class that implements an interface must define a body for every method that the interface specifies. It

A class that implements an interface defines each specified method might also define methods not declared in the interface. That is, an interface need not declare every method defined in a class. In addition, a class can implement more than one interface.

To implement an interface, a class must do two things:

1. Include the phrase

```
implements Interface_Name
```

at the start of the class definition. To implement more than one interface, just list all the interface names, separated by commas, as in

```
implements MyInterface, YourInterface
```

2. Define each method declared in the interface(s).

In this way, a programmer can guarantee—and indicate to other programmers—that a class defines certain methods. Additionally, recall that Java does not allow a class to be derived from multiple parent classes. However, a class can implement multiple interfaces. This is a way to capture some of the behavior that would be possible with multiple inheritance.

For example, to implement the interface Measurable shown in Listing 8.7, a class Rectangle must begin as follows:

```
public class Rectangle implements Measurable
```

The class must also implement the two methods getPerimeter and getArea. A full definition of the class Rectangle is given in Listing 8.8.

Other classes, such as the class Circle shown in Listing 8.9, can implement the interface Measurable. Notice that Circle defines the method getCircumference in addition to the methods declared in the interface. It isn't unusual for a class to define two methods that perform the same task. Doing so provides a convenience for programmers who use the class but prefer a more familiar name for a particular method. Notice, however, that getCircumference calls getPerimeter instead of performing its own calculation. Doing so makes the class easier to maintain. For example, if we ever discovered a problem with the statements in getPerimeter, fixing it would also fix getCircumference.

#### **REMEMBER** Interfaces Help Designers and Programmers

Writing an interface is a way for a class designer to specify methods for another programmer. Implementing an interface is a way for a programmer to guarantee that a class defines certain methods.

#### LISTING 8.8 An Implementation of the Interface Measurable

```
/**
A class of rectangles.
*/
public class Rectangle implements Measurable
{
    private double myWidth;
    private double myHeight;
    public Rectangle(double width, double height)
    {
        myWidth = width;
        myHeight = height;
    }
    public double getPerimeter()
    {
        return 2 * (myWidth + myHeight);
    }
    public double getArea()
    {
        return myWidth * myHeight;
    }
}
```

#### **REMEMBER Several Classes Can Implement the Same Interface**

Different classes can implement the same interface, perhaps in different ways. For example, many classes can implement the interface Measurable and provide their own version of the methods getPerimeter and getArea.

## An Interface as a Type

An interface is a reference type. Thus, you can write a method that has a parameter of an interface type, such as a parameter of type Measurable. For example, suppose that your program defines the following method:

An interface is a reference type

Your program can invoke this method, passing it an object of any class that implements the interface Measurable.

## LISTING 8.9 Another Implementation of the Interface Measurable

```
/**
A class of circles.
* /
public class Circle implements Measurable
    private double myRadius;
    public Circle(double radius)
    {
        myRadius = radius;
    }
    public double getPerimeter()
    {
        return 2 * Math.PI * myRadius;
    }
                                               This method is not declared
    public double getCircumference()
                                               in the interface.
    {
        return getPerimeter();
                                               Calls another method
                                               instead of repeating its body
    public double getArea()
    {
        return Math.PI * myRadius * myRadius;
    }
}
```

For instance, your program might contain the following statements:

```
Measurable box = new Rectangle(5.0, 5.0);
Measurable disc = new Circle(5.0);
```

Even though the type of both variables is Measurable, the objects referenced by box and disc have different definitions of getPerimeter and getArea. The variable box references a Rectangle object; disc references a Circle object. Thus, the invocation

```
display(box);
displays
    Perimeter = 20.0; area = 25.0
while the invocation
    display(disc);
displays
    Perimeter = 31.4; area = 78.5
```

The classes Rectangle and Circle implement the same interface, so we are able to substitute an instance of one for an instance of the other when we call the method display. This is another example of polymorphism—the ability

to substitute one object for another using dynamic binding. These terms refer to the fact that the method invocation is not bound to the method definition until the program executes.

As another example, consider the following code:

```
Measurable m;
Rectangle box = new Rectangle(5.0, 5.0);
m = box;
display(m);
Circle disc = new Circle(5.0);
m = disc;
display(m);
```

The two calls to display are identical, and the code within the method display is identical in both cases. Thus, the invocations of getPerimeter and getArea within display are identical. Yet these invocations use different definitions for getPerimeter and getArea, and so the two invocations of display produce different output, just as they did in our earlier example.

A variable of an interface type can reference an object of a class that implements the interface, but the object itself always determines which method actions to use for every method name. The type of the variable does not matter. What matters is the class name when the object was created, because Java uses dynamic binding. Not even a type cast will fool Java.

You therefore need to be aware of how dynamic binding interacts with the Java compiler's type checking. For example, consider

```
Measurable m = new Circle(5.0);
```

We can assign an object of type Circle to a variable of type Measurable, again because Circle implements Measurable. However, we can use the variable to invoke only a method that is in the interface Measurable. Thus, the invocation of getCircumference in

```
System.out.println(m.getCircumference()); //ILLEGAL!
```

is illegal, because getCircumference is not the name of a method in the Measurable interface. In this invocation, the variable m is of type Measurable, but the object referenced by m is still an object of type Circle. Thus, although the object has the method getCircumference, the compiler does not know this! To make the invocation valid, you need a type cast, such as the following:

```
Circle c = (Circle)m;
System.out.println(c.getCircumference());//Legal
```

#### **REMEMBER** What Is Legal and What Happens

A variable's type determines what method names can be used, but the object the variable references determines which definition of the method will be used.





## RECAP Dynamic Binding and Polymorphism Apply to Interfaces

Dynamic binding applies to interfaces just as it does with classes. The process enables objects of different classes to substitute for one another, if they have the same interface. This ability—called polymorphism—allows different objects to use different method actions for the same method name.

#### **SELF-TEST QUESTIONS**

- 23. Imagine a class Oval that defines the methods getPerimeter and getArea but does not have the clause implements Measurable. Could you pass an instance of Oval as an argument to the method display given in the previous section?
- 24. Can a class implement more than one interface?

## **Extending an Interface**

Once you have an interface, you can define another interface that builds on, or **extends**, the first one by using a kind of inheritance. Thus, you can create an interface that consists of the methods in an existing interface plus some new methods.

For example, consider the classes of pets we discussed earlier and the following interface:

```
public interface Nameable
{
    public void setName(String petName);
    public String getName();
}
```

We can extend Nameable to create the interface Callable:

```
public interface Callable extends Nameable
{
    public void come(String petName);
}
```

A class that implements Callable must implement the methods come, setName, and getName.

You also can combine several interfaces into a new interface and add even more methods if you like. For example, suppose that in addition to the previous two interfaces, we define the following interfaces:

You can define an interface based on another interface

```
public interface Capable
{
    public void hear();
    public String respond();
}
public interface Trainable extends Callable, Capable
{
    public void sit();
    public String speak();
    public void lieDown();
}
```

A class that implements Trainable must implement the methods setName, getName, come, hear, and respond, as well as the methods sit, speak, and lieDown.



### **SELF-TEST QUESTIONS**

- 25. Suppose a class C implements the interface Trainable, as defined in the previous section. Can you pass an instance of C to a method whose parameter is of type Capable?
- 26. Suppose a class D implements the interfaces Callable and Capable, as defined in the previous section. Can you pass an instance of D to a method whose parameter is of type Trainable?

## **CASE STUDY** Character Graphics

Java has methods to draw graphics on your computer screen. Suppose, however, that the screen on the inexpensive device you are designing for has no graphics capability, allowing only text output. In this case study, we will design three interfaces and three classes that produce graphics on a screen by placing ordinary keyboard characters on each line to draw simple shapes. Our drawings will not be sophisticated, but we will be able to explore the use of interfaces and inheritance in solving a problem.

Let's begin by writing an interface that specifies the methods that our objects should have. Suppose the method drawHere draws the shape beginning at the current line and drawAt draws it after moving a given number of lines down from the current one.

All shapes have some properties in common. For example, each of the shapes will have an offset telling how far it is indented from the left edge of the screen. We can include set and get methods for this offset. Each shape will also have a size, but the size of some shapes is described by a single number, while the size of others is determined by several numbers. Since the size will

Specify the solution by writing an interface

be specified according to the kind of shape, it isn't an attribute that all shapes will have in common. Listing 8.10 contains an interface for the methods that all shapes will have.

Suppose we want to draw rectangles and triangles. The size of a rectangle is given as its width and height, each expressed as a number of characters. Because characters are taller than they are wide, a rectangle might look taller than we expect. For example, a 5 by 5 rectangle will not look square on the screen, but will appear as shown in Figure 8.5.

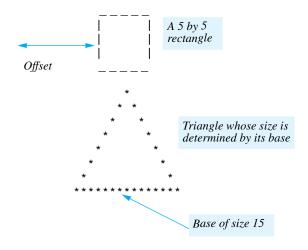
Suppose we decide that a triangle will always point up, with its base at the bottom. After choosing the length of the base, and to make the other sides smooth, the slopes of the sides are limited to what we get by indenting one character per line. So once the base is chosen, we have no choice regarding what the sides of the triangle will be. Figure 8.5 also shows a sample of a triangle.

If we could be content to specify a shape's offset and size in its constructor alone, the interface we wrote in Listing 8.10 would suffice. But suppose that we also want to be able to redefine the size of an existing shape. That is, we want a mutator method. Since the size of a shape depends on the shape being

#### LISTING 8.10 An Interface for Drawing Shapes Using Keyboard Characters

```
/**
Interface for simple shapes drawn on
the screen using keyboard characters.
*/
public interface ShapeInterface
{
    /**
    Sets the offset for the shape.
    */
    public void setOffset(int newOffset);
    /**
    Returns the offset for the shape.
    */
    public int getOffset();
    /**
    Draws the shape at lineNumber lines down from the current line.
    */
    public void drawAt(int lineNumber);
    /**
    Draws the shape at the current line.
    */
    public void drawHere();
}
```

FIGURE 8.5 A Sample Rectangle and Triangle



drawn, we will define two more interfaces, one for rectangles and one for triangles. Listing 8.11 contains these interfaces. Note that both of them extend ShapeInterface.

LISTING 8.11 Interfaces for Drawing Rectangles and Triangles

```
/**
Interface for a rectangle to be drawn on the screen.
*/
public interface RectangleInterface extends ShapeInterface
{
    /**
    Sets the rectangle's dimensions.
    */
    public void set(int newHeight, int newWidth);
}
/**
Interface for a triangle to be drawn on the screen.
*/
public interface TriangleInterface extends ShapeInterface
{
    /**
    Sets the triangle's base.
    */
    public void set(int newBase);
}
```

Try writing some code that uses the specifications of your classes

We now have our specifications, so we can try to write some Java statements that use our drawing methods. For example, we could draw an 8 by 4 rectangle on the current line, offset five spaces, as follows:

```
RectangleInterface box = new Rectangle(5, 8, 4);
box.drawHere();
```

We then could revise the size and indentation of the object box and draw it after moving down on the screen by two lines, as follows:

```
box.set(5, 5);
box.setOffset(10);
box.drawAt(2);
```

Attributes and methods common to the classes can form a base class

Our specifications seem reasonable, so we'll now go on to some implementation issues. Let's write a base class named ShapeBasics that implements ShapeInterface. Later we can derive the classes Rectangle and Triangle from this base class. We saw that the only common attribute is the offset, so the class ShapeBasics will have only the following instance variable:

```
private int offset;
```

ShapeBasics is our base class

/ \* \*

Our interface specifies the class's methods, so we need only define them and add some appropriate constructors. Listing 8.12 contains a definition for the class ShapeBasics.

(continued)

## LISTING 8.12 The Base Class ShapeBasics (part 1 of 2)

```
Class for drawing simple shapes on the screen using keyboard characters. This class will draw an asterisk on the screen as a test. It is not intended to create a "real" shape, but rather to be used as a base class for other classes of shapes.

*/
public class ShapeBasics implements ShapeInterface
{
    private int offset;
    public ShapeBasics()
    {
        offset = 0;
    }
    public ShapeBasics(int theOffset)
    {
        offset = theOffset;
    }
    public void setOffset(int newOffset)
    {
        offset = newOffset;
    }
```

#### LISTING 8.12 The Base Class ShapeBasics (part 2 of 2)

The method drawAt has one parameter of type int, whose value indicates the number of blank lines to be inserted before the drawing of the shape. The shape is drawn by a call to drawHere. drawAt calls drawHere

al Derived classes
s must override
drawHere
e

The method drawHere indents a number of spaces on the screen equal to the offset and then writes an asterisk on the screen. This simple output is just so you can have something to test. You do not intend to use this version of drawHere in any application. You will override the definition of drawHere when you define classes for rectangles and triangles.

Now we turn our attention to the class for drawing a rectangle. The class, called Rectangle, will be a derived class of the class ShapeBasics. Thus, the class definition will begin with

```
public class Rectangle extends ShapeBasics
```

Since we want our class to implement RectangleInterface, we add an implements clause, as follows:

```
public class Rectangle extends ShapeBasics
  implements RectangleInterface
```

When you have both an extends clause and an implements clause, the extends clause is always first. An easy way to remember the order of these two clauses is to notice that the keywords extends and implements are in alphabetical order.

extends is always before implements

We need to decide what instance variables, if any, to add to those already in the class ShapeBasics. We also need to decide whether to override any method definitions in ShapeBasics. Our class Rectangle will be able to use the instance variable offset in the base class, but we need to have instance variables for the height and the width of the rectangle. Thus, the class definition looks like the following:

```
public class Rectangle extends ShapeBasics
   implements RectangleInterface
{
    private int height;
    private int width;
    <Method definitions>
}
```

Note that we do not list the instance variable offset within Rectangle.

We know that Rectangle needs the usual constructors and a set method for the sides. Rectangle inherits the methods setOffset, getOffset, drawAt, and drawHere from the class ShapeBasics. However, we need to override the definition of the method drawHere so that it does indeed draw a rectangle. Do we need to override the method drawAt? When we look at the method drawAt in Listing 8.12, we see that, as long as drawHere is correctly defined, the method drawAt will work fine for a rectangle or any other shape. Polymorphism will ensure that the correct version of drawHere is called.

Let's look first at a sample constructor, one that sets all instance variables to the values given as its arguments. But one instance variable, namely offset, is a private instance variable of the base class ShapeBasics, so we cannot access it directly by name. However, we can either call the method setOffset or use super to call the base class constructor. We choose the latter, so the definition of this constructor is as follows:

```
public Rectangle(int theOffset, int theHeight, int theWidth)
{
    super(theOffset);
    height = theHeight;
    width = theWidth;
}
```

The default constructor similarly calls the base class default constructor and sets the rectangle's dimensions to zero. We could omit an explicit call to super in the default constructor, and it would be called automatically anyway, but we leave it in for clarity.

The method set, as specified in RectangleInterface, is straightforward, so let's examine the method drawHere, which depends heavily on the particulars of the shape it is drawing. We can use a technique known as **top-down design**. In this technique, we break down the task to be performed into subtasks. We have the following subtasks:

### Algorithm to draw a rectangle

- 1. Draw the top line.
- 2. Draw the side lines.
- 3. Draw the bottom line.

Each constructor in a derived class calls a constructor in the base class ShapeBasics

Note that not every way of choosing subtasks will work. You might at first be tempted to draw the sides of the box in two subtasks. However, output must be produced one line after the other, and you are not allowed to back up. Thus, we must draw the two sides together so they will be side by side, as they should be.

The definition of the method drawHere is easy:

```
public void drawHere()
    drawHorizontalLine();
    drawSides();
    drawHorizontalLine();
}
```

Although that was easy, it does postpone most of the work. You still need to define the methods drawHorizontalLine and drawSides. Because these are helping methods, they will be private methods.

Subtasks of drawHere are realized as private methods

The logic for drawHorizontalLine is not complicated, as you can see from the following pseudocode:

#### Algorithm for drawHorizontalLine

- 1. Display offset blank spaces.
- 2. Display width copies of the character '-'.
- System.out.println();

The task of writing a specified number of blanks is done by another helping method called skipSpaces, which contains a simple loop. The final code for the method drawHorizontalLine is

```
private void drawHorizontalLine()
{
    skipSpaces(getOffset());
    for (int count = 0; count < width; count++)</pre>
         System.out.print('-');
    System.out.println();
}
```

Next we consider the method drawSides. Its task is to draw a shape like the Drawing both following:

sides



Since each line is identical, we can treat the display of one of these lines as a subtask. So the definition of the method drawSides is

```
private void drawSides()
{
   for (int count = 0; count < (height - 2); count++)]
        drawOneLineOfSides();
}</pre>
```

Note that we display two fewer lines than the height. The top and bottom horizontal lines account for those extra two units of height.

Just about all that is left to do is to define the helping method drawOne-LineOfSides. Because we already have a method for the subtask of writing spaces, the pseudocode for drawOneLineOfSides turns out to be Java code:

```
skipSpaces(getOffset());
System.out.print('|');
skipSpaces(width - 2);
System.out.println('|');
```

We are basically done. Listing 8.13 gives the complete class definition of Rectangle.

#### LISTING 8.13 The Class Rectangle (part 1 of 2)

```
/**
Class for drawing rectangles on the screen using keyboard
characters. Each character is higher than it is wide, so
these rectangles will look taller than you might expect.
Inherits getOffset, setOffset, and drawAt from the class
ShapeBasics.
public class Rectangle extends ShapeBasics
                       implements RectangleInterface
{
    private int height;
    private int width;
    public Rectangle()
    {
        super();
        height = 0;
        width = 0;
    }
    public Rectangle(int theOffset, int theHeight,
                     int theWidth)
    {
        super(theOffset);
        height = theHeight;
        width = theWidth;
    }
```

(continued)

#### LISTING 8.13 The Class Rectangle (part 2 of 2)

```
public void set(int newHeight,int newWidth)
{
    height = newHeight;
    width = newWidth:
public void drawHere();
    drawHorizontalLine();
    drawSides();
    drawHorizontalLine();
}
private void drawHorizontalLine()
{
    skipSpaces(getOffset());
    for (int count = 0; count < width; count++)</pre>
        System.out.print('-');
    System.out.println();
}
private void drawSides()
    for (int count = 0; count < (height - 2); count++)</pre>
        drawOneLineOfSides();
private void drawOneLineOfSides()
    skipSpaces(getOffset());
    System.out.print('|');
    skipSpaces(width - 2);
    System.out.println('|');
}
//Writes the indicated number of spaces.
private static void skipSpaces(int number)
    for (int count = 0; count < number; count++)</pre>
        System.out.print(' ');
                For clarity, the method skipSpaces was made
                static because it does not depend on an object.
```

Although we will not stop to describe the testing process in this case study, all the methods in the class ShapeBasics, the class Rectangle, and the class Triangle—which we have not yet discussed—need to be tested. Remember, each method should be tested in a program in which it is the only untested method.

}

Listing 8.14 contains the definition of the class Triangle. We can design this class using the same techniques we used to design the class Rectangle. We will discuss only one part of the method drawHere for which the technical details might not be clear at first. The method drawHere divides its task into

Test the methods along the way

#### LISTING 8.14 The Class Triangle (part 1 of 2)

```
/ * *
Class for drawing triangles on the screen using keyboard
characters. A triangle points up. Its size is determined
by the length of its base, which must be an odd integer.
Inherits getOffset, setOffset, and drawAt from the class
ShapeBasics.
*/
public class Triangle extends ShapeBasics
                      implements TriangleInterface
{
    private int base;
    public Triangle()
        super();
        base = 0:
    public Triangle(int theOffset, int theBase)
    {
        super(theOffset);
        base = theBase;
    }
    /** Precondition: newBase is odd. */
    public void set(int newBase)
    {
        base = newBase;
    public void drawHere()
        drawTop();
        drawBase();
    }
    private void drawBase()
        skipSpaces(getOffset());
        for (int count = 0; count < base; count++)</pre>
             System.out.print('*');
        System.out.println();
    private void drawTop()
    {
        //startOfLine == number of spaces to the
        //first '*' on a line. Initially set to the
        //number of spaces before the topmost '*'.
        int startOfLine = getOffset() + base / 2;
        skipSpaces(startOfLine);
        System.out.println('*');//top '*'
```

(continued)

#### LISTING 8.14 The Class Triangle (part 2 of 2)

```
int lineCount = base / 2 - 1;//height above base
        //insideWidth == number of spaces between the
        //two '*'s on a line.
        int insideWidth = 1;
        for (int count = 0; count < lineCount; count++)</pre>
            //Down one line, so the first '*' is one more
            //space to the left.
            startOfLine --:
            skipSpaces(startOfLine);
            System.out.print.('*');
            skipSpaces(insideWidth);
            System.out.println('*');
            //Down one line, so the inside is 2 spaces wider.
            insideWidth = insideWidth + 2;
    }
    private static void skipSpaces(int number)
        for (int count = 0; count < number; count++)</pre>
            System.out.print(' ');
    }
}
```

two subtasks: Draw the inverted V for the top of the triangle, and draw the horizontal line for the bottom of the triangle.

The method drawTop draws a shape like the following:

drawTop draws two sides of the triangle



Note that the entire shape is offset. The indentation for the wide bottom of the shape is exactly this offset. But going up from bottom to top, each line has a greater indentation. Alternatively, moving down the lines from top to bottom—as the computer must—the indentation decreases by one character per line. So if the indentation for the top of the triangle is given by the value of the int variable startOfLine, the first indentation can be performed by

```
skipSpaces(startOfLine);
```

We then write a single asterisk.

Loop that draws two sides without the asterisk at their juncture After writing the asterisk for the first line, we need to write two asterisks for each subsequent line. We write a loop that decreases startOfLine by 1 on each iteration and executes a statement exactly like the previous call to skipSpaces. We then write an asterisk and skip some more spaces before writing the second asterisk. The size of the gap between the two asterisks on a line increases by 2 as we move down from line to line. If this gap is given by the value of the int variable insideWidth, the loop for drawing all of the inverted V except for the top asterisk can be

```
for (int count = 0; count < lineCount; count++)
{
    startOfLine--;
    skipSpaces(startOfLine);
    System.out.print(*);
    skipSpaces(insideWidth);
    System.out.println(*);
    insideWidth = insideWidth + 2;
}</pre>
```

The complete definition of the method drawTop is given in Listing 8.14.

The base of the triangle is a line of asterisks. Ideally, we should use an odd number of asterisks, for otherwise the triangle will look slightly off-balance. However, to keep the class simple, we simply state this as a precondition of Triangle's set method and do not try to enforce it.

The sample application program shown in Listing 8.15 demonstrates our classes by drawing a triangle and a rectangle to form a crude picture of a fir tree.

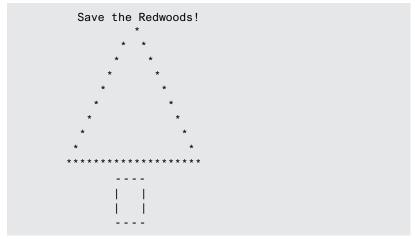
# LISTING 8.15 A Demonstration of Triangle and Rectangle (part 1 of 2)

(continued)

# LISTING 8.15 A Demonstration of Triangle and Rectangle (part 2 of 2)

```
public static void drawTree(int topWidth, int bottomWidth,
                                int bottomHeight)
    {
       System.out.println("
                                 Save the Redwoods!");
       TriangleInterface treeTop = new Triangle(INDENT, topWidth);
       drawTop(treeTop);
        RectangleInterface treeTrunk = new Rectangle(INDENT +
                           (topWidth / 2) - (bottomWidth / 2),
                           bottomHeight, bottomWidth);
       drawTrunk(treeTrunk);
    private static void drawTop(TriangleInterface treeTop)
        treeTop.drawAt(1);
    private static void drawTrunk(RectangleInterface treeTrunk)
       treeTrunk.drawHere(); // or treeTrunk.drawAt(0);
}
```

#### Screen Output



## SELF-TEST QUESTIONS

27. Is the definition of drawHere given in Listing 8.13 an example of overloading or overriding?

- 28. Is the definition of drawHere given in Listing 8.14 an example of overloading or overriding?
- 29. Are the two definitions of the constructors given in Listing 8.14 an example of overloading or overriding?
- 30. The private method skipSpaces appears in the definitions of both Rectangle (Listing 8.13) and Triangle (Listing 8.14). Can we move this method to the base class ShapeBasics (Listing 8.12) so that both Rectangle and Triangle can inherit it instead of each defining its own copy?
- 31. Describe the implementation of the method drawHere for a class called Diamond that is derived from the class ShapeBasics. Programming Project 2 at the end of this chapter asks you to actually write this class. (*Hint*: The class Diamond is similar to the class Triangle.)

## **CASE STUDY** The Comparable Interface

Java has many predefined interfaces that are used by many classes. One of them is the Comparable interface, and it is used to impose an ordering upon the objects that implement it. The Comparable interface has only one method heading. The method compareTo must be written for a class to implement the Comparable interface.

```
public int compareTo(Object other);
```

The interface allows you to specify how one object compares to another in terms of when one should "come before" or "come after" or "equal" the other. It is the programmer's responsibility to follow the semantics appropriately. For example, if you define A to come before B, and B to come before C, you shouldn't allow C to come before A.

The compareTo method should return

- a negative number if the calling object "comes before" the parameter other,
- a zero if the calling object "equals" the parameter other,
- and a positive number if the calling object "comes after" the parameter other.

As an example, consider the idiom that one can't compare apples to oranges. Let's show that this idiom doesn't quite apply to Java classes because we can define the compareTo method as we see fit. Our first attempt to define a Fruit class to represent apples and oranges might look like the code in Listing 8.16. This simple class uses a String to store the name of the fruit along with methods to get and set the name. The constructor takes the name of the fruit. This initial attempt does not implement any interfaces.

#### LISTING 8.16 First Attempt to Define a Fruit Class

```
public class Fruit
{
    private String fruitName;
    public Fruit()
    {
        fruitName = "";
    }
    public Fruit(String name)
    {
        fruitName = name;
    }
    Public void setName(String name)
    {
        fruitName = name;
    }
    public String getName()
    {
        return fruitName;
    }
}
```

A short demo program is given in Listing 8.17 that attempts to use the Fruit class. In this example we make an array that contains four Fruit objects. Then we try to sort the array using Arrays.sort described in Section 7.4.

## LISTING 8.17 Program to Sort an Array of Fruit Objects

The program in Listing 8.17 will compile and run but produce the following run-time error:

Exception in thread "main" java.lang.ClassCastException: Fruit cannot be cast to java.lang.Comparable

This error occurs because Java doesn't know how to compare two instances of the Fruit class to each other to see if one "comes after" the other when attempting to sort the array. More precisely, the Arrays.sort method has been written with the expectation that the objects passed in the array have a compareTo method in accordance with the Comparable interface. Arrays. sort attempts to invoke compareTo on objects in the array (for example, to see if fruits[0] is greater than fruits[1]) so they can be rearranged in sorted order, but since the method doesn't exist there is an error.

The solution is to make sure that the Fruit class implements the Comparable interface with a compareTo method. One way we might compare one fruit to another is to use the lexicographic ordering of the fruit name. Lexicographic ordering is the same as alphabetical ordering when both strings are either all uppercase or all lowercase letters. For example, apples would come before oranges because the word "apple" is lexicographically ordered before "orange." To accomplish this we can use the compareTo method defined for the String class. That is, if we have two strings str1 and str2 then

```
str1.compareTo(str2)
```

will return a negative number if str1 is lexicographically before str2, the value 0 if str1 is equal to str2, and a positive number if str1 is lexicographically after str2. The compareTo method we write for the Fruit class can then return the result of the compareTo method for the names of the fruits being compared. The code in Listing 8.18 contains a version of the Fruit class with these changes highlighted.

# LISTING 8.18 A Fruit Class Implementing Comparable (part 1 of 2)

```
public class Fruit implements Comparable
{
    private String fruitName;
    public Fruit()
    {
        fruitName = "";
    }
    public Fruit(String name)
    {
        fruitName = name;
    }
}
```

(continued)

# LISTING 8.18 A Fruit Class Implementing Comparable (part 2 of 2)

Now the program in Listing 8.17 will run and produce the output:

Apple Durian Kiwi Orange

The Arrays.sort method is now successful because it can call the compareTo method to compare objects in the array and reorder them. To drive home the point that our compareTo method is being called from within the Arrays. sort method, we can redefine compareTo with different criteria to sort fruit. Instead of lexicographic ordering, let's use the length of the fruit name as the comparison metric. Fruit with shorter names will come before fruit with longer names. Below is an alternate definition of the compareTo method:

```
return -1;
         else
               return 0;
    return -1; // Default if other object is not a Fruit
}
```

The program in Listing 8.17 will now produce the output:

Kiwi Apple **Orange** Durian

The fruits are now sorted in order of shortest word first.

#### **Abstract Classes**

When we wrote the class ShapeBasics in Listing 8.12, we did not plan to create objects of the class ShapeBasics. Instead, we designed it as a base class for other classes, such as the class Rectangle in Listing 8.13. Although we do not really need to create objects of the class ShapeBasics, we can do so, as in the following statement:

```
ShapeBasics shapeVariable = new ShapeBasics();
```

To make this statement valid, however, we needed to write a definition for the method drawHere in the class ShapeBasics. The definition that we wrote is just a place holder; all it does is draw a single asterisk, just so something would happen if we invoked it. We never intended to invoke the method drawHere of an object of the base class ShapeBasics. Rather, we planned to use the method drawHere only with objects of derived classes, such as Rectangle and Triangle.

Instead of giving a contrived definition of a method that we plan to override in a derived class, however, we can declare the method to be abstract, as follows:

```
public abstract void drawHere();
```

We write the keyword abstract in the method heading, follow the heading with a semicolon, and omit a method body. An abstract method must be overridden by any (nonabstract) derived class and given a definition. Including an abstract method in a class is a way to force a derived class to define a particular method.

Java requires that if a class has at least one abstract method, the class must be declared to be abstract. You do this by including the keyword abstract in the heading of the class definition, as in the following:

```
public abstract class ShapeBase
{ . . .
```

An abstract method has no body

An abstract class has at least one abstract method A class defined in this way is said to be an **abstract class**. If a class is abstract, you cannot create objects of that class; it can be used only as a base class for other classes. For this reason, an abstract class is sometimes called an **abstract base class**.

You cannot create an object of an abstract class

In Listing 8.19, we have revised the class ShapeBasics as an abstract class and named it ShapeBase. If we had used this abstract class ShapeBase in the previous case study, all of our derived classes would work as before, even though we could not create objects of ShapeBase.

Although the class ShapeBase is abstract, not all of its methods are abstract. All the method definitions, except for the method drawHere, are exactly the same as in our original ShapeBasics. They are full definitions and do not use the keyword abstract. When it makes sense to define a body for a method in an abstract class, it should be given. That way, as much detail as possible is pushed into the abstract class, so that such detail need not be repeated in each derived class.

Why have abstract classes? They simplify your thinking. We have already explained in the case study that we defined the class ShapeBasics so we would not have to duplicate the definitions of methods such as drawAt for every kind of shape. But we also had to write a useless definition for the method drawHere. An abstract class makes it easier to define a base class by relieving you of the obligation to write useless method definitions. If a method will always be overridden, make it an abstract method—and so

# LISTING 8.19 The Abstract Class ShapeBase

```
Abstract base class for drawing simple shapes on the screen
using characters.
public abstract class ShapeBase implements ShapeInterface
    private int offset;
    public abstract void drawHere();
    The rest of the class is identical to ShapeBasics in Listing 8.12, except for the names
    of the constructors. Only the method drawHere is abstract. Methods other than
    drawHere have bodies and do not have the keyword abstract in their headings.
    We repeat one such method here:
    public void drawAt(int lineNumber)
    {
         for (int count = 0; count < lineNumber; count++)</pre>
              System.out.println();
         drawHere();
    }
}
```

make the class abstract. An abstract method serves a purpose, even though it is not given a full definition. It serves as a place holder for a method that must be defined in all (nonabstract) derived classes. Note that the method drawAt in Listing 8.19 includes an invocation of the method drawHere. If the abstract method drawHere were omitted, this invocation of drawHere would be illegal.

You might notice that an abstract class is very similar to an interface. Both define methods and you can't make instances of either one. However, you can define default methods for the derived classes in an abstract class and you can only specify the method heading in an interface. Conceptually, an abstract class represents a conceptual view of an abstract entity in the problem you are trying to solve. An interface specifies functionality that a class must support.

# **REMEMBER** An Abstract Class Is a Type

You cannot create an object of an abstract class. For example, given the abstract class ShapeBase as defined in Listing 8.19, the following statement is illegal:

```
ShapeBase f = new ShapeBase(); // ILLEGAL!
```

Nonetheless, it makes perfectly good sense to have a parameter of type ShapeBase. Then an object of any of the descendant classes of ShapeBase can be plugged in for the parameter.





# **SELF-TEST QUESTIONS**

32. Is the following valid if ShapeBase is defined as in Listing 8.19?

ShapeInterface shapeVariable = new ShapeBase();

33. Is the following valid if ShapeBase is defined as in Listing 8.19, and Rectangle is as defined in Listing 8.13 but ShapeBasics is replaced by ShapeBase?

ShapeBase shapeVariable = new Rectangle();

## **8.5** GRAPHICS SUPPLEMENT

Good Heavens! For more than forty years I have been speaking prose without knowing it.

—MOLIÈRE, Le Bourgeois Gentilhomme

# **Event-Driven Programming**

In this section, we explain how to assign actions to a control like a button. JavaFX applications use events and event handlers. An event is an object that represents some user action that elicits a response, such as clicking a button with the mouse. When an object generates an event, it is said to **fire the event**. For example, when the user clicks a button, the button fires an event. In a JavaFX application, every object that can fire events can have one or more **listener objects** that receive events automatically. A listener object has methods that specify what will happen when the listener receives events of various kinds. These methods are called **event handlers**.

You the programmer specify what objects are the listeners for any given object that might fire an event. You also define the event-handler methods. The relationship between an event-firing object, such as a button, and its event-handling listener is illustrated in Figure 8.6.

We actually haven't presented anything new. Event objects, listeners, and event handlers are all implemented using a Java interface as discussed in Section 8.4. In our case, the interface is named EventHandler. This interface requires us to implement the method named handler. The listener object is the class that implements EventHandler. The event object will be an object of class ActionEvent. It is created by JavaFX when an event occurs, such as when a button is clicked. This object contains information about the type of event that occurred and the object that initiated the event (e.g., the button that was clicked). The process is diagrammed in Figure 8.7.

Next, we present three options to select the class that will be the listener. Regardless of the option, the listener class must implement EventHandler<ActionEvent>. The <ActionEvent> notation is discussed in Chapter 12 and essentially says that we are making an event handler that will handle items of type ActionEvent. We can make our class in a new, separate class, whose sole purpose is to handle the event. This is the "normal" technique we have been using to create a class that implements an interface. An alternate technique is to make the main GUI class itself implement the interface. Finally,

FIGURE 8.6 Event Firing and an Event Listener

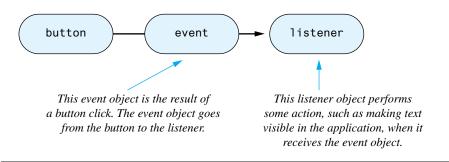
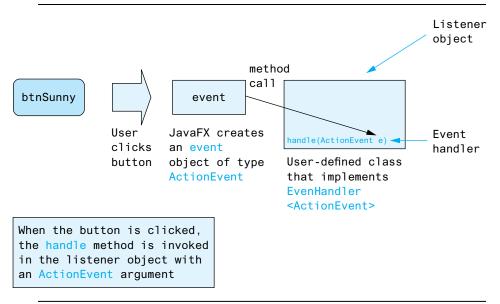


FIGURE 8.7 Buttons and an Event Handler



a third alternative technique is to create an anonymous inner class. In this section we present examples using all three techniques.



# **Event Handling in a Separate Class**

Listing 8.20 creates a simple JavaFX application with two buttons in a VBox layout pane. The listener object for the buttons is the class HandleButtonClick that is provided in Listing 8.21. To associate the button click event with a HandleButtonClick object, we use the setOnAction method. The following

# LISTING 8.20 Event Handling in a Separate Class (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.VBox;
import javafx.scene.control.Button;

/**
Simple demonstration of programming buttons in a JavaFX application.
This version outputs a message when clicked.
*/
public class ButtonDemo1 extends Application
```

(continued)

# LISTING 8.20 Event Handling in a Separate Class (part 2 of 2)

```
{
   public static void main(String[] args)
   {
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
        VBox root = new VBox();
        Button btnSunny;
        Button btnCloudy;
        btnSunny = new Button("Sunny");
        btnCloudy = new Button("Cloudy");
         // Create an event object to handle the button click.
         // The "handle" method in HandleButtonClick will be
         // invoked when the button is clicked.
         HandleButtonClick clickEvent = new HandleButtonClick();
         btnSunny.setOnAction(clickEvent);
         // We can also create the HandleButtonClick object without
         // a named reference by creating it inside the call to setOnAction
         btnCloudy.setOnAction(new HandleButtonClick("It is cloudy."));
        root.getChildren().add(btnSunny);
        root.getChildren().add(btnCloudy);
        Scene scene = new Scene(root, 300, 100);
        primaryStage.setTitle("Button Event Handling Demo");
        primaryStage.setScene(scene);
        primaryStage.show();
   }
}
Program Output
                                      The program outputs "It is sunny!" to
Button Event Handling ...
                          X
                                      the console when the "Sunny" button
 Sunny
                                      is clicked, and "It is cloudy." When the
 Cloudy
                                      "Cloudy" button is clicked.
```

# LISTING 8.21 A Button Click Listener and Event Handler

```
import javafx.event.ActionEvent;
import javafx.event.EventHandler;
/**
This class handles a button click and outputs a message.
The handle method is invoked when the button is clicked.
* /
public class HandleButtonClick implements EventHandler<ActionEvent>
    private String message;
    public HandleButtonClick()
    {
        message = "It is sunny!";
    public HandleButtonClick(String customMessage)
        message = customMessage;
    @Override
    public void handle(ActionEvent event)
        System.out.println(message);
}
```

example creates a new HandleButtonClick object and associates it with btnSunny:

```
HandleButtonClick clickEvent = new HandleButtonClick();
btnSunny.setOnAction(clickEvent);
```

This is telling JavaFX that the HandleButtonClick class will handle any processing when btnSunny is clicked.

Since HandleButtonClick is a regular class, we can overload the constructor. In Listing 8.21, we have created a second constructor that takes a String message and stores it internally so that the message will be output when the event occurs. We can create an instance of HandleButtonClick using this constructor and associate it with a button all in one line:

```
btnCloudy.setOnAction(new HandleButtonClick("It is cloudy."));
```

Note that HandleButtonClick is not just any class. The class we use to set the action must implement the interface EventHandler<ActionEvent>. This interface requires that you override the method

```
public void handle(ActionEvent event)
```

In Listing 8.21, our implementation of the handle method simply outputs the message variable, which is "It is sunny!" by default. When the application is run, clicking the "Sunny" button will output "It is sunny!" to the console, while clicking the "Cloudy" button will output "It is cloudy." to the console.

# **Event Handling in the Main GUI Application Class**

One minor inconvenience to the approach in Listing 8.20 is that we have to go through some overhead to define a class to handle our button click event. Another inconvenience is that the HandleButtonClick class doesn't have access to any of the member variables in the ButtonDemo1 class. It is common for a control to need to interact with other controls in the application. We could work around this problem by passing in a reference to other controls we may need to access in the constructor to HandleButtonClick, but this is also somewhat inconvenient if we have to send a large number of arguments.

Another approach is to make the HandleButtonClick a private inner class within the ButtonDemo1 class. This will allow the HandleButtonClick class to access member variables in ButtonDemo1. To do this, we simply move the HandleButtonClick class inside ButtonDemo1, at the same level as the methods in ButtonDemo1, and change public to private. Inner classes are described in Chapter 12.

An alternate approach is to make the ButtonDemo class itself implement the EventHandler<ActionEvent> interface. This means that we will need to add the handle method into the ButtonDemo class. Since this method is inside ButtonDemo, it will have access to any member variables that are part of the class, such as other UI controls.

In Listing 8.22, we have taken this approach and modified ButtonDemo1 into ButtonDemo2:

```
public class ButtonDemo2 extends Application
  implements EventHandler<ActionEvent>
```

To set the button action to the handle method in our ButtonDemo2 class, all we need to do is to send in this to set a reference to the active object:

```
btnSunny.setOnAction(this);
btnCloudy.setOnAction(this);
```

This does bring up a new complication. Since we now only have a single object (the current object) to handle both button clicks, if we want to distinguish which button was clicked we now have to make that determination within the handle method. In our previous version, we could distinguish which button was clicked by associating different instances of HandleButtonClick to each button. One way to do this is to invoke the getText() method, which retrieves the text in the button. We can then check the text value and act accordingly.

In Listing 8.22, the handle method disables the other button when one is clicked. To use the getText() method, we type cast back to a Button object. For

# LISTING 8.22 Event Handling in the Main GUI Application Class (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.VBox;
import javafx.scene.control.Button;
import javafx.event.ActionEvent;
import javafx.event.EventHandler;
/ * *
Demonstration of event handling within the ButtonDemo2 class.
public class ButtonDemo2 extends Application implements
EventHandler<ActionEvent>
   private Button btnSunny;
   private Button btnCloudy;
   public static void main(String[] args)
      launch(args);
   @Override
   public void handle(ActionEvent event)
      // This method can access the member variables
      // which reference the other GUI controls
      if (event.getSource() instanceof Button)
           Button btnClicked = (Button) event.getSource();
           if (btnClicked.getText().equals("Sunny"))
             // Disable the cloudy button if sunny clicked
             btnCloudy.setDisable(true);
           else if (btnClicked.getText().equals("Cloudy"))
             // Disable the sunny button if cloudy clicked
             btnSunny.setDisable(true);
         }
     }
   @Override
   public void start(Stage primaryStage) throws Exception
                                                         (continued)
```

# LISTING 8.22 Event Handling in the Main GUI Application Class (part 2 of 2)

```
VBox root = new VBox();
        btnSunny = new Button("Sunny");
        btnCloudy = new Button("Cloudy");
        btnSunny.setOnAction(this);
        btnCloudy.setOnAction(this);
        root.getChildren().add(btnSunny);
        root.getChildren().add(btnCloudy);
        Scene scene = new Scene(root, 300, 100);
        primaryStage.setTitle("Button Demo 2");
        primaryStage.setScene(scene);
        primaryStage.show();
   }
}
Program Output
 Button Demo 2
                         П
                               X
 Sunny
 Cloudy
```

# After "Sunny" is clicked



a safety check, we only perform these steps if the source object that caused the event is a Button object. We can get the source object from the event argument.

# **Event Handling in an Anonymous Inner Class**

Finally, we show one more way to make an event handler. This technique has the benefit of giving the event handler access to any member variables in the main GUI class but also allows us to create different instances of the listener object. The technique is to create what is called an **anonymous inner class**. This is a class with no name that we declare and instantiate at the same time. It can be used to quickly create a class with methods that override any parent methods that we are required to implement for an interface.

The format to create an anonymous inner class that implements interface EventHandler<ActionEvent> is:

```
new EventHandler<ActionEvent>()
{
// Define any member variables or methods for the class
}
```

We can plug this into the setOnAction method where we flesh out the handle method. In this example, we change the text in a label in the ButtonDemo class to "It is sunny!".

```
btnSunny.setOnAction(new EventHandler<ActionEvent>()
{
    @Override
    public void handle(ActionEvent event)
    {
        lblMessage.setText("It is sunny!");
    }
}
```

Listing 8.23 illustrates this technique by creating separate anonymous inner classes for the two buttons. The text in the label is changed depending upon which button is clicked.

# LISTING 8.23 Event Handling with Anonymous Inner Classes (part 1 of 3)

# LISTING 8.23 Event Handling with Anonymous Inner Classes (part 2 of 3)

```
{
   public static void main(String[] args)
      launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
   {
     VBox root = new VBox();
     Button btnSunny;
     Button btnCloudy;
     Label lblMessage;
     btnSunny = new Button("Sunny");
     btnCloudy = new Button("Cloudy");
     lblMessage = new Label("Click a button.");
     // Create an anonymous inner class to handle btnSunny
     btnSunny.setOnAction(new EventHandler<ActionEvent>()
      {
         @Override
         public void handle(ActionEvent event)
             lblMessage.setText("It is sunny!");
     }
     );
     // Create an anonymous inner class to handle btnCloudy
     btnCloudy.setOnAction(new EventHandler<ActionEvent>()
      {
         @Override
         public void handle(ActionEvent event)
             lblMessage.setText("It is cloudy!");
      }
     );
     root.getChildren().add(btnSunny);
     root.getChildren().add(btnCloudy);
     root.getChildren().add(lblMessage);
     Scene scene = new Scene(root, 300, 100);
     primaryStage.setTitle("Button Demo 3");
```

(continued)

# LISTING 8.23 Event Handling with Anonymous Inner Classes (part 3 of 3)

## **SELF-TEST QUESTIONS**

- 34. A JavaFX event handler is a method that is a manifestation of what Java programming construct?
- 35. What is an advantage of having the main application class extend EventHandler<ActionEvent>? What is a disadvantage compared to having the listener object in a separate class?
- 36. What Java construct allows us to define and instantiate an instance of a class with no named reference within the body of your code?

## PROGRAMMING EXAMPLE

**Adding Numbers** 

In this example, we tie together the BorderPane and GridPane layouts presented in Chapter 6 with an event handler from this chapter to make a JavaFX application that allows the user to enter a number into either of two text fields, click a button, and display the sum of the numbers in a label. The root will contain the BorderPane with explanatory text in the top region and the sum of the numbers in the bottom region. The center region will contain the GridPane that will hold the text fields and button.

For the event handler, we use an anonymous inner class that retrieves the text entered into the text fields, converts them to numbers, and then outputs the sum of the numbers in a label. We make the UI controls private instance

variables so they can be accessed from the event handler. To read in the values typed by the user into the text fields we use the getText method. This method returns the input as a string, so we will need to convert each string to an integer using the parseInt method so we can compute the sum. Finally, we can set the label's text to the sum by using the setText method (Listing 8.24).

LISTING 8.24 JavaFX Application to Add Numbers (part 1 of 3)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.GridPane;
import javafx.scene.layout.BorderPane;
import javafx.scene.control.TextField;
import javafx.scene.control.Label;
import javafx.scene.control.Button;
import javafx.geometry.Insets;
import javafx.event.ActionEvent;
import javafx.event.EventHandler;
/**
This application embeds a GridPane in the center of a
BorderPane. It allows the user to enter numbers into text fields
which are added together in the button click event. The sum is
displayed in a label in the bottom region of the BorderPane.
* /
public class AddingNumbersApp extends Application
   public static void main(String[] args)
   {
      launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
   {
      BorderPane root = new BorderPane();
      // Margin of 10 pixels
      root.setPadding(new Insets(10,10,10,10));
      Button btnAdd;
      TextField txtNum1, txtNum2;
      Label lblSum:
                                                          (continued)
```

# LISTING 8.24 JavaFX Application to Add Numbers (part 2 of 3)

```
// Add a label message in the top. We create the
// label without a named reference since the label
// is read-only; we never change it so no reference is needed.
root.setTop(new Label("Enter an integer into each textbox " +
          "and click the button to compute the sum."));
// The label that will display the sum goes into the bottom.
// Initially it is just a blank string.
1b1Sum = new Label("");
root.setBottom(1b1Sum);
// Create a GridPane in the center of the BorderPane
GridPane center = new GridPane();
center.setVgap(5);
center.setHgap(5);
txtNum1 = new TextField("0"); // Default text of 0
txtNum1.setPrefWidth(150);
txtNum2 = new TextField("0");
txtNum2.setPrefWidth(150);
center.add(new Label("Number 1"), 0, 0);
center.add(new Label("Number 2"), 0, 1);
center.add(txtNum1, 1, 0);
center.add(txtNum2, 1, 1);
btnAdd = new Button("Add Numbers");
center.add(btnAdd, 1, 2);
root.setCenter(center);
// Set the event handler when the button is clicked
btnAdd.setOnAction(new EventHandler<ActionEvent>()
 {
    @Override
    public void handle(ActionEvent event)
        int num1 = Integer.parseInt(txtNum1.getText());
        int num2 = Integer.parseInt(txtNum2.getText());
        int sum = num1 + num2;
        lblSum.setText("The sum is " + sum);
    }
}
);
Scene scene = new Scene(root, 450, 150);
primaryStage.setTitle("Compute the Sum");
primaryStage.setScene(scene);
                                                    (continued)
```

# LISTING 8.24 JavaFX Application to Add Numbers (part 3 of 3)

## **CHAPTER SUMMARY**

- A Java interface contains the headings of public methods and the definitions of public named constants. It does not declare constructors or private instance variables.
- A class that implements an interface must define a body for every method that the interface specifies. It might also define methods not declared in the interface. A class can implement more than one interface.
- An interface provides a way for a class designer to specify methods for another programmer. By implementing an interface, a programmer can guarantee that a class defines certain methods.
- An interface is a reference type, and so you can declare variables and method parameters as having an interface type.
- You can extend an interface to create an interface that consists of the methods in the existing interface plus some new methods.
- Dynamic, or late, binding is a process that enables objects of different classes to substitute for one another, if they have identical interfaces. This ability—called polymorphism—allows different objects to use different method actions for the same method name.
- A derived class is obtained from a base class by adding instance variables and methods. The derived class inherits all public instance variables and public methods that are in the base class.
- When defining a constructor for a derived class, your definition should first call a constructor of the base class by using super. If you do not make an explicit call, Java will automatically call the default constructor of the base class.

- Within a constructor, this calls a constructor of the same class, but super invokes a constructor of the base class.
- You can redefine a method from a base class so that it has a different definition in the derived class. This is called overriding the method definition.
- When you override a method definition, the new method definition given in the derived class must have the same name, the exact same number and types of parameters, and the same return type as the method in the base class. If the method in the derived class has a different number of parameters or a parameter position of a different type from the method in the base class, the method is overloaded, not overridden.
- Within the definition of a method of a derived class, you can call an overridden method of the base class by prefacing the method name with super and a dot.
- Private instance variables and private methods of a base class cannot be accessed directly by name within a derived class.
- An object of a derived class has the type of the derived class, and it also has the type of the base class. More generally, a derived class has the type of every one of its ancestor classes.
- You can assign an object of a derived class to a variable of any ancestor type, but not the other way around.
- In Java, every class is a descendant of the predefined class Object. So every object of every class is of type Object, as well as the type of its class and any other ancestor classes.
- JavaFX uses event handlers, which are based on interfaces, to respond to events.

## **Exercises**

- 1. Consider a program that will keep track of the items sold in a multi-storied electronics showroom. Draw a class hierarchy, including a base class, for items of different categories. Consider items that cannot be checked out.
- 2. Implement your base class for the hierarchy from the previous exercise.
- 3. Draw a hierarchy for a database management system (DBMS) you might find in a database. Note that some DBMS can have rows and columns and some DBMS may have data structures as trees while some have graphs. Some DBMS have objects with data and instructions associated with them.
- 4. Suppose we want to implement a drawing program that creates various shapes using keyboard characters. Implement an abstract base class DrawableShape that knows the center (two integer values) and the color (a string) of the

**Graphics** 

- object. Give appropriate accessor methods for the attributes. You should also have a mutator method that moves the object by a given amount.
- 5. Create a class Square derived from DrawableShape, as described in the previous exercise. A Square object should know the length of its sides. The class should have an accessor method and a mutator method for this length. It should also have methods for computing the area and perimeter of the square. Although characters are taller than they are wide—so the number of characters in the vertical sides will differ from the number in the horizontal sides—you need not worry about this detail when drawing the square.
- 6. Create a class MncEmployee that is the base class for employees at a multinational company. It should have attributes for an employee's name, department number, salary, hire date, and the name of their manager. It should have appropriate accessor and mutator methods for each of the attributes.
- 7. Derive a class SmartEmployee from MncEmployee, as described in the previous exercise. The new class should override the accessor method for the salary, reporting the actual salary plus 3000. It should also override the accessor for the manager, stating that the reporting structure of the employee be concatenated to include another manager, "Mr. Pichhoy."
- 8. Create an abstract class FeeComputer that has an attribute hourlyFee given in dollars per hour. The class should also have a method getFee(hours) that returns the fee amount for a given duration of time.
- 9. Derive a class FullCourseFee from FeeComputer, as described in the previous exercise. It should have a constructor that has a parameter for the hourly fee. It should not override any of the methods. Then derive a class CrashCourseFee from FeeComputer that overrides the getFee method. The new method should return the amount returned by the base class method plus 10000.
- 10. Create an abstract class DiscountPolicy. It should have a single abstract method computeDiscount that will return the discount for the purchase of a given number of a single item. The method has two parameters, count and itemCost.
- 11. Derive a class BulkDiscount from DiscountPolicy, as described in the previous exercise. It should have a constructor that has two parameters, minimum and percent. It should define the method computeDiscount so that if the quantity purchased of an item is more than minimum, the discount is percent percent.
- 12. Derive a class BuyNItemsGetOneFree from DiscountPolicy, as described in Exercise 10. The class should have a constructor that has a single parameter n. In addition, the class should define the method computeDiscount so that every *n*th item is free. For example, the following

table gives the discount for the purchase of various counts of an item that costs \$10, when n is 3:

Count	1	2	3	4	5	6	7
Discount	0	0	10	10	10	20	20

- 13. Derive a class CombinedDiscount from DiscountPolicy, as described in Exercise 10. It should have a constructor that has two parameters of type DiscountPolicy. It should define the method computeDiscount to return the maximum value returned by computeDiscount for each of its two private discount policies. The two discount policies are described in Exercises 11 and 12.
- 14. Define DiscountPolicy as an interface instead of the abstract class described in Exercise 10.
- 15. Create an interface MessageEncoder that has a single abstract method encode(plainText), where plainText is the message to be encoded. The method will return the encoded message.
- 16. Create a class SubstitutionCipher that implements the interface MessageEncoder, as described in the previous exercise. The constructor should have one parameter called shift. Define the method encode so that each letter is shifted by the value in shift. For example, if shift is 3, a will be replaced by d, b will be replaced by e, c will be replaced by f, and so on. (*Hint*: You may wish to define a private method that shifts a single character.)
- 17. Create a class ShuffleCipher that implements the interface MessageEncoder, as described in Exercise 15. The constructor should have one parameter called n. Define the method encode so that the message is shuffled n times. To perform one shuffle, split the message in half and then take characters from each half alternately. For example, if the message is abcdefghi, the halves are abcde and fghi. The shuffled message is afbgchdie. (*Hint*: You may wish to define a private method that performs one shuffle.)

## PRACTICE PROGRAMS

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

1. Define a class named Employee whose objects are records for employees. Derive this class from the class Person given in Listing 8.1. An employee record inherits an employee's name from the class Person. In addition, an employee record contains an annual salary represented as a single value of type double, a hire date that gives the year hired as a single value of type int, and an identification number that is a value of type String. Give

- your class a reasonable complement of constructors, accessor methods, and mutator methods, as well as an equals method. Write a program to fully test your class definition.
- 2. Define a class named Doctor whose objects are records for a clinic's doctors. Derive this class from the class Person given in Listing 8.1. A Doctor record has the doctor's name—defined in the class Person—a specialty as a string (for example Pediatrician, Obstetrician, General Practitioner, and so on), and an office-visit fee (use the type double). Give your class a reasonable complement of constructors and accessor methods, and an equals method as well. Write a driver program to test all your methods.
- 3. Create a base class called Vehicle that has the manufacturer's name (type String), number of cylinders in the engine (type int), and owner (type Person given in Listing 8.1). Then create a class called Truck that is derived from Vehicle and has additional properties: the load capacity in tons (type double, since it may contain a fractional part) and towing capacity in tons (type double). Give your classes a reasonable complement of constructors and accessor methods, and an equals method as well. Write a driver program (no pun intended) that tests all your methods.
- 4. Create a new class called Dog that is derived from the Pet class given in Listing 6.1 of Chapter 6. The new class has the additional attributes of breed (type String) and boosterShot (type boolean), which is true if the pet has had its booster shot and false if not. Give your classes a reasonable complement of constructors and accessor methods. Write a driver program to test all your methods, then write a program that reads in five pets of type Dog and displays the name and breed of all dogs that are over two years old and have not had their booster shots.



## **PROGRAMMING PROJECTS**

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

- 1. Define a class called Diamond that is derived from either the class ShapeBasics (Listing 8.12) or the abstract class ShapeBase (Listing 8.19). A diamond has the same sort of top half as a Triangle object, and its bottom half is an inverted version of its top half. Define a utility class having public static methods, such as the method skipSpaces and other methods that draw horizontal lines, big V's, and inverted big V's. Recall that Self-Test Question 31 asked you to describe one method in this class.
- 2. Define two derived classes of the abstract class ShapeBase in Listing 8.19. Your two classes will be called RightArrow and LeftArrow. These classes

will be like the classes Rectangle and Triangle, but they will draw arrows that point right and left, respectively. For example, the following arrow points to the right:

The size of the arrow is determined by two numbers, one for the length of the "tail" and one for the width of the arrowhead. (The width is the length of the vertical base.) The arrow shown here has a length of 16 and a width of 7. The width of the arrowhead cannot be an even number, so your constructors and mutator methods should check to make sure that it is always odd. Write a test program for each class that tests all the methods in the class. You can assume that the width of the base of the arrowhead is at least 3.

- 3. Define two classes, Patient and Billing, whose objects are records for a clinic. Derive Patient from the class Person given in Listing 8.1. A Patient record has the patient's name (defined in the class Person) and identification number (use the type String). A Billing object will contain a Patient object and a Doctor object (from Practice Program 2). Give your classes a reasonable complement of constructors and accessor methods, and an equals method as well. First write a driver program to test all your methods, then write a test program that creates at least two patients, at least two doctors, and at least two Billing records and then displays the total income from the Billing records.
- 4. Create the classes RightTriangle and Rectangle, each of which is derived from the abstract class ShapeBase in Listing 8.19. Then derive a class Square from the class Rectangle. Each of these three derived classes will have two additional methods to calculate area and circumference, as well as the inherited methods. Do not forget to override the method drawHere. Give your classes a reasonable complement of constructors and accessor methods. The Square class should include only one dimension, the side, and should automatically set the height and width to the length of the side. You can use dimensions in terms of the character width and line spacing even though they are undoubtedly unequal, so a square will not look square (just as a Rectangle object, as discussed in this chapter, won't look square). Write a driver program that tests all your methods.
- Create an interface MessageDecoder that has a single abstract method decode(cipherText), where cipherText is the message to be decoded. The method will return the decoded message. Modify the classes

SubstitutionCipher and ShuffleCipher, as described in Exercises 16 and 17, so that they implement MessageDecoder as well as the interface MessageEncoder that Exercise 15 describes. Finally, write a program that allows a user to encode and decode messages entered on the keyboard.

6. For this Programming Project, start with implementations of the Person, Student, and Undergraduate classes as depicted in Figure 8.4 and the polymorphism demo in Listing 8.6. Define the Employee, Faculty, and Staff classes as depicted in Figure 8.2. The Employee class should have instance variables to store the employee ID as an int and the employee's department as a String. The Faculty class should have an instance variable to store the faculty member's title (e.g., "Professor of Computer Science") as a String. The Staff class should have an instance variable to store the staff member's pay grade (a number from 1 to 20) as an int. Every class should have appropriate constructors, accessors, and mutators, along with a writeOutput method that outputs all of the instance variable values.

Modify the program in Listing 8.6 to include at least one Faculty object and at least one Staff object in addition to the Undergraduate and Student objects. Without modification to the for loop, the report should output the name, employee ID, department, and title for the Faculty objects, and the name, employee ID, department, and pay grade for the Staff objects.

- 7. Modify the Student class in Listing 8.2 so that it implements the Comparable interface. Define the compareTo method to order Student objects based on the value in studentNumber. In a main method create an array of at least five Student objects, sort them using Arrays.sort, and output the students. They should be listed by ascending student number. Next, modify the compareTo method so it orders Student objects based on the lexicographic ordering of the name variable. Without modification to the main method, the program should now output the students ordered by name.
- 8. Create a JavaFX application that uses a TextField to get a message and encode or decode it using the classes described in Programming Project 5. Use buttons to control the kind of cipher used and to specify whether to encode or decode the message. Also use a TextField to get the number used in the constructor for the ciphers.

Graphics

9. Create a JavaFX application that acts as a simple calculator. Create buttons for digits 0-9 and a text field that concatenates digits for the current number as the buttons are clicked. Add additional buttons for operators +, -, \*, and /. Add a final button for = that calculates the previously computed value with the value entered in the text field. Consider using the layout described in Programming Project 17 from Chapter 7.

Graphics

Graphics

10. Create a JavaFX application that will draw a spiral using line segments. The equations for the points on a spiral are:

$$x = 250 + k\theta \sin \theta$$
$$y = 250 + k\theta \sin \theta$$

You should draw 150 points. Start  $\theta$  at 0 and increase it by 0.1 for each new point. Let k be 15. Set the size of the window to 500 by 500.

# **Answers to Self-Test Questions**

- 1. Overriding refers to redefining a base-class method so that it has a different definition in a derived class. Overloading refers to giving a method name two definitions that have different parameter lists. In both cases, the methods have the same name. When you override a method definition, the new method definition given in the derived class has the exact same name, return type, and number and types of parameters. On the other hand, if the method in the derived class were to have a different number of parameters or a parameter of a different type from the method in the base class, the derived class would have both methods. That would be overloading. You can also overload method names in a single class definition without involving a base class.
- 2. No, a derived class does not inherit the private instance variables of its base class. However, SportsCar can access or change the values of speed, manufacturer, and numberOfCylinders if the base class provides public methods for that purpose.
- 3. Yes, it will have the methods. A derived class has all the public methods that the base class has, and they perform exactly the same actions in the derived class as they do in the base class. However, the derived class can contain a new overriding definition of a method, and the new definition will replace the old definition—provided it has the same name, return type, and number and types of parameters.
- 4. No.
- 5. No.
- 6. The method hasSameName is not listed in the class diagram for Student. So you follow the arrow to the class diagram for Person. The method hasSameName is in the class diagram for Person. The data type of this method's parameter is Person. But since you know that a Student is a Person, you can pass a Student object to this method as an argument. So the definition used for the method hasSameName is in the class definition of Person.

7. You start at the class diagram for Student. The method setStudentNumber is in the class diagram for Student, so you need look no further. The definition used for the method setStudentNumber is in the class definition of Student.

```
8. public class TitledPerson extends Person
      private String title;
      public TitledPerson()
           super();
          title = "no title yet";
  /* //ALTERNATE DEFINITION OF DEFAULT CONSTRUCTOR:
      public TitledPerson()
          this("no title yet");
  */
      public TitledPerson(String initialName, String initialTitle)
           super(initialName);
          title = initialTitle;
      public void reset(String newName, String newTitle)
           setName(newName);
          title = newTitle;
      public String getTitle()
          return title;
      public void setTitle(String newTitle)
          title = newTitle;
      public void writeOutput()
          System.out.println("Name: " + getName());
          System.out.println("Title: " + title);
      public boolean equals(TitledPerson otherPerson)
      { // 'this' is optional in the next statement
            return this.sameName(otherPerson) &&
                this.title.equalsIgnoreCase(otherPerson.title);
      }
  }
```

- 12. Yes. If class A is derived from class B, an object of type B can be referenced by a variable of type A and a variable of type B.
- 13. Variables of the types Undergraduate, Student, and Person can reference this object. (As you will find out soon in this chapter, a variable of type Object could also reference this object. Object is a predefined Java class that we are about to introduce in the next section.)
- 14. It is used as the name for a constructor of the base class. (See Listing 8.2.) When used as a receiving object, as in super. writeOutput(); super indicates that the method in the base class should be called. In Listing 8.4, for example, this statement calls the method writeOutput of the base class Student, as opposed to the method writeOutput of the class Undergraduate.
- 15. The keyword this, when used as a method name, names a constructor in the same class as the one being defined. The keyword super, when used as a method name, names a constructor for the base class of the derived class being defined.
- 16. Because the value returned by toString includes the new-line character '\n'.
- 17. a. Valid. A Student is a Person.
  - b. Valid. An Undergraduate is a Person.
  - c. Illegal. A Person object will not be able to perform all Student actions.
  - d. Valid. An Undergraduate is a Student.
  - e. Illegal. A Person object will not be able to perform all Undergraduate actions.

- Illegal. A Student object will not be able to perform all Undergraduate actions.
- g. Valid. A Student is an Object.
- h. Illegal. An Object object will not be able to perform all Student actions.
- 18. *Polymorphism* means using the process of dynamic binding to allow objects to behave correctly, regardless of the type of the variable that names them. The meaning of a method name depends on the object named by a variable
- 19. *Dynamic binding* and *late binding* are two terms for the same thing (so we will give only one definition and only one example). With dynamic binding, or late binding, the meaning of a method invocation is not bound to its location until you run the program. Java uses dynamic binding. When deciding which definition of a method to use, Java uses the definition in effect when the object was created using the new operator. It does not necessarily use the definition that applies to the type of the variable naming the object.
- 20. This question may not have a definitive answer. In the original definition of *polymorphism*, overloading was considered an example of polymorphism, and some books still use that old definition. In current usage, and in this book, overloading a method name is *not* an example of polymorphism.
- 21. No, they will produce different output. The first will output the name Sam and the Student Number 9999. The second will output the name Sam, the Student Number 9999, and the Student Level 1.
- 22. The definition of writeOutput given in Undergraduate is used—not the definition of writeOutput given in Person—because p references an Undergraduate object.
- 23. No. The class Oval must contain an implements clause stating that it implements Measurable.
- 24. Yes, a class can implement several interfaces. Simply list the interfaces, separated by commas, after the keyword implements.
- 25. Yes.
- 26. No.
- 27. Overriding.
- 28. Overriding.
- 29. Overloading.
- 30. No. A derived class cannot inherit a private method. We could make this move if we made skipSpaces a public method instead of a private one. A better solution would be to define a utility class having public static

- methods, like the method skipSpaces and other methods that draw horizontal lines, big V's, and inverted big V's.
- 31. The method drawHere can call two private methods, drawTop and drawBottom. We can use the method drawTop from Triangle, where the variable base is the width of the diamond. The method drawBottom is like drawTop, but with the following changes: startOfLine begins at the offset, and insideWidth begins at 2 \* lineCount 1; at the end of each iteration, startOfLine increases by 1 and insideWidth decreases by 2. The method skipSpaces is the same as in Triangle.
- 32. No, it is illegal because ShapeBase in Listing 8.19 is an abstract class.
- 33. Yes, it is legal.
- 34. An event handler is a method that implements a prescripted interface.
- 35. An advantage of having the main application class be the event listener object is the event handler has easy access to other GUI controls defined in the class. You also don't need to create a separate class. A disadvantage is you only have one instance of the main application class, so you can't make separate event listener objects for different UI controls. The handle method will need to determine what source control initiated the event rather than have a dedicated handler per source control.
- 36. An anonymous inner class.

# **Exception Handling**

## 9.1 BASIC EXCEPTION HANDLING 710

Exceptions in Java 711
Predefined Exception Classes 721

# 9.2 DEFINING YOUR OWN EXCEPTION CLASSES 723

## 9.3 MORE ABOUT EXCEPTION CLASSES 733

Declaring Exceptions (Passing the Buck) 733 Kinds of Exceptions 736 Errors 738 Multiple Throws and Catches 739
The finally Block 745
Rethrowing an Exception (*Optional*) 746
Case Study: A Line-Oriented Calculator 747

# 9.4 GRAPHICS SUPPLEMENT 759

Additional User Interface Controls and Shapes 759 Images and Shapes 763 Handling Mouse Events 765 The Timeline Class 769



It's the exception that proves the rule.

—COMMON MAXIM, (Possibly a corruption of something like *It's the Exception that Tests the Rule*)

One way to write a program is first to assume that nothing unusual or incorrect will happen. For example, if the program takes an entry from a list, you might assume that the list is not empty. Once you have the program working for the core situation, in which things go as planned, you can then add code to take care of the exceptional cases. Java has a way to reflect this approach in your code. Basically, you write your code as if nothing very unusual will happen. After that, you add code for exceptional cases, using the facilities in Java. This chapter introduces you to these facilities.

# **OBJECTIVES**

After studying this chapter, you should be able to

- Describe the notion of exception handling
- React correctly when certain exceptions occur
- Use Java's exception-handling facilities effectively in your own classes and programs
- Learn additional GUI controls, how to handle mouse events, and an introduction to the Timeline object

# **PREREQUISITES**

Section 9.1 of this chapter requires only that you have read Chapters 1 through 6. The remainder of the chapter also requires some material about inheritance in Chapter 8. Arrays are also mentioned, but if you have not read Chapter 7 as yet, you can ignore those occurrences.

# 9.1 BASIC EXCEPTION HANDLING

Jack, be nimble, Jack, be quick, Jack, jump over the candle stick. —ANONYMOUS

Java provides a way to handle certain kinds of special conditions in your program. This facility enables you to divide a program or method definition into separate sections for the normal case and for the exceptional case. In this way, you treat one larger programming task as two smaller and more easily doable programming tasks.

An **exception** is an object that signals the occurrence of an unusual event during the execution of a program. The process of creating this object—that is, generating an exception—is called **throwing an exception**. You place the code that deals with the exceptional case at another place in your program—perhaps in a separate class or method. The code that detects and deals with the exception is said to **handle the exception**.

An exception signals an unusual event during execution

Using exceptions is perhaps most important when a method has a special case that some programs will treat in one way, but others will treat in another way. As you will see, such a method can throw an exception if the special case occurs. This allows the special case to be handled outside of the method in a way that is appropriate to the situation. For example, if a division by zero occurs in a method, it may turn out that, for some invocations of the method, the program should end, but for other invocations of the method, something else should happen.

Java code can handle an exception that is thrown

# **Exceptions in Java**

Most short programs need very little, if any, exception handling, and the exception handling they do use is often not easy to see in the code. For simplicity, we will use a toy program for our initial example. First we will write the program without using Java's exception-handling facilities, and then we will rewrite it using exception handling.

For this example, suppose that milk is such an important item in our society that people almost never allow themselves to run out of it, but still we would like our programs to accommodate the very unlikely situation of running out of milk. The basic code, which assumes that we do not run out of milk, might be as follows:

If the number of glasses of milk entered is zero—that is, if we have no milk—this code will produce a division by zero. To take care of the unlikely scenario in which we run out of milk and get an erroneous division, we can add a test for this unusual situation. The complete program with this added test for the special situation is shown in Listing 9.1.

Now let's revise this program, using Java's exception-handling facilities. A division by zero produces an exception. So instead of avoiding such a division, we can let it occur but react to the resulting exception, as we have done in Listing 9.2. Because this example is so simple, we probably would not actually

# LISTING 9.1 One Way to Deal with a Problem Situation

```
import java.util.Scanner;
public class GotMilk
    public static void main(String[] args)
        Scanner keyboard = new Scanner(System.in);
        System.out.println("Enter number of donuts:");
        int donutCount = keyboard.nextInt();
        System.out.println("Enter number of glasses of milk:");
        int milkCount = keyboard.nextInt();
        //Dealing with an unusual event without Java's exception
        //handling features:
        if (milkCount < 1)</pre>
        {
            System.out.println("No milk!");
            System.out.println("Go buy some milk.");
        }
        else
        {
           double donutsPerGlass = donutCount / (double)milkCount;
            System.out.println(donutCount + " donuts.");
            System.out.println(milkCount + " glasses of milk.");
            System.out.println("You have " + donutsPerGlass +
                                " donuts for each glass of milk.");
        System.out.println("End of program.");
    }
}
```

# Sample Screen Output

```
Enter number of donuts:

2
Enter number of glasses of milk:

0
No milk!
Go buy some milk.
End of program.
```

use exception handling here. The revised program as a whole is certainly not simpler than the original one in Listing 9.1. However, the code between the words try and catch is cleaner than the code used in the original program and

hints at the advantage of handling exceptions. A clear organization and structure are essential for large, complex programs.

The code in Listing 9.2 is basically the same as the code in Listing 9.1, except that instead of the big if-else statement, this program has the following smaller if statement:

```
if (milkCount< 1)
    throw new Exception("Exception: No milk!");</pre>
```

This if statement says that if we have no milk, the program should do something exceptional. That something exceptional is given after the word

# LISTING 9.2 An Example of Exception Handling (part 1 of 2)

```
This program is just a simple
   import java.util.Scanner;
                                               example of the basic syntax
   public class ExceptionDemo
                                               for exception handling.
       public static void main(String[] args)
        {
            Scanner keyboard = new Scanner(System.in);
            try
            {
                System.out.println("Enter number of donuts:");
                int donutCount = keyboard.nextInt();
                System.out.println("Enter number of glasses of milk:");
                int milkCount = keyboard.nextInt();
                if (milkCount < 1)</pre>
try block
                    throw new Exception("Exception: No milk!");
                double donutsPerGlass = donutCount / (double)milkCount;
                System.out.println(donutCount + " donuts.");
                System.out.println(milkCount + " glasses of milk.");
                System.out.println("You have " + donutsPerGlass +
                                     " donuts for each glass of milk.");
            }
            catch(Exception e)
                System.out.println(e.getMessage());
catch block
                System.out.println("Go buy some milk.");
            System.out.println("End of program.");
        }
   }
```

# LISTING 9.2 An Example of Exception Handling (part 2 of 2)

# Sample Screen Output 1

```
Enter number of donuts:

3
Enter number of glasses of milk:

2
3 donuts.
2 glasses of milk.
You have 1.5 donuts for each glass of milk.
End of program.
```

# Sample Screen Output 1

```
Enter number of donuts:

2
Enter number of glasses of milk:
0
Exception: No milk!
Go buy some milk.
End of program.
```

catch. The idea is that the normal situation is handled by the code following the word try and that the code following the word catch is used only in exceptional circumstances. Let's look at the details.

The basic way of handling exceptions in Java consists of a try-throw-catch threesome. A try **block** has the syntax

A try block contains the code for the basic algorithm when everything goes smoothly. It is called a try block because you are not 100 percent sure that all will go smoothly, but you want to give it a try.

If something does go wrong, you want to throw an exception, which is a way of indicating that there is some sort of problem. So the basic outline, when we add a throw **statement**, is as follows:

A try block detects an exception

```
try
{
    Code_To_Try
    Possibly_Throw_An_Exception
    More_Code
}
```

The try block in Listing 9.2 has this form and contains the statement

```
throw new Exception("Exception: No milk!");
```

A throw statement throws an exception

If this throw statement executes, it creates a new object of the predefined class Exception with the expression

```
new Exception("Exception: No milk!")
```

and **throws** the exception object. The string "Exception: No milk!" is an argument for the constructor of the class Exception. The Exception object created here stores this string in an instance variable of the object so that it can be recovered later.

When an exception is thrown, the code in the surrounding block stops execution, and another portion of code, known as a **catch block**, begins execution. Executing the catch block is called **catching the exception**. When an exception is thrown, it should ultimately be caught by some catch block. In Listing 9.2, the catch block immediately follows the try block.

The catch block looks a little like a method definition that has a parameter. Although it is not a method definition, a catch block behaves like a method in some ways. It is a separate piece of code that is executed when a program executes a throw statement from within the preceding try block. This throw statement is similar to a method call, but instead of calling a method, it calls the catch block and causes the code in the catch block to be executed.

Let's examine the first line of the catch block in Listing 9.2:

```
catch(Exception e)
```

The identifier e looks like a parameter and acts very much like a parameter. So even though the catch block is not a method, we call this e the **catch-block parameter**. The catch-block parameter gives us a name for the exception that is caught, so that we can write code within the catch block to manipulate the exception object. The most common name for a catch-block parameter is e, but you can use any legal identifier.

When an exception object is thrown, it is plugged in for the catch-block parameter e, and the code in the catch block is executed. So in this case, you can think of e as the name of the exception object that was thrown. Every exception object has a method called getMessage, and unless you provide code specifying otherwise, this method retrieves the string that was given to the exception object by its constructor when the exception was thrown. In our example, the invocation e.getMessage() returns "Exception: No milk!"Thus, when the catch block in Listing 9.2 executes, it writes the following lines to the screen:

An exception's getMessage method returns a description of the exception

Exception: No milk! Go buy some milk.

The class name preceding the catch-block parameter specifies what kind of exception the catch block can catch. The class Exception in our example indicates that this catch block can catch an exception of type Exception. Thus, a thrown exception object must be of type Exception in order for this particular

A catch block deals with a particular exception Only one catch block executes per try block

catch block to apply. As you will see, other types of exceptions are possible, and several catch blocks—one for each type of exception to be handled—can follow a try block. Only one of these catch blocks—the one corresponding to the type of exception thrown—can execute, however. The rest are ignored when handling a particular exception. Since all exceptions are of type Exception, the solitary catch block in our example will catch any exception. Although this might sound like a good idea, it generally is not. Several specific catch blocks are usually preferable to one general one.

For the program in Listing 9.2, when the user enters a positive number for the number of glasses of milk, no exception is thrown. The flow of control in this case is shown in Listing 9.3. Listing 9.4 shows the flow of control when an exception is thrown because the user enters zero or a negative number for the number of glasses of milk.

LISTING 9.3 Flow of Control When No Exception Is Thrown

```
Here we assume that the user
import java.util.Scanner;
                                           enters a positive number for the
public class ExceptionDemo
                                           number of glasses of milk.
    public static void main(String[] args)
       Scanner keyboard = new Scanner(System.in);
       try
       {
          System.out.println("Enter number of donuts:");
         int donutCount = keyboard.nextInt();
         System.out.println("Enter number of glasses of milk:");
         ▶int milkCount = keyboard.nextInt(); milkCount is positive, so an
                                                exception is NOT thrown here.

if (milkCount < 1) ←</pre>
               throw new Exception("Exception: No milk!");
         double donutsPerGlass = donutCount / (double)milkCount;
         ►System.out.println(donutCount + " donuts.");
         ►System.out.println(milkCount + " glasses of milk.");
         System.out.println("You have " + donutsPerGlass
                          + " donuts for each glass of milk.");
       catch(Exception e)
                                                            This code
          System.out.println(e.getMessage());
                                                            is NOT
          System.out.println("Go buy some milk.");
                                                            executed.
       System.out.println("End of program.");
}
```

LISTING 9.4 Flow of Control When an Exception Is Thrown

```
import java.util.Scanner;
                                               Here we assume that the user
public class ExceptionDemo
                                               enters zero for the number
                                               of glasses of milk, and so an
    public static void main(String[] args)
                                               exception is thrown.
        Scanner keyboard = new Scanner(System.in);
        try
           - System.out.println("Enter number of donuts:");
           int donutCount = keyboard.nextInt();
           ■ System.out.println("Enter number of glasses of milk:");
             int milkCount = keyboard.nextInt();
                                                    milkCount is zero or
                                                    negative, so an exception
                                                    IS thrown here.
           ▶ if (milkCount < 1)</pre>
                 throw new Exception("Exception: No milk!");
             double donutsPerGlass = donutCount / (double)milkCount;
    This code
            System.out.println(donutCount + " donuts.");
    is NOT
            System.out.println(milkCount + " glasses of milk.");
    executed.
            System.out.println("You have " + donutsPerGlass
                              + " donuts for each glass of milk.");
        }
        catch(Exception e)
             System.out.println(e.getMessage());
             System.out.println("Go buy some milk.");
       System.out.println("End of program.");
}
```

In summary, a try block contains some code that can throw an exception. It is able to throw an exception because it either includes a throw statement or, as you will see later, invokes another method that contains a throw statement. The throw statement is normally executed only in exceptional circumstances, but when it is executed, it throws an exception of some exception class. (So far, Exception is the only exception class we have discussed, but we will talk about others soon.) When an exception is

If an exception occurs within a try block, the rest of the block is ignored

If no exception occurs within a try block, the catch blocks are ignored

Comparing trythrow-catch and if-else thrown, execution of the try block ends. All the rest of the code in the try block is ignored, and control passes to a suitable catch block, if one exists. A catch block applies only to an immediately preceding try block. If an exception is thrown and caught, that exception object is plugged in for the catch-block parameter and the statements in the catch block are executed. After the catch-block code is executed, the program proceeds with the code after the last catch block; it does not return to the try block. So none of the try-block code after the statement that threw the exception is executed, as shown in Listing 9.4. (Later, we will discuss what happens when there is no appropriate catch block.)

Now let's look at what happens when no exception is thrown in a try block. When the try block executes normally to completion, without throwing an exception, program execution continues with the code after the last catch block. In other words, if no exception is thrown, all associated catch blocks are ignored, as shown in Listing 9.3.

This explanation makes it seem as though a try-throw-catch sequence is equivalent to an if-else statement. They are almost equivalent, except for the message carried by the thrown exception. An if-else statement cannot send a message to one of its branches. This may not seem like much of a difference, but as you will see, the ability to send a message gives the exception-handling mechanism more versatility than an if-else statement.

# **REMEMBER** An Exception Is an Object

A statement, such as

```
throw new Exception("Illegal character.");
```

does not just specify some action that is taken and forgotten. It creates an object that has a message. In this example, the message is "Illegalcharacter."

To see this, note that the previous statement is equivalent to the following:

```
Exception exceptObject = new Exception
   ("Illegal character.");
throw exceptObject;
```

The first of these statements invokes a constructor of the class Exception, creating an object of the class Exception. The second statement throws this exception object. This object and its message are available to a catch block, and so the effect of throwing an exception is more than just a transfer of control to the first statement of a catch block.

#### **RECAP Throwing Exceptions**

The throw statement throws an exception.

#### SYNTAX

```
throw new Exception_Class_Name(Possibly_Some_Arguments);
```

A throw statement is usually embedded in an if statement or an if-else statement. A try block can contain any number of explicit statements or any number of method invocations that might throw exceptions.

#### **EXAMPLE**

```
throw new Exception("Unexpected End of Input.");
```

#### **RECAP Handling Exceptions**

The try and catch statements, used together, are the basic mechanism for handling exceptions.

```
try
{
    Code_To_Try
    Possibly_Throw_An_Exception
    More_Code
}
catch (Exception_Class_NameCatch_Block_Parameter)
{
    Process_Exception_Of_Type_Exception_Class_Name
}
Possibly_Other_Catch_Blocks
```

If an exception is thrown within the try block, the rest of the try block is ignored and execution continues with the first catch block that matches the type of the thrown exception. After the catch block is completed, any code after the last catch block is executed.

If no exception is thrown in the try block, after it completes execution, program execution continues with the code after the last catch block. In other words, if no exception is thrown, the catch blocks are ignored. More than one block is allowed for each try block, but each catch block can handle only one class of exceptions. Catch\_Block\_Parameter is an identifier that serves as a place holder for an exception that might

(continued)

be thrown. When an exception of the class *Exception\_Class\_Name* is thrown in the preceding try block, that exception is plugged in for the *Catch\_Block\_Parameter*. The code in the catch block may refer to the *Catch\_Block\_Parameter*. A common choice for *Catch\_Block\_Parameter* is e; however, you may use any legal identifier.

#### **RECAP The** getMessage **Method**

Every exception object has a String instance variable that contains some message, which typically identifies the reason for the exception. For example, if the exception is thrown by the statement

```
throw new Exception(String_Argument);
```

the value of this String instance variable is *String\_Argument*. If the exception object is called e, the invocation e.getMessage( ) returns this string.

# **SELF-TEST QUESTIONS**

1. What output is produced by the following code?

```
int waitTime = 46;
try
{
    System.out.println("Try block entered.");
    if (waitTime> 30)
        throw new Exception("Time Limit Exceeded.");
    System.out.println("Leaving try block.");
}
catch(Exception e)
{
    System.out.println("Exception: " + e.getMessage());
}
System.out.println("After catch block");
```

- 2. What output would the code in the previous question produce if we changed 46 in the first statement to 12?
- 3. What is an exception? Is it an identifier? A variable? A method? An object? A class? Something else?
- 4. Is the following statement legal?

```
Exception myException = new Exception("Hi Mom!");
```

5. In the code in Listing 9.2, how would the program's behavior change if you were to replace

```
if (milkCount < 1)
    throw new Exception("Exception: No milk!");
with the following?
if (milkCount < 1)
{
    Exception e = new Exception("Exception: No milk!");
    throw e;
}</pre>
```

- 6. Which part of the code given in Self-Test Question 1 is the statement?
- 7. What happens when a throw statement is executed? Discuss what happens in general, not simply what happens in the code in Self-Test Question 1 or some other sample code.
- 8. In the code given in Self-Test Question 1, identify the try block.
- 9. In the code given in Self-Test Question 1, identify the catch block.
- 10. In the code given in Self-Test Question 1, identify the catch-block parameter.
- 11. Would the code given in Self-Test Question 1 perform any differently if the catch block were changed to the following?

12. Write a statement that will throw an exception of type Exception if the value of the String variable named status is "bad". The string recovered by getMessage should be "Exception thrown: Bad Status." You need not write the try block and catch block.

# **Predefined Exception Classes**

When you learn about the methods of predefined classes, you will sometimes be told that they might throw certain types of exceptions. These exceptions are of predefined exception classes within the Java Class Library. If you use one of these methods, you can put the method invocation in a try block and follow it with a catch block to catch the exception. The names of predefined

Java provides several exception classes exceptions are designed to be self-explanatory. Some examples of predefined exception classes are

```
BadStringOperationException
ClassNotFoundException
IOException
NoSuchMethodException
```

When you catch an exception of one of these predefined exception classes, the string returned by the getMessage method will usually provide you with enough information to identify the source of the exception. Thus, if you have a class called SampleClass, and this class has a method called doStuff, which throws exceptions of the class IOException, you might use the following code:

```
SampleClass object = new SampleClass();
try
{
     <Possibly some code>
     object.doStuff(); //may throw IOException
     <Possibly some more code>
}
catch(IOException e)
{
     <Code to deal with the exception, probably including the following:>
        System.out.println(e.getMessage());
}
```

If you think that continuing with program execution is infeasible after the exception occurs, the catch block can include a call to System. exit to end the program, as follows:

```
catch(IOException e)
{
    System.out.println(e.getmessage());
    System.out.println("Program aborted");
    System.exit(0);
}
```



# PROGRAMMING TIP Catch Specific Exceptions

You can use the class Exception in a catch block, as we did in our initial examples, but catching a more specific exception, such as IOException, is more useful.

# PROGRAMMING TIP Importing Exceptions

Most of the exceptions you will see in this book do not need to be imported, as they are in the package java.lang. Some, however, are in different packages

and do need to be imported. For example, the class IOException is in the package java.util. When you examine the documentation for an exception, note which package contains it so you can provide an import statement if necessary.



## **SELF-TEST QUESTIONS**

13. Are the following statements legal?

```
IOException sos = new IOException("Hello Houston!");
throw sos;

14. Is the following catch block legal?
    catch(NoSuchMethodException exception)
    {
        System.out.println(exception.getmessage());
        System.exit(0);
}
```

### 9.2 DEFINING YOUR OWN EXCEPTION CLASSES

I'll make an exception this time.

—MY MOTHER

You can define your own exception classes, but they must be derived classes of some already defined exception class. An exception class can be a derived class of any predefined exception class or of any exception class that you have already successfully defined. Our examples will be derived classes of the class Exception.

When you define an exception class, you typically define only constructors

When defining an exception class, the constructors are the most important and often the only methods, other than those inherited from the base class. For example, Listing 9.5 contains an exception class, called DivideByZeroException, whose only methods are a default constructor and a constructor having one String parameter. For our purposes, that is all we need to define. However, the class does inherit all the methods of the base class Exception. In particular, the class DivideByZeroException inherits the method getMessage, which returns a string message. In the definition of the default constructor, this string message is set by the following statement:

Call the base-class constructor and pass it a message

```
super("Dividing by Zero!");
```

This statement calls a constructor of the base class Exception. As we have already noted, when you pass a string to the constructor of the class Exception, the value of a String instance variable is set. You can recover this value later

### LISTING 9.5 A Programmer-Defined Exception Class

by calling the method getMessage, which is an ordinary accessor method of the class Exception and is inherited by the class DivideByZeroException. For example, Listing 9.6 shows a sample program that uses this exception class. The exception is created by the default constructor and then thrown, as follows:

throw new DivideByZeroException();

# LISTING 9.6 Using a Programmer-Defined Exception Class (part 1 of 3)

```
import java.util.Scanner;
                                            We will present an improved
public class DivideByZeroDemo
                                            version of this program later
{
                                            in this chapter.
    private int numerator;
    private int denominator;
    private double quotient;
    public static void main(String[] args)
        DivideByZeroDemo oneTime = new DivideByZeroDemo();
        oneTime.doIt();
    public void doIt()
    {
        try
        {
             System.out.println("Enter numerator:");
             Scanner keyboard = new Scanner(System.in);
             numerator = keyboard.nextInt();
                                                            (continued)
```

# LISTING 9.6 Using a Programmer-Defined Exception Class (part 2 of 3)

```
System.out.println("Enter denominator:");
        denominator = keyboard.nextInt();
        if (denominator == 0)
            throw new DivideByZeroException();
        quotient = numerator / (double)denominator;
        System.out.println(numerator + "/" + denominator +
                            " = " + quotient);
    catch(DivideByZeroException e)
    {
        System.out.println(e.getMessage());
        giveSecondChance();
    System.out.println("End of program.");
}
public void giveSecondChance()
    System.out.println("Try again:");
    System.out.println("Enter numerator:");
    Scanner keyboard = new Scanner(System.in);
    numerator = keyboard.nextInt();
    System.out.println("Enter denominator:");
    System.out.println("Be sure the denominator is not zero.");
    denominator = keyboard.nextInt();
                               Sometimes, dealing with an exceptional case
                               without throwing an exception is better.
    if (denominator == 0)
        System.out.println("I cannot do division by zero.");
        System.out.println("Since I cannot do what you want,");
        System.out.println("the program will now end.");
        System.exit(0);
    }
    quotient = ((double)numerator) / denominator;
    System.out.println(numerator + "/" + denominator +
                        " = " + quotient);
}
                                                     (continued)
```

}

# LISTING 9.6 Using a Programmer-Defined Exception Class (part 3 of 3)

### Sample Screen Output 1

```
Enter numerator:

5
Enter denominator:

10
5/10 = 0.5
End of program.
```

#### Sample Screen Output 2

```
Enter numerator:

5
Enter denominator:

0
Dividing by Zero!
Try again.
Enter numerator:

5
Enter denominator:
Be sure the denominator is not zero.

10
5/10 = 0.5
End of program.
```

#### Sample Screen Output 3

```
Enter numerator:
5
Enter denominator:
0
Dividing by Zero!
Try again.
Enter numerator:
5
Enter denominator:
Be sure the denominator is not zero.
0
I cannot do division by zero.
Since I cannot do what you want, the program will now end.
```

This exception is caught in the catch block, which contains the following statement:

```
System.out.println(e.getMessage());
```

This statement displays the following output on the screen, as shown in the sample screen output of Listing 9.6:

```
Dividing by Zero!
```

The class DivideByZeroException in Listing 9.5 also defines a second constructor. This constructor has one parameter of type String, allowing you to choose any message you like when you throw an exception. If the throw statement in Listing 9.6 was instead

```
throw new DivideByZeroException(
   "Oops. Shouldn't Have Used Zero.");
```

the statement

```
System.out.println(e.getMessage());
```

would have produced the following output to the screen:

```
Oops. Shouldn't Have Used Zero.
```

Notice that the try block in Listing 9.6 contains the normal part of the program. If all goes normally, that is the only code that will be executed, and the output will be like that shown in Sample Screen Output 1. In the exceptional case, when the user enters zero for the denominator, the exception is thrown and then is caught in the catch block. The catch block displays the message of the exception and then calls the method giveSecondChance. The method giveSecondChance gives the user a second chance to enter the input correctly and then carries out the calculation. If the user tries a second time to divide by zero, the method ends the program without throwing an exception. The method giveSecondChance exists only for this exceptional case. So we have separated the code for the exceptional case of a division by zero into a separate method, where it will not clutter the code for the normal case.

A try block contains the normal case; a catch block deals with the exceptional case

# PROGRAMMING TIP Preserve getMessage in Your Own Exception Classes

For all predefined exception classes, the method getMessage will return the string that is passed as an argument to the constructor. (If no argument is passed to the constructor—that is, if you invoke the default constructor—getMessage returns a default string.) For example, suppose the exception is thrown as follows:

```
throw new Exception("This is a big exception!");
```

The value of the String instance variable is set to "This is a big exception!" If the exception object is called e, the method call e.getMessage() returns "This is a big exception!"

You should preserve this behavior of the method getMessage in any exception class you define. For example, suppose you define an exception class called MySpecialException and throw an exception as follows:

```
throw new MySpecialException("Wow, what an exception!");
```

If e is a name for the exception thrown, e.getMessage() should return "Wow, what an exception!" To ensure that the exception classes that you define behave in this way, be sure to include a constructor that has a string parameter and whose definition begins with a call to super, as illustrated by the following constructor:

```
public MySpecialException(String message)
{
    super(message);
    //There can be more code here, but often there is none.
}
```

The call to super is a call to a constructor of the base class. If the base-class constructor handles the message correctly, so will a class defined in this way.

You should also include a default constructor in each exception class. This default constructor should set up a default value to be retrieved by getMessage. The constructor's definition should begin with a call to super, as illustrated by the following constructor:

```
public MySpecialException()
{
    super("MySpecialException thrown.");
    //There can be more code here, but often there is none.
}
```

If getMessage works as we described for the base class, this default constructor will work correctly for the new exception class being defined.

#### **REMEMBER Characteristics of Exception Objects**

The two most important things about an exception object are

- The object's type—that is, the name of the exception class. The upcoming sections explain why this is important.
- The message that the object carries in an instance variable of type String. This string can be recovered by calling the accessor method getMessage. The string allows your code to send a message along with an exception object so that the catch block can recover the message.

# PROGRAMMING TIP When to Define an Exception Class

As a general rule, if you are going to insert a throw statement in your code, it is probably best to define your own exception class. That way, when your code catches an exception, your catch blocks can tell the difference between your exceptions and exceptions thrown by methods in predefined classes. For example, in Listing 9.6, we used the exception class DivideByZeroException, which we defined in Listing 9.5.

Although doing so would not be a good idea, you might be tempted to use the predefined class Exception to throw the exception in Listing 9.6, as follows:

```
throw new Exception("Dividing by Zero!");
You could then catch this exception with the catch block
catch(Exception e)
{
    System.out.println(e.getMessage());
    giveSecondChance();
}
```

Although this approach will work for the program in Listing 9.6, it is not the best technique, because the previous catch block will catch any exception, such as an IOException. An IOException, however, might need a different action than the one provided by a call to giveSecondChance. Thus, rather than using the class Exceptionto deal with a division by zero, it is better to use the more specialized programmer-defined class DivideByZeroException, as we did in Listing 9.6.

#### **RECAP Programmer-Defined Exception Classes**

You can define your own exception classes, but every such class must be derived from an existing exception class—either a predefined class or one defined by you.

#### **GUIDELINES**

- Use the class Exception as the base, if you have no compelling reason to use any other class as the base class.
- You should define at least two constructors, including a default constructor and one that has a single String parameter.
- You should start each constructor definition with a call to the constructor of the base class, using super. For the default constructor, the call to super should have a string argument that indicates what kind of exception it is. For example,

```
super("Tidal Wave Exception thrown!");
```

(continued)

If the constructor has a String parameter, the parameter should be the argument in the call to super. For example,

```
super(message);
```

In this way, the string can then be recovered using the getMessage method.

- Your exception class inherits the method getMessage. You should not override it.
- Normally, you do not need to define any other methods, but it is legal to do so.

#### **EXAMPLE**

```
public class TidalWaveException extends Exception
{
    public TidalWaveException()
    {
        super("Tidal Wave Exception thrown!");
    }
    public TidalWaveException(String message)
        super(message);
    }
}
```

super is a call to the constructor of the base class Exception

# **SELF-TEST QUESTIONS**



- 15. Define an exception class called CoreBreachException. The class should have a default constructor. If an exception is thrown using this zero-argument constructor, getMessage should return "Core Breach! Evacuate Ship!" The class should also define a constructor having a single parameter of type String. If an exception is thrown using this constructor, getMessage should return the value that was used as an argument to the constructor.
- 16. Repeat the previous question, but instead name the class MessageTooLongException. Also, if an exception is thrown using the default constructor, getMessage should return "Message Too Long!"
- 17. Suppose the exception class ExerciseException is defined as follows:

```
public class ExerciseException extends Exception
{
```

```
public ExerciseException()
       {
            super("Exercise exception thrown!");
           System.out.println("Exception thrown.");
       public ExerciseException(String message)
           super(message);
           System.out.println("ExerciseException invoked "+
                "with an argument.");
       }
   }
   What output would be produced by the following unlikely code?
   ExerciseException e = new ExerciseException("Do Be Do");
   System.out.println(e.getMessage());
18. Suppose the exception class CrazyException is defined as follows:
   public class CrazyException extends Exception
   {
       public CrazyException()
            super("Crazy exception thrown!");
           System.out.println("Wow, Crazy exception thrown!");
       public CrazyException(String message)
            super(message);
           System.out.println("Wow, crazy exception thrown with "+
                "an argument!");
       public void crazyMethod()
           System.out.println("Message is " + getMessage());
   }
   What output would be produced by the following unlikely code?
   CrazyException exceptionObject = new CrazyException();
   System.out.println(exceptionObject.getMessage());
   exceptionObject.crazyMethod();
19. Suppose the exception class DoubleException is defined as follows:
   public class DoubleException extends Exception
       public DoubleException()
```

```
super("Double exception thrown!");
    }
    public DoubleException(String message)
        super(message + " " + message);
    }
}
What output would be produced by the following unlikely code?
try
    System.out.println("try block entered:");
    int number = 42;
    if (number > 0)
        throw new DoubleException("DoubleException thrown!");
    System.out.println("Leaving try block.");
}
catch(DoubleException exceptionObject)
   System.out.println(exceptionObject.getMessage());
System.out.println("End of code.");
```

- 20. Suppose that, in the catch block of the previous question, we change the type DoubleException to Exception. How would this change affect the output?
- 21. Suppose that, in Self-Test Question 19, we change the value of number from 42 to -99. How would this change affect the output?
- 22. Although an exception class normally carries only a string message, you can define exception classes to carry a message of any type. You can give your exception class instance variables and methods. For example, objects of the following type can also carry an int "message," as well as a string message:

```
public class IntException extends Exception
{
    private int intMessage;
    public IntException()
    {
        super("IntException thrown!");
    }
    public IntException(String message)
    {
        super(message + " " + message);
    }
}
```

```
public IntException(int number)
{
    super("IntException thrown!");
        intMessage = number;
}
public int getNumber()
{
    returnintMessage;
}
```

What output would be produced by the following unlikely code?

```
IntException e = new IntException(42);
System.out.println(e.getNumber());
System.out.println(e.getMessage());
```

23. Can you derive an exception class from the predefined class IOException, or must it be derived from the class Exception?

### 9.3 MORE ABOUT EXCEPTION CLASSES

The buck stops here.

—SIGN ON HARRY S. TRUMAN'S DESK WHILE HE WAS PRESIDENT

In this section, we discuss techniques for using exceptions that go beyond the basics but are still fundamental.

# **Declaring Exceptions (Passing the Buck)**

Sometimes it makes sense to delay handling of an exception. For example, you might have a method whose code throws an exception, but you may not want to catch the exception in that method. Perhaps some programs that use the method should simply end if the exception is thrown, and other programs that use the method should do something else. As a result, you would not know what to do about the exception if you caught it inside the method. In these cases, it makes sense not to catch the exception in the method definition, but instead to have any code that uses the method place the method invocation in a try block and catch the exception in a catch block that follows that try block.

If a method does not catch an exception, it must at least warn programmers that any invocation of the method might possibly throw an exception. This warning is called a throws clause. For example, a method that might throw a

A method might not catch an exception that its code throws A method that does not handle an exception that it throws must have a throws clause in its heading DivideByZeroException but that does not catch the exception would have a heading like the following one:

```
public void sampleMethod() throws DivideByZeroException
```

The part throwsDivideByZeroException is a throws clause. It states that an invocation of the method sampleMethod might throw a DivideByZeroException.

Most exceptions that might be thrown when a method is invoked must be accounted for in one of two ways:

- Catch the possible exception in a catch block within the method definition.
- Declare the possible exception by writing a throws clause in the method's
  heading and let whoever uses the method worry about how to handle the
  exception.

In any one method, you can mix these two alternatives, catching some exceptions and declaring others in a throws clause.

You already know about handling exceptions in a catch block. The second technique is a form of "passing the buck." For example, suppose methodA has a throws clause as follows:

```
public void methodA() throws DivideByZeroException
```

In this case, methodA is absolved of the responsibility of catching any exceptions of type DivideByZeroException that might occur when methodA is executed. If, however, the definition of methodB includes an invocation of methodA, methodB must deal with the exception. When methodA adds the throws clause, it is "saying" to methodB, "If you invoke me, you must worry about any DivideByZeroException that I throw." In effect, methodA has passed the responsibility ("passed the buck") for any exceptions of type DivideByZeroException from itself to any method that calls it.

Of course, if methodA passes the buck to methodB by including a throws clause in its heading, methodB can also pass the buck to whatever method calls it by including the same throws clause in its definition. But in a well-written program, every exception that is thrown should eventually be caught by a catch block in some method that does not pass the buck.

A throws clause can contain more than one exception type. In such cases, you separate the exception types with commas, as follows:

```
public int myMethod() throws IOException, DivideByZeroException
```

If a derived class overrides a base-class method that has a throws clause, you cannot add exceptions to the throws clause of the new overriding method.

# **REMEMBER** Throwing an Exception Can End a Method

If a method throws an exception, and the exception is not caught inside the method, the method invocation ends immediately after the exception is thrown.

A method that can throw several different exceptions has only one throws clause

So if this method needs to throw an exception that is not already listed in the throws clause of the overridden method in the base class, the overriding method must handle that exception in try-catch blocks. You can, however, declare fewer exceptions in the throws clause of the overriding method.

Listing 9.7 shows a revision of the program in Listing 9.6 so that the normal case is in a method called doNormalCase. This method can throw a A throws clause in an overriding method can declare fewer, but not more, exceptions than the overridden method declares

#### LISTING 9.7 Passing the Buck Using a throws Clause

```
import java.util.Scanner;
public class DoDivision
    private int numerator;
    private int denominator;
    private double quotient;
    public static void main(String[] args)
    {
        DoDivision doIt = new DoDivision();
        try
        {
            doIt.doNormalCase();
        catch(DivideByZeroException e)
            System.out.println(e.getMessage());
            doIt.giveSecondChance();
        System.out.println("End of program.");
    }
    public void doNormalCase() throws DivideByZeroException
        System.out.println("Enter numerator:");
        Scanner keyboard = new Scanner(System.in);
        numerator = keyboard.nextInt();
        System.out.println("Enter denominator:");
        denominator = keyboard.nextInt();
        if (denominator == 0)
            throw new DivideByZeroException();
        quotient = numerator / (double)denominator;
        System.out.println(numerator + "/" + denominator +
                            " = " + quotient);
    }
         The method giveSecondChance and the input/output
```

samples are identical to those given in Listing 9.6.

DivideByZeroException, but it does not catch it. Thus, we need to declare this possible exception in a throws clause in the heading of the method's definition. If we set up our program in this way, the case in which nothing goes wrong is completely isolated and easy to read. It is not even cluttered by try blocks and catch blocks. However, when the method main calls the method doNormalCase, it must do so within a try block.

#### RECAP The throws Clause

If you define a method that might throw an exception of some particular class, normally you either must catch the exception within a catch block in the method definition or declare the exception class by writing a throws clause in the method's heading.

#### **SYNTAX**

```
public Type Method_Name(Parameter_List)
throws List_Of_Exceptions
    Body_Of_Method
```

#### **EXAMPLE**

```
public void methodA(int n) throws IOException,
MyException
{
    ...
}
```

#### REMEMBER throw Versus throws

The keyword throw is used to throw an exception, whereas throws is used in a method's heading to declare an exception. Thus, a throw statement throws an exception, but a throws clause declares one.

# **Kinds of Exceptions**

Thus far, we have said that, in most cases, an exception must either be caught in a catch block or be declared in a throws clause in a method's heading. That is the basic rule, but there are exceptions to this rule. (An exception to a rule about exceptions! Seems reasonable enough.) Java has some exceptional exceptions that you do not need to account for in this way—although you can catch them in a catch block if you want to.

All Java exceptions are categorized as either checked or unchecked. A checked exception must either be caught in a catch block or declared in a

throws clause. Such exceptions often indicate serious problems that likely should lead to program termination. The exceptions BadStringOperationException, ClassNotFoundException, IOException, and NoSuchMethodException—mentioned earlier in this chapter—are all checked exceptions in the Java Class Library.

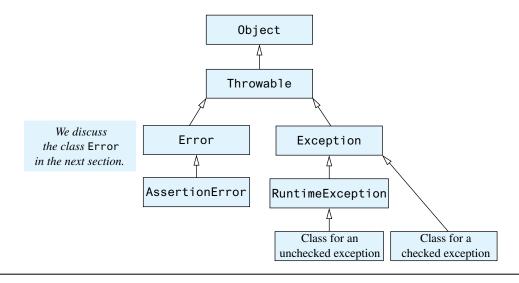
Some exceptions do not need to be caught

An unchecked, or run-time, exception need not be caught in a catch block or declared in a throws clause. These exceptions usually indicate that something is wrong with your code and that you should fix it. Normally, you would not have written a throw statement for these exceptions. They are usually thrown during the evaluation of an expression or by a method in predefined classes. For example, if your program attempts to use an array index that is either too small or too large, an ArrayIndexOutOfBoundsException occurs. If an arithmetic operation causes a problem, such as a division by zero, an ArithmeticException occurs. For such exceptions, you should repair your code, not add a catch block. Note that an uncaught run-time exception terminates program execution.

How do you know whether an exception is checked or unchecked? You can consult the documentation for the Java Class Library to learn the exception's base class and from that deduce whether it is checked or unchecked. Figure 9.1 shows the hierarchy of the predefined exception classes. The class Exception is the base class of all exceptions. Every exception class is a descendant of the class Exception—that is, it is derived either directly from the class Exception or from a class that ultimately is derived from the class Exception. Classes of unchecked exceptions are derived from the class RuntimeException. All other exception classes are of checked exceptions that must be caught.

All exception classes are derived from the predefined class Exception

FIGURE 9.1 Hierarchy of the Predefined Exception Classes



You need not worry too much about which exceptions you do and do not need to catch or declare in a throws clause. If you fail to account for some exception that Java requires you to handle, the compiler will tell you about it. You can then either catch it or add it to a throws clause.

### **RECAP** Kinds of Exceptions

Every exception class is a descendant class of the class Exception. RuntimeException is derived from Exception, and classes derived from RuntimeException or any of its descendants represent unchecked exceptions. Such exceptions do not need to be caught or declared in a throws clause of a method's heading. All other exceptions are checked and must be either caught or declared in a throws clause.

#### **Errors**

An error is not an exception, but is similar to one

An error is an object of the class Error, which is derived from Throwable, as Figure 9.1 indicates. Note that Throwable is also the base class of Exception. Technically speaking, the class Error and its descendant classes are not considered exception classes, because they are not descendants of the class Exception. To us, however, they look like exceptions. Objects of the class Error are similar to unchecked exceptions in that we need not catch or declare them in a throws clause, even though you could. Errors are more or less beyond your control. For example, an OutOfMemoryError occurs if your program has run out of memory. This means that you must either revise your program to make it more efficient in its use of memory, change a setting to let Java access more memory, or buy more memory for your computer. Adding a catch block will not help in this case.

When we discussed the assert operator and assertion checking in Chapter 4, we said that if your program contains an assertion check and the assertion check fails, your program will end with an error message. What actually happens is that an AssertionError occurs. As the name suggests, the class AssertionError is derived from the class Error.

#### **RECAP The Class Error**

Errors are objects of the class Error that are generated when certain abnormal conditions occur. Most programs should not catch them or declare them in a throws clause. Errors are technically not exceptions, even though they look like them.

# **Multiple Throws and Catches**

A try block can potentially throw any number of exceptions, which can be of different types. Each catch block can catch exceptions of only one type, but you can catch exceptions of different types by placing more than one catch block after a try block. For example, the program in Listing 9.8

A try block may be followed by several catch blocks

### LISTING 9.8 Catching Multiple Exceptions (part 1 of 2)

```
import java.util.Scanner;
                                       This is just an example of handling
                                       exceptions using two catch blocks.
public class TwoCatchesDemo
    public static void main(String[] args)
    {
        try
        {
            System.out.println("Enter number of widgets " +
                                 "produced:");
            Scanner keyboard = new Scanner(System.in);
            int widgets = keyboard.nextInt();
            if (widgets < 0)</pre>
                throw new NegativeNumberException("widgets");
            System.out.println("How many were defective?");
            int defective = keyboard.nextInt();
            if (defective < 0)</pre>
                throw new NegativeNumberException("defective " +
                                                    "widgets");
            double ratio = exceptionalDivision(widgets,
                                                  defective);
            System.out.println("One in every " + ratio +
                                 " widgets is defective.");
        catch(DivideByZeroException e)
        {
           System.out.println("Congratulations! A perfect " +
                                "record!");
        catch(NegativeNumberException e)
            System.out.println("Cannot have a negative number of " +
                                 e.getMessage());
        }
                                                           (continued)
```

### LISTING 9.8 Catching Multiple Exceptions (part 2 of 2)

### Sample Screen Output 1

```
Enter number of widgets produced:
1000
How many were defective?
500
One in every 2.0 widgets is defective.
End of program.
```

### Sample Screen Output 2

```
Enter number of widgets produced:
-10
Cannot have a negative number of widgets
End of program.
```

### Sample Screen Output 3

```
Enter number of widgets produced:
1000
How many were defective?
0
Congratulations! A perfect record!
End of program.
```

has two catch blocks after its try block. One catch block is for exceptions of type DivideByZeroException—defined earlier in Listing 9.5—and the second is for exceptions of type NegativeNumberException, which is defined in Listing 9.9.

#### LISTING 9.9 The Class NegativeNumberException

```
public class NegativeNumberException extends Exception
{
    public NegativeNumberException()
    {
        super("Negative Number Exception!");
    }
    public NegativeNumberException(String message)
    {
        super(message);
    }
}
```

# ■ PROGRAMMING TIP Catch the More Specific Exception First

When catching multiple exceptions, the order of the catch blocks can be important. When an exception is thrown in a try block, the catch blocks are examined in order of appearance. The first block that matches the type of the exception thrown is the one that executes. Thus, the following ordering of catch blocks would not be good:

```
catch(Exception e) //This catch block should not be first.
{
    ...
}
catch(DivideByZeroException e)
{
    ...
}
The second catch block can never be reached.
```

With this ordering, the catch block for DivideByZeroException would never be used, because all exceptions are caught by the first catch block. Fortunately, the compiler will probably warn you about this problem.

The correct ordering is to reverse the catch blocks so that the more specific exception comes before its parent exception class, as shown in the following code:

The order of catch blocks matters

# PROGRAMMING TIP User Input

When your program reads input data entered by the user of your program, you likely will need to deal with exceptions. Users can type almost anything as input, unintentionally or not!

# **PROGRAMMING TIP** Exception Handling and Information Hiding

You know that a method invocation can cause an exception that is declared in the method's throws clause. Any time an exception is thrown, regardless of whether you write a throw statement or call a method, you handle it in the exact same way: It is either caught in a catch block or declared in another throws clause. When analyzing a method invocation that might throw an exception, do not think about where in the method definition the throw statement is located. It does not matter how the exception is thrown. All that matters is that the method invocation might throw an exception. The exception is handled in the same way no matter what happens inside the method.

# **SELF-TEST QUESTIONS**

24. Correct the following method definition by adding a suitable throws clause:

```
public void doStuff(int n)
{
    if (n < 0)
        throw new Exception("Negative number.");
}</pre>
```

- 25. What happens if you invoke a method and it throws a checked exception that it does not catch?
- 26. Consider an invocation of method A. Suppose that method A calls method B, and method B calls method C. If method C throws an exception that it does not catch itself, where might the exception be caught? In B? In A? Outside of A?
- 27. What output will be produced by the following code? The definition of the class NegativeNumberException is given in the preceding material, but you do not need to look at it to answer this question.

```
try
{
   int n = 7;
   if (n > 0)
        throw new Exception();
   else if (n < 0)
        throw new NegativeNumberException();
   else
        System.out.println("Hello!");
   }
   catch(NegativeNumberException e)
   {
      System.out.println("First catch.");
   }
   catch(Exception e)
   {
      System.out.println("Second catch");
   }
   System.out.println("End of code");</pre>
```

- 28. Repeat Self-Test Question 27, but change the value of n from 7 to −7.
- 29. Repeat Self-Test Question 27, but change the value of n from 7 to 0.
- 30. What output is produced by the following program?

```
public class Question30
   public static void main(String[] args)
        Question30 object = new Question30();
        try
        {
            System.out.println("Trying");
            object.sampleMethod();
            System.out.println("Trying after call.");
        }
        catch(Exception e)
            System.out.println("Catching");
            System.out.println(e.getMessage());
        }
   public void sampleMethod() throws Exception
        System.out.println("Starting sampleMethod.");
        throw new Exception("From sampleMethod with love.");
}
```

#### FAQ When should my code throw an exception?

The use of a throw statement should be reserved for cases in which it is unavoidable. If you are tempted to include a throw statement, think about how you might write your program or class definition without this throw statement. If you can think of an alternative that produces reasonable code, you probably should not throw an exception. But if the way to deal with an exceptional condition depends on how and where a method is invoked, the best approach is to let the programmer who invokes the method handle the exception. In all other situations, it is preferable to avoid throwing exceptions.

Predefined methods often leave exception handling to the programmer invoking the method. When you learn about a predefined method, you may be told that it throws exceptions of certain kinds. You, as the programmer who uses the predefined method, are then expected to handle any exception thrown by the method.

## PROGRAMMING TIP Where to Throw an Exception

Thus far, we have used some very simple code to illustrate the basic concepts of exception handling. However, our examples were unrealistically simple. In general, you should separate throwing an exception and catching the exception into separate methods. For example, one method might have the following form:

```
public void methodA() throws MyException
{
    ...
    throw new MyException("Blah Blah Blah");
    ...
}
```

and some other method—perhaps even in some other class—might be

The reason for this is related to the previous FAQ on when you should throw an exception. If a method knows how to deal with a certain situation, it likely should do so without throwing an exception. If an exception is thrown by some code within a method—for example, if your method invokes another method that throws an exception—handle it if you can. Otherwise, declare the exception in a throws clause in your method, and let a different method contain the catch block.



## GOTCHA Nested try-catch Blocks

Although you can place a try block and its subsequent catch blocks inside a larger try block or inside a larger catch block, doing so is rarely useful. If you are tempted to nest these blocks, you should at least consider whether there is another way to organize your code. For example, you might eliminate one or more try blocks completely, or you could place the inner try-catch blocks inside a method definition and invoke that method within the outer try block or catch block. It is almost always better to avoid nested try-catch blocks.

Suppose, however, that you do use nested try-catch blocks. If you place a try block and its subsequent catch blocks inside a larger try block, and an exception is thrown in the inner try block but is not caught in the inner catch blocks, the exception is thrown to the outer try block for processing and might be caught in one of the outer catch blocks. If you place a try block and its subsequent catch blocks inside a larger catch block, you will need to use different names for the catch-block parameters in the inner and outer blocks, respectively. After all, try blocks and catch blocks are blocks, so you need to remember how Java handles nested blocks of any kind.

# The finally Block

You can add a finally block after a sequence of catch blocks. The code in the finally block is executed whether or not an exception is thrown. This block gives you an opportunity to clean up any loose ends that linger as a result of the exception.

A finally block always executes

The general syntax is as follows:

To see the significance and potential usefulness of a finally block, suppose that the try-catch-finally blocks are inside a method definition. After all, every set of try-catch-finally blocks is inside some method, even if it is only the method main.

Possible outcomes with a finally block

One of three possible outcomes will occur when the code in the try-catch-finally blocks is run:

- The try block runs to the end, and no exception is thrown. In this situation, the finally block executes after the try block.
- An exception is thrown within the try block and is caught in a corresponding catch block positioned after the try block. In this case, the finally block executes after the catch block executes.
- An exception is thrown in the try block, but no matching catch block exists to catch the exception. The method invocation ends, and the exception object is thrown to the enclosing method. In this case, the finally block executes before the method ends. Note that you cannot account for this third case simply by placing code after the string of catch blocks.

A catch block can throw an exception

At this stage of your programming, you might not have much need for a finally block, but we've included this description of it for completeness. At some point, you may find it useful.

# Rethrowing an Exception (Optional)

It is legal to throw an exception within a catch block. In rare cases, you may want to catch an exception and then, depending either on the string produced by getMessage or on something else, decide to throw the same or a different exception for handling further up the chain of exception-handling blocks.

# **SELF-TEST QUESTIONS**

- 31. Can you have a try block and corresponding catch blocks inside another, larger try block?
- 32. Can you have a try block and corresponding catch blocks inside another, larger catch block?
- 33. Consider the following program:

```
public class Question33
{
    public static void main(String[] args)
    {
        try
        {
            sampleMethod(99);
        }
}
```

```
catch(Exception e)
        {
            System.out.println("Caught in main.");
        }
    public static void sampleMethod(int n) throws Exception
        try
        {
            if (n > 0)throw new Exception();
            else if (n < 0)
                throw new NegativeNumberException();
            else
                System.out.println("No exception.");
            System.out.println("Still in sampleMethod.");
        }
        catch (NegativeNumberException e)
        {
            System.out.println("Caught in sampleMethod.");
        finally
        {
            System.out.println("In finally block.");
        System.out.println("After finally block.");
   }
}
```

- a. What output does the program produce?
- b. What output would the program produce if the argument to sampleMethod were -99 instead of 99?
- c. What output would the program produce if the argument to sampleMethod were 0 instead of 99?

# **CASE STUDY** A Line-Oriented Calculator

We have been asked to write a program that can be used as a calculator, similar to a handheld calculator. The calculator should do addition, subtraction, multiplication, and division. For our initial draft of the program, we won't use a windowing interface, but instead we will use simple line-by-line text input and text output—like the previous programs in this chapter.

Specify the task

We need to specifically define the user interface. Let's tell the user to enter an operation, a space, and a number, all on one line, as in the following example:

```
+ 3.4
```

Any extra whitespace before or after the operation or the number is optional. As the user enters more operations and numbers, the program

keeps track of the results of the operations performed so far. These results are like the number displayed on a handheld calculator—the running result of the operations. On the screen, it is shown as, for example,

```
updated result = 3.4
```

The user can add, subtract, multiply, and divide, using instructions such as

\* 3

# Design the user interface

For example, we might have the following interaction between the user and the program:

```
result = 0
+ 80
result + 80 = 80
updated result = 80
- 2
result - 2 = 78
updated result = 78
e
```

The user's input is shown in color, and the black text is output from the program. The program assumes that the initial "result" is zero. The program echoes the input data and shows the result of each computation. To end a set of calculations, let's ask the user to enter the letter E in either uppercase or lowercase.

After our suggested interface is accepted, we can begin designing a class for a calculator. We can give the class a main method that is a complete, simple calculator program that adheres to our specifications for a user interface. Later, we can design a more elaborate interface and let the calculator be a bit more powerful. Ultimately, we could give our calculator a windowing interface.

Let's maintain the current result in a private instance variable called result. The program always adds, subtracts, multiplies, or divides the current result and the number entered. For instance, if the user enters

```
- 9.5
```

and the current value of result is 80, the value of result is changed to 70.5. Let's give the class at least the following methods:

- A method reset to reset the value of result to zero
- A method evaluate to calculate the result of one operation
- A method doCalculation that performs a series of operations
- An accessor method getResult that returns the value of the instance variable result
- A mutator method setResult that sets the value of result to any specified value

#### **Desired methods**

The definitions of the methods reset, setResult, and getResult are routine, but the methods evaluate and doCalculation require a bit of

# Design a class

Keep track of the result in an instance variable result thought. To simplify the first draft of our code, let's assume that everything will go smoothly. That is, nothing unusual will occur to cause an exception. We might note possible exceptions as we think of them, but we will not write any exception-handling code until after the core of the class is designed.

To make our class more versatile, the method evaluate can return the result of one operation, rather than updating the instance variable result directly. Thus, we can specify the method as follows:

Specification of a method to return the result of one operation

```
/**
Returns n1 op n2,
provided op is one of '+', '-', '*', or '/'.
*/
public double evaluate(char op, double n1, double n2)
```

The heart of the calculator's action is performed by the method doCalculation, which we specify as

```
/**
Interacts with the user to perform a series
of calculations and updates result.
*/
public void doCalculation()
```

Specification of a method to return the result of a series of operations

Let's develop doCalculation first. The method should repeat the following sequence again and again until the user enters a sentinel such as the letter E:

```
char nextOp = (keyboard.next()).charAt(0);
double nextNumber = keyboard.nextDouble();
result = evaluate(nextOp, result, nextNumber);
```

Here keyboard.next() reads the operator as a string, and charAt(0) returns it as a character. Also, nextOp and nextNumber are local variables, while result is the instance variable.

We will embed the previous code in a loop within doCalculation, as follows:

The basic logic of the method doCalculation

Next, let's consider the method evaluate. We can write a large switch statement like the following one:

The basic logic of the method evaluate

```
switch (op)
{
    case '+':
        answer = n1 + n2;
        break;
    case '-':
        answer = n1 - n2;
        break:
    case '*':
        answer = n1 * n2;
        break:
    case '/':
        answer = n1 / n2; //Worry about division by zero
    default: //Worry about illegal characters
}
return answer;
```

In the first test of our code, we could completely ignore our comments about the things that can be wrong, but to shorten this case study, we will throw some exceptions. We will not, however, handle the exceptions right now. Suppose we include the following code in the preceding case for division:

Do not compare a floating-point number with zero

```
if (n2 == 0.0)
    throw new DivideByZeroException();
```

This approach is conceptually fine, but there is one problem: The numbers involved are of type double. Floating-point numbers such as these represent only approximate quantities, so we should not use == to test them for exact equality, as we discussed in Chapter 3. The value of n2 might be so close to zero that dividing another number by it would have the same effect as dividing by zero, yet the test would say that it is not equal to zero. We should throw an exception whenever the denominator is very close to zero. How should we define "very close to zero"? We could, for example, consider any quantity less than one ten-thousandth as very close to zero. But we might find later that this value is not the best choice, so instead let's use an instance variable, named precision. For now, the definition of precision can be

```
private double precision = 0.0001;
```

Thus, the case for division becomes

```
case '/':
   if ( (-precision < n2) && (n2 < precision) )
       throw new DivideByZeroException();
   answer = n1 / n2;
   break;</pre>
```

Preventing division by zero or almost zero

Now, what if the user enters some character other than '+', '-', '\*', or '/' for the operation? We can throw another exception in the default case of the switch statement, as follows:

Throw an exception if the operator is not recognized

```
default:
    throw new UnknownOpException(op);
```

The DivideByZeroException class was defined in Listing 9.5. UnknownOpException is a new exception class that we need to define. It is similar to other exception classes we have written and is given in Listing 9.10. Note that when the user enters an unknown operator, we want to provide an error message that includes the erroneous character. Thus, our class has a constructor that names the operator as an argument of type char.

### LISTING 9.10 The UnknownOpException Class

```
public class UnknownOpException extends Exception
{
   public UnknownOpException()
   {
      super("UnknownOpException");
   }

   public UnknownOpException(char op)
   {
      super(op + " is an unknown operator.");
   }

   public UnknownOpException(String message)
   {
      super(message);
   }
}
```

The heading of the method doCalculation must include a throws clause for the exception classes UnknownOpException and DivideByZeroException, even though the body of doCalculation does not contain any throw statements. The throws clause is necessary because doCalculation calls the method evaluate, and the method evaluate can throw an UnknownOpException or a DivideByZeroException.

At this point, we have most of the program written, except for the exception handling. Our preliminary version of the program is shown in Listing 9.11. We can debug and test it before we write the exception-handling portion. As long as the user does not enter an unknown operator or attempt to perform a division by zero, this version will run fine.

Our first draft can throw exceptions but will not handle them

## LISTING 9.11 The Unexceptional Cases (part 1 of 3)

```
This version of the program does
  not handle exceptions and thus is
  not yet complete. However, it does
  run and can be used for debugging.
import java.util.Scanner;
PRELIMINARY VERSION without exception handling.
Simple line-oriented calculator program. The class
can also be used to create other calculator programs.
*/
public class PrelimCalculator
{
    private double result;
    private double precision = 0.0001;
    //Numbers this close to zero are treated as if equal to zero.
                                                   The definition of the main
    public static void main(String[] args)
                                                   method will change before
                   throws DivideByZeroException,
                                                   this case study ends.
                           UnknownOpException
    {
        PrelimCalculator clerk = new PrelimCalculator();
        System.out.println("Calculator is on.");
        System.out.print("Format of each line: ");
        System.out.println("operator space number");
        System.out.println("For example: + 3");
        System.out.println("To end, enter the letter e.");
        clerk.doCalculation();
        System.out.println("The final result is " +
                              clerk.resultValue());
        System.out.println("Calculator program ending.");
    }
    public PrelimCalculator()
    {
        result = 0;
    }
    public void reset()
    {
        result = 0;
    }
                                                            (continued)
```

### LISTING 9.11 The Unexceptional Cases (part 2 of 3)

```
reset, setResult, and getResult
are not used in this program, but might
be needed by some other application
that uses this class.
public void setResult(double newResult)
    result = newResult;
public double getResult()
    return result;
}
Returns n1 op n2, provided op is one of '+', '-', '*', or '/'.
Any other value of op throws UnknownOpException.
public double evaluate(char op, double n1, double n2)
           throws DivideByZeroException, UnknownOpException
{
    double answer;
    switch (op)
        case '+':
            answer = n1 + n2;
            break;
        case '-':
            answer = n1 - n2;
            break:
        case '*':
            answer = n1 * n2;
            break:
        case '/':
            if ((-precision < n2) && (n2 < precision))
                 throw new DivideByZeroException();
            answer = n1 / n2;
            break:
        default:
            throw new UnknownOpException(op);
    }
    return answer;
}
                                                       (continued)
```

### LISTING 9.11 The Unexceptional Cases (part 3 of 3)

```
public void doCalculation() throws DivideByZeroException,
                                       UnknownOpException
   {
       Scanner keyboard = new Scanner(System.in);
       boolean done = false;
        result = 0;
       System.out.println("result = " + result);
       while (!done)
            char nextOp = (keyboard.next()).charAt(0);
            if ((nextOp == 'e') || (nextOp == 'E'))
                done = true;
            else
            {
                double nextNumber = keyboard.nextDouble();
                result = evaluate(nextOp, result, nextNumber);
                System.out.println("result " + nextOp + " " +
                                    nextNumber + " = " + result):
                System.out.println("updated result = " + result);
            }
       }
   }
}
```

#### Sample Screen Output

```
Calculator is on.
Format of each line: operator space number
For example: + 3
To end, enter the letter e.
result = 0.0
+ 4
result + 4.0 = 4.0
updated result = 4.0
* 2
result* 2.0 = 8.0
updated result = 8.0
e
The final result is 8.0
Calculator program ending.
```

Once we have debugged the preliminary version of our program, we can add exception handling. The most significant exception is UnknownOpException, so we consider it first. We have already given the definition of the class UnknownOpException, but we have not yet done anything with it, other than to throw it in the method evaluate and to declare it in throws clauses. The method evaluate is invoked by the method doCalculation, and the method doCalculation is invoked by the method main. We have three typical ways of handling the exception:

Our final version adds exception handling

- Catch the exception in the method evaluate.
- Declare the exception UnknownOpException in a throws clause in the method evaluate, and then catch the exception in the method doCalculation.
- Declare the exception UnknownOpException in a throws clause in both the method evaluate and the method doCalculation, and then catch the exception in the method main.

Possible ways to handle an exception due to an unknown operator

The approach we choose depends on what we want to have happen when an exception is thrown. We would use either of the first two ways if we wanted the user to try again to enter the operator. We would use the last way if we wanted to restart the entire calculation. Suppose we decide on this last approach and place the try and catch blocks in the method main. This decision leads us to rewrite main, as shown in Listing 9.12. In doing so, we introduce two new methods, handleUnknownOpException and handleDivideByZeroException. All that is left to do is to define these two methods for handling exceptions.

We handle exceptions in separate methods

If you look at the catch block in the method main, you will see that, when an UnknownOpException is thrown, it is handled by the method handleUnknownOpException. We designed this method to give the user a second chance to enter the calculation, starting from the beginning. If the user enters an unknown operator during this second chance, another UnknownOpException is thrown, but this time it is caught in the method handleUnknownOpException and the program ends. (There are other good ways to handle an UnknownOpException, but this one is satisfactory.) To see the code for this case, look at the catch block in the method handleUnknownOpException in Listing 9.12.

If the user attempts to divide by zero, we will simply end the program. (Perhaps we will do something more elaborate in a future version of this program, but this will do for now.) Thus, the method handleDivideByZeroException is quite simple.

# PROGRAMMING TIP Documentation Should Describe Possible Exceptions

When using classes and methods written by another programmer, you would want documentation that describes the possible exceptions. Such documentation can give you some idea of how to handle these exceptions. Consider this when writing the javadoc comments and other documentation for the code that you write.

# LISTING 9.12 The Complete Line-Oriented Calculator (part 1 of 3)

```
import java.util.Scanner;
Simple line-oriented calculator program. The class
can also be used to create other calculator programs.
public class Calculator
{
    private double result;
    private double precision = 0.0001;
    //Numbers this close to zero are treated as if equal to zero.
    public static void main(String[] args)
    {
        Calculator clerk = new Calculator();
        try
        {
            System.out.println("Calculator is on.");
            System.out.print("Format of each line: ");
            System.out.println("operator space number");
            System.out.println("For example: + 3");
            System.out.println("To end, enter the letter e.");
            clerk.doCalculation();
        }
        catch(UnknownOpException e)
            clerk.handleUnknownOpException(e);
        catch(DivideByZeroException e)
            clerk.handleDivideByZeroException(e);
        System.out.println("The final result is " +
                            clerk.resultValue());
        System.out.println("Calculator program ending.");
    }
    public Calculator()
        result = 0;
    }
                                                          (continued)
```

# LISTING 9.12 The Complete Line-Oriented Calculator (part 2 of 3)

```
public void handleDivideByZeroException
                                     (DivideByZeroException e)
    {
        System.out.println("Dividing by zero.");
        System.out.println("Program aborted");
        System.exit(0);
    public void handleUnknownOpException(UnknownOpException e)
        System.out.println(e.getMessage());
        System.out.println("Try again from the beginning:");
        try
        {
            System.out.print("Format of each line: ");
            System.out.println("operator number");
            System.out.println("For example: + 3");
            System.out.println("To end, enter the letter e.");
            doCalculation();
                                        The first UnknownOpException
        }
                                         gives the user another chance.
        catch(UnknownOpException e2) ←
                                               This block catches an
                                               UnknownOpException
        {
                                               if it is thrown a second time.
            System.out.println(e2.getMessage());
            System.out.println("Try again at some other time.");
            System.out.println("Program ending.");
            System.exit(0);
        catch(DivideByZeroException e3)
            handleDivideByZeroException(e3);
        }
The methods reset, setResult, getResult, evaluate, and doCalculation
are the same as in Listing 9.11.
}
                                                          (continued)
```

# LISTING 9.12 The Complete Line-Oriented Calculator (part 3 of 3)

#### Sample Screen Output

```
Calculator is on.
Format of each line: operator space number
For example: + 3
To end, enter the letter e.
result = 0.0
+ 80
result + 80.0 = 80.0
updated result = 80.0
result -2.0 = 78.0
updated result = 78.0
% 4
% is an unknown operator.
Try again from the beginning:
Format of each line is: operator space number
For example: + 3
To end, enter the letter e.
result = 0.0
+ 80
result + 80.0 = 80.0
updated result = 80.0
- 2
result -2.0 = 78.0
updated result = 78.0
* 0.04
result * 0.04 = 3.12
updated result = 3.12
The final result is 3.12
Calculator program ending.
```



## **SELF-TEST QUESTIONS**

- 34. Write an accessor method called getPrecision that can be added to the class Calculator in Listing 9.12 and that returns the value of the instance variable precision. Also, write a mutator method called setPrecision that changes the value of the instance variable precision to any specified value.
- 35. What would happen if you ran the program in Listing 9.11 and entered an unknown operator—such as % or #—that the program cannot recognize?

## 9.4 GRAPHICS SUPPLEMENT

That's an interesting color. What's it called?

—A FRIEND ON SEEING MY NEWLY PAINTED DINING ROOM

In this supplement, we introduce a few additional user interface controls and shapes that can be used in window applications. They include the CheckBox, RadioButton, Spinner, ChoiceBox, ImageView, Circle, and Rectangle classes. Then we give an example processing mouse events and animating objects within a loop timer. There are many other additional classes available as part of JavaFX. You can read about them on Oracle's JavaFX website.

# **Additional User Interface Controls and Shapes**

The CheckBox control allows you to create a box that is either checked or not checked. It can be used to allow the user to select a Boolean option. You can check to see if the box is checked by using the isSelected method and you can set the box to check or not check by using the setSelected method.

In Listing 9.13, check boxes are used to select pizza toppings. The check boxes allow any combination of pizza toppings to be selected.

The **RadioButton** control allows a user to select only one out of a group of radio button options. Out of all of the radio buttons in the same ToggleGroup, only the last radio button that was clicked will be selected. In our pizza example, we use radio buttons to select only one of two possible crusts: hand

# LISTING 9.13 Demo of Additional JavaFX Controls (part 1 of 3)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.VBox;
import javafx.scene.control.Button;
import javafx.scene.control.CheckBox;
import javafx.scene.control.RadioButton;
import javafx.scene.control.ToggleGroup;
import javafx.scene.control.Spinner;
import javafx.scene.control.SpinnerValueFactory;
import javafx.scene.control.ChoiceBox;
import javafx.collections.FXCollections;
import javafx.scene.control.Label;
import javafx.event.ActionEvent;
import javafx.event.EventHandler;
/**
Simple demonstration of some additional JavaFX
UI controls.
public class AdditionalControlsDemo extends Application
{
   public static void main(String[] args)
      launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
   {
    VBox root = new VBox();
     // Demonstrate radio buttons
     root.getChildren().add(new Label("Select pizza crust"));
     ToggleGroup toggleCrust = new ToggleGroup();
     RadioButton rbHand = new RadioButton("Hand tossed");
     rbHand.setToggleGroup(toggleCrust);
     rbHand.setSelected(true);
     RadioButton rbDeepDish = new RadioButton("Deep dish");
     rbDeepDish.setToggleGroup(toggleCrust);
     root.getChildren().add(rbHand);
     root.getChildren().add(rbDeepDish);
     // Demonstrate checkboxes
     root.getChildren().add(new Label("Select pizza toppings"));
     CheckBox cbCheese = new CheckBox("Extra cheese");
     CheckBox cbPepperoni = new CheckBox("Pepperoni");
                                                         (continued)
```

#### LISTING 9.13 Demo of Additional JavaFX Controls (part 2 of 3)

```
CheckBox cbMushrooms = new CheckBox("Mushrooms");
root.getChildren().add(cbCheese);
root.getChildren().add(cbPepperoni);
root.getChildren().add(cbMushrooms);
// Demonstrate Spinner with integer values from 1-10
root.getChildren().add(new Label("Select quantity"));
Spinner<Integer> spinnerQuantity = new Spinner<Integer>();
final int defaultValue = 1;
// Value factory.
SpinnerValueFactory<Integer> quantityFactory =
    new SpinnerValueFactory.IntegerSpinnerValueFactory
            (1, 10, defaultValue);
spinnerQuantity.setValueFactory(quantityFactory);
root.getChildren().add(spinnerQuantity);
 // Demonstrate ChoiceBox with delivery options
 root.getChildren().add(new Label("Select delivery mode"));
 ChoiceBox<String> cbModes = new ChoiceBox<String>(
    FXCollections.observableArrayList("Delivery",
                              "Dine-In", "Carryout"));
 root.getChildren().add(cbModes);
 // Button to display selections
 Button btnSelections = new Button("Get Selections");
 // Set the event handler when the button is clicked
btnSelections.setOnAction(new EventHandler<ActionEvent>()
      @Override
      public void handle(ActionEvent event)
      {
           System.out.println("Hand tossed: " +
               rbHand.isSelected());
           System.out.println("Deep dish: " +
               rbDeepDish.isSelected());
           System.out.println("Cheese: " +
               cbCheese.isSelected());
           System.out.println("Pepperoni: " +
               cbPepperoni.isSelected());
           System.out.println("Mushrooms: " +
               cbMushrooms.isSelected());
           System.out.println("Quantity: " +
               spinnerQuantity.getValue());
           System.out.println("Mode: " +
               cbModes.getValue());
      }
}
);
```

# LISTING 9.13 Demo of Additional JavaFX Controls (part 3 of 3)

root.getChildren().add(btnSelections);

```
Scene scene = new Scene(root, 350, 300);
       primaryStage.setTitle("Additional Controls Demo");
       primaryStage.setScene(scene);
       primaryStage.show();
    }
}
Program Output
 Additional Controls Demo
Select pizza crust

    Hand tossed

 Deep dish
Select pizza toppings

✓ Extra cheese

  Pepperoni

✓ Mushrooms

Select quantity
Select delivery mode
 Delivery *
 Get Selections
 and tossed: true
 eep dish: false
Cheese: true
 epperoni: false
Mushrooms: true
 uantity: 2
  de: Delivery
```

tossed and deep dish. The following code creates a ToggleGroup and adds two radio buttons to it:

```
ToggleGroup toggleCrust = new ToggleGroup();
RadioButton rbHand = new RadioButton("Hand tossed");
rbHand.setToggleGroup(toggleCrust);
rbHand.setSelected(true);
RadioButton rbDeepDish = new RadioButton("Deep dish");
rbDeepDish.setToggleGroup(toggleCrust);
```

As with the check box, use the isSelected and setSelected methods to determine if a radio button is checked and to select a radio button.

The **Spinner** creates a box with a single item. The user can click up or down to increment or decrement the selected item. It is somewhat like the ChoiceBox that is discussed next, except instead of generating a pull-down

menu of options, the user scrolls through available options in the spinner's box. To create a Spinner object, we have to specify the data type that will be contained in the spinner. This is done through a mechanism called **generic types** that is discussed in Chapter 12. For now, simply put the desired data type inside the <>. The type must be a reference type, not a primitive type. The following creates a spinner of integers:

```
Spinner<Integer> spinnerQuantity = new Spinner<Integer>();
```

This creates a spinner named spinnerQuantity that spins through integer values. In our pizza example, we use this to specify how many pizzas the customer wishes to purchase. The range of integer values that is allowed is specified through a SpinnerValueFactory. The following allows values in the range from 1 to 10:

This specifies that the SpinnerValueFactory cycles through integers in the range from 1 to 10 and sets the spinnerQuantity spinner to use this factory. To retrieve the value selected by the user, use the getValue method.

The ChoiceBox control is similar in function to a spinner, but upon clicking on the box the user is presented with a list of menu choices and is allowed to select one of the menu choices. A simple way to create a ChoiceBox is to explicitly list all of the options. For our pizza example, the choice box is used to select delivery, dine-in, or carryout. The ChoiceBox also uses generic types as with the spinner:

To retrieve the value selected by the user, use the getValue method.

Listing 9.13 combines the checkbox, radio button, spinner, and choice box controls into a pizza configuration interface. Upon clicking the button the selected options are output to the console.

# **Images and Shapes**

Earlier we saw how to draw shapes and images onto a GraphicsContext but we can also do the same thing with shape and image objects. The advantage of the latter approach is we can more easily manipulate a single object as well as take advantage of a layout pane. Listing 9.14 demonstrates adding a circle and a rectangle to a VBox layout. We specify the size of the shapes and they are laid out onto the form according to the rules of the pane.

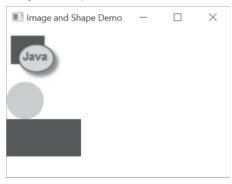
To display an image we have to first load it into an Image object. Second, we add the image into an ImageView that is added to the pane. Listing 9.14 also demonstrates the display of a JPG image alongside the rectangle and circle.

## LISTING 9.14 Demo of Image and Shapes (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.VBox;
import javafx.scene.image.Image;
import javafx.scene.image.ImageView;
import javafx.scene.shape.Circle;
import javafx.scene.shape.Rectangle;
import javafx.scene.paint.Color;
Demonstration of some shapes and an image
within a VBox layout.
* /
public class ImageShapeDemo extends Application
{
    public static void main(String[] args)
    {
         launch(args);
    @Override
    public void start(Stage primaryStage) throws Exception
         VBox root = new VBox();
         ImageView imv = new ImageView();
         // Java looks for "java.jpg" in the default folder
         Image img = new Image("java.jpg");
         imv.setImage(img);
         Circle c = new Circle();
         c.setRadius(25);
         c.setFill(Color.PINK);
         Rectangle r = new Rectangle();
         r.setWidth(100);
         r.setHeight(50);
         r.setFill(Color.BLUE);
         root.getChildren().add(imv);
         root.getChildren().add(c);
         root.getChildren().add(r);
         Scene scene = new Scene(root, 300, 200);
         primaryStage.setTitle("Image and Shape Demo");
         primaryStage.setScene(scene);
         primaryStage.show();
    }
}
                                                          (continued)
```

LISTING 9.14 Demo of Image and Shapes (part 2 of 2)

#### Program Output



# **Handling Mouse Events**

In the previous chapter, we learned how to handle button clicks with the ActionEvent handler. In this section, we demonstrate how to handle some mouse events. More specifically, we perform an action when the mouse is clicked and when the mouse is moved.

To write a handler when the mouse is pressed, assign the handler that implements EventHandler<MouseEvent> using the setOnMousePressed method. Listing 9.15 associates a mouse pressed handler to the canvas using the anonymous inner class notation. When the mouse is pressed the handler draws a white rectangle over the entire canvas, effectively erasing anything that was drawn on it.

In a similar fashion, we also create a handler when the mouse is moved with respect to the canvas. The handler sets the current color to a random color and then draws a circle at the location of the mouse coordinates. The mouse coordinates are retrieved using the methods event.getX() and event.getY() and the coordinates are relative to the upper left corner of the reference object, which in this case is the canvas.

LISTING 9.15 Painting Circles with a Mouse Listener (part 1 of 3)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.Group;
import javafx.scene.canvas.GraphicsContext;
import javafx.scene.paint.Color;
import javafx.scene.input.MouseEvent;
```

(continued)

# LISTING 9.15 Painting Circles with a Mouse Listener (part 2 of 3)

```
import javafx.event.EventHandler;
import java.util.Random;
This program draws a circle of random color
at the location of the mouse whenever the mouse
moves.
* /
public class MousePaint extends Application
   private Random rnd = new Random();
   public static void main(String[] args)
      Application.launch(args);
   @Override
   public void start(Stage primaryStage) throws Exception
      Group root = new Group();
      Canvas canvas = new Canvas (650, 600);
      GraphicsContext gc = canvas.getGraphicsContext2D();
      // When the mouse is pressed erase the
      // screen by drawing a white rectangle on the
      // entire canvas
      canvas.setOnMousePressed(new EventHandler<MouseEvent>()
        @Override
        public void handle(MouseEvent event)
            gc.setFill(Color.WHITE);
            gc.fillRect(0,0,canvas.getWidth(),canvas.getHeight());
      });
      // When the mouse is moved get a random color
      // and draw a circle at the mouse's coordinates
      canvas.setOnMouseMoved(new EventHandler<MouseEvent>()
         @Override
         public void handle(MouseEvent event)
           // Get a random color
           gc.setFill(Color.rgb(rnd.nextInt(255),
                rnd.nextInt(255),
                rnd.nextInt(255)));
           gc.fillOval(event.getX(),event.getY(),100,100);
                                                         (continued)
```

# LISTING 9.15 Painting Circles with a Mouse Listener (part 3 of 3)

```
}
});
root.getChildren().add(canvas);
primaryStage.setScene(new Scene(root));
primaryStage.setTitle("Mouse Paint");
primaryStage.show();
}
```

#### Program Output



Listing 9.16 is similar to Listing 9.15, except instead of drawing a new circle every time the mouse is moved, a single Circle shape is moved to the coordinates of the mouse using the setCenterX and setCenterY methods.

The circle is displayed using the Pane class, which is the base class for the other panes we have been using. This class is used when absolute positioning is desired. It does not perform any layout beyond resizing.

# LISTING 9.16 Following the Mouse with a Circle (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.Pane;
import javafx.scene.paint.Color;
import javafx.scene.input.MouseEvent;
import javafx.event.EventHandler;
import javafx.scene.shape.Circle;

(continued)
```

# LISTING 9.16 Following the Mouse with a Circle (part 2 of 2)

```
/**
This program sets the X/Y coordinates of a Circle to the
location of the mouse.
* /
public class MouseCircle extends Application
   public static void main(String[] args)
      Application.launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
      Pane root = new Pane();
      root.setPrefSize(400,400);
      Circle circle = new Circle();
      circle.setRadius(30);
      circle.setFill(Color.RED);
      root.setOnMouseMoved(new EventHandler<MouseEvent>()
           @Override
           public void handle(MouseEvent event)
                circle.setCenterX(event.getX());
                circle.setCenterY(event.getY());
           }
      });
      root.getChildren().add(circle);
      primaryStage.setScene(new Scene(root));
      primaryStage.setTitle("Mouse Circle");
      primaryStage.show();
   }
}
Program Output
Mouse Circle
```

#### The Timeline Class

A JavaFX timeline is used to create animations. The timeline has key frames that map to properties of an animation. In our example, we will only use a timeline in a very simple way—to indefinitely call a handler at a regular interval.

In our example, we'll use the handler to animate a ball. The ball will "bounce" off the sides of the screen. Every 10 milliseconds (ms) the handler will run and update the location of the ball. By only invoking the handler every 10 ms, the application will remain responsive and be able to process other events.

To create the Ball class, we make it a derived class from Circle. Listing 9.17 defines the class. We give the ball a radius of 30 pixels and keep track of the center of the ball in variables x and y. The variables xVel and yVel are the velocities of the ball in the x and y directions and initialized to random values. To update the ball's location, we add the current x value to xVel and the current y value to yVel. The velocities will be negative when the ball is moving to the left or toward the top. To reverse the velocities, we simply multiply by -1.

## LISTING 9.17 Ball Class (part 1 of 2)

```
import javafx.scene.shape.Circle;
import javafx.scene.paint.Color;
import java.util.Random;
public class Ball extends Circle
 private static final int RADIUS = 30;
 private int x,y;
 private int xVel, yVel;
 public Ball()
  {
      Random rnd = new Random();
      setRadius(RADIUS);
      setFill(Color.RED);
      x = 50;
      y = 50;
      xVel = rnd.nextInt(20) + 5;
      yVel = rnd.nextInt(20) + 5;
 public void updateLocation()
         x += xVel;
         y += yVe1;
         setCenterX(x);
         setCenterY(y);
  }
```

(continued)

## LISTING 9.17 Ball Class (part 2 of 2)

```
public int getX()
{
         return x;
}

public int getY()
{
         return y;
}

public void reverseX()
{
         xVel *= -1;
}

public void reverseY()
{
         yVel *= -1;
}
```

To animate the ball we create a Timeline object with a KeyFrame that contains an ActionEvent handler that will update every 10 ms indefinitely, or until the app is closed by the user. Inside the handler we update the location of the ball and then set its x and y coordinates to the ball's new location. If the ball hits one of the borders of the application, then the velocity is reversed. Listing 9.18 contains the main application logic to animate the ball.

LISTING 9.18 Bouncing Ball using the Timeline (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.canvas.Canvas;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.Pane;
import javafx.event.EventHandler;
import javafx.animation.KeyFrame;
import javafx.animation.Timeline;
import javafx.util.Duration;
import javafx.event.ActionEvent;

/**
This program animates a red ball within
The window.
*/
public class BounceBall extends Application
{
    public static void main(String[] args)
```

(continued)

## LISTING 9.18 Bouncing Ball using the Timeline (part 2 of 2)

```
{
      Application.launch(args);
   }
   @Override
   public void start(Stage primaryStage) throws Exception
      Pane root = new Pane();
      root.setPrefSize(400,400);
      Ball ball = new Ball();
      // Timeline to call the event handler every 10ms
      // to update a bouncing ball
      Timeline timeline = new Timeline(
        new KeyFrame(Duration.millis(10),
               new EventHandler<ActionEvent>()
                     {
                         @Override
                        public void handle(ActionEvent event)
                         {
                               ball.updateLocation();
                               if ((ball.getX() < 0) | |
                                   (ball.getX() > root.getWidth()))
                                    ball.reverseX();
                               if ((ball.getY() < 0) ||
                                  (ball.getY() > root.getHeight()))
                                    ball.reverseY();
                        }
                     }
      )
      );
      timeline.setCycleCount(Timeline.INDEFINITE);
      timeline.setAutoReverse(true);
      timeline.play();
      root.getChildren().add(ball);
      primaryStage.setScene(new Scene(root));
      primaryStage.setTitle("Bouncing Ball");
      primaryStage.show();
   }
Program Output
```

The program will draw a red ball similar in appearance to the circle in Listing 9.16 that bounces within the window.

}



## **SELF-TEST QUESTIONS**

- 36. What control should you use if you want the user to select one out of four different options?
- 37. If you place three radio buttons into a JavaFX program but do not put them into a Togg1eGroup then how will the radio buttons behave when the program is run?
- 38. What layout can you use if you want to use absolute positioning of nodes within the scene?

#### **CHAPTER SUMMARY**

- An exception is an object of a class derived from the class Exception. Descendants of the class Error are not exceptions, but they behave like them.
- Exception handling allows you to design and code the normal case for your program separately from the code that handles exceptional situations.
- Java provides predefined exception classes. You can also define your own exception classes.
- Java has two kinds of exceptions: checked and unchecked (run-time). A method that throws a checked exception must either handle it or declare it in a throws clause within its heading. Checked exceptions must be caught eventually. Otherwise, program execution will terminate. Unchecked, or run-time, exceptions need not be caught or declared in a throws clause and usually are not. Unchecked exceptions belong to classes derived from the class RuntimeException. All other exceptions are checked.
- Certain Java statements themselves might throw an exception. Methods from class libraries might throw exceptions. You can also explicitly throw an exception in your code by using a throw statement.
- When a method might throw an exception but not catch it, the exception class usually must be listed in a throws clause for the method.
- An exception is caught in a catch block.
- A try block is followed by one or more catch blocks. In this case, always list the catch block for a more specific exception class before the catch block for a more general exception class.
- Every exception has a getMessage method that can be used to recover a description of the caught exception.
- Do not overuse exceptions.

- Additional JavaFX controls and shapes include check boxes, radio buttons, spinners, choice boxes, image viewers, circles, rectangles, and other shapes.
- Mouse event handlers can capture mouse clicks or mouse motion.
- The Timeline object can be used for animation.

#### **Exercises**

- 1. Write a program that allows owners to allot their frequency bands at 92, 93, 94, 95, 96, 97, or 98 Hz. Use an array of appropriate number of strings to store the names for the frequency bands. Write a loop that iterates as long as the array has a free space. Within a try block, allow the user to enter a frequency and a band name. If the frequency band is free, put the name in the array. If the band is not free, throw a FrequencyInUseException. If the frequency band is not valid, throw an InvalidFrequencyException. Use a catch block for each different kind of exception.
- 2. Write a program that allows the user to compute the subtracted value after the subtraction of two integer values. The subtraction value of x y is stored in z. Catch any exception thrown and allow the user to enter new values.
- 3. Write an exception class that is appropriate for indicating that a time entered by a user is not valid. The time will be in the format *minute:second*.
- 4. Derive exception classes from the class you wrote in the previous exercise. Each new class should indicate a specific kind of error. For example, InvalidMinuteException could be used to indicate that the value entered for *minute* was not an integer in the range 0 to 60.
- 5. Write a class TimeOfDay that uses the exception classes defined in the previous exercise. Give it a method setTimeTo(timeString) that changes the time if timeString corresponds to a valid time of day. If not, it should throw an exception of the appropriate type.
- 6. Write code that reads a string from the keyboard and uses it to set the variable myTime of type TimeOfDay from the previous exercise. Use trycatch blocks to guarantee that myTime is set to a valid time.
- 7. Create a class SongCard that represents a gift card for the purchase of songs online. It should have the following private attributes:
  - songs—the number of songs on the card
  - activated—true if the card has been activated

and the following methods:

- SongCard(n)—a constructor for a card with n songs.
- activate—activates the gift card. Throws an exception if the card has already been activated.

- buyASong—records the purchase of one song by decreasing the number of songs left for purchase using this card. Throws an exception if the gift card is either completely used or not active.
- songsRemaining—returns the number of songs that can be purchased using the gift card.
- 8. Create a class Rational that represents a rational number. It should have private attributes for
  - The numerator (an integer)
  - The denominator (an integer)

and the following methods:

- Rational (numerator, denominator)—a constructor for a rational number.
- Accessor methods getNumerator and getDenominator and mutator methods setNumerator and setDenominator for the numerator and the denominator.

You should use an exception to guarantee that the denominator is never zero.

- Revise the class Rational described in the previous exercise to use an assertion instead of an exception to guarantee that the denominator is never zero.
- 10. Suppose you are going to create an object used to count the number of books in a bag. We impose a condition that the number of books in the bag can never be zero or negative. Create a BooksCounter class having three public methods:
  - removeBook—removes one book from the bag
  - addBook—adds one book to the bag
  - getBooksCount—returns the number of books in the bag

If removeBook would make the number of books zero or less than zero, throw a ZeroOrNegativeCounterException.

- 11. Revise the class BooksCounter described in the previous exercise to use an assertion instead of an exception to prevent the number of books in the bag from becoming zero or negative.
- 12. Show the modifications needed to add mod operator to the class Calculator in Listing 9.12. Use % to indicate the mod operator and to perform the computation. Mod is used to return remainder after division.
- 13. Write a class LapTimer that can be used to time the laps in a race. The class should have the following private attributes:
  - running—a boolean indication of whether the timer is running
  - startTime—the time when the timer started
  - lapStart—the timer's value when the current lap started

- lapTime—the elapsed time for the last lap
- totalTime—the total time from the start of the race through the last completed lap
- lapsCompleted—the number of laps completed so far
- lapsInRace—the number of laps in the race

The class should have the following methods:

- LapTimer(n)—a constructor for a race having n laps.
- start—starts the timer. Throws an exception if the race has already started.
- markLap—marks the end of the current lap and the start of a new lap. Throws an exception if the race is finished.
- getLapTime—returns the time of the last lap. Throws an exception if the first lap has not yet been completed.
- getTotalTime—returns the total time from the start of the race through the last completed lap. Throws an exception if the first lap has not yet been completed.
- getLapsRemaining—returns the number of laps yet to be completed, including the current one.

Express all times in seconds.

To get the current time in milliseconds from some baseline date, invoke

Calendar.getInstance().getTimeInMillis()

This invocation returns a primitive value of type long. By taking the difference between the returned values of two invocations at two different times, you will know the elapsed time in milliseconds between the invocations. Note that the class Calendar is in the package java.util.

#### PRACTICE PROGRAMS

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

- 1. Use the exception class MessageTooLongException of Self-Test Question 16 in a program that asks the user to enter a line of text having no more than 20 characters. If the user enters an acceptable number of characters, the program should display the message, "You entered *x* characters, which is an acceptable length" (with the letter *x* replaced by the actual number of characters). Otherwise, a MessageTooLongException should be thrown and caught. In either case, the program should repeatedly ask whether the user wants to enter another line or quit the program.
- 2. A method that returns a special error code can sometimes cause problems. The caller might ignore the error code or treat the error code as a valid return value. In this case it is better to throw an exception instead. The following class maintains an account balance and returns a special error code.



```
public class Account
{
    private double balance;
    public Account()
    {
        balance = 0;
    }
    public Account(double initialDeposit)
        balance = initialDeposit;
    public double getBalance()
        return balance;
    // returns new balance or -1 if error
    public double deposit(double amount)
    {
        if (amount > 0)
             balance += amount;
        else
            return -1; // Code indicating error
        return balance;
    }
    // returns new balance or -1 if invalid amount
    public double withdraw(double amount)
        if ((amount > balance) || (amount < 0))</pre>
             return -1;
        else
             balance -= amount;
        return balance;
    }
}
```

Rewrite the class so that it throws appropriate exceptions instead of returning –1 as an error code. Write test code that attempts to withdraw and deposit invalid amounts and catches the exceptions that are thrown.

3. The following snippet of code inputs a double and outputs it:

```
double num=0.0;
Scanner kbd = new Scanner(System.in);
num = kbd.nextDouble();
System.out.println(num);
```

Run this program but enter text instead of a double. The program should crash and tell you what kind of exception was thrown by the nextDouble

method. Wrap this code inside a try-catch block where you catch the exception that is thrown.

#### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

1. Write a program that converts a time from 24-hour notation to 12-hour notation. The following is a sample interaction between the user and the program:

```
Enter time in 24-hour notation:
13:07
That is the same as
1:07 PM
Again? (y/n)
Enter time in 24-hour notation:
10:15
That is the same as
10:15 AM
Again? (y/n)
Enter time in 24-hour notation:
10:65
There is no such time as 10:65
Try Again:
Enter time in 24-hour notation:
16:05
That is the same as
4:05 PM
Again? (y/n)
End of program
```

Define an exception class called TimeFormatException. If the user enters an illegal time, like 10:65, or even gibberish, like 8&\*68, your program should throw and handle a TimeFormatException.

- 2. Write a program that uses the class Calculator in Listing 9.12 to create a more powerful calculator. This calculator will allow you to save one result in memory and call the result back. The commands the calculator takes are
  - e for end
  - c for clear; sets result to zero

- m for save in memory; sets memory equal to result
- r for recall memory; displays the value of memory but does not change result

You should define a derived class of the class Calculator that has one more instance variable for the memory, a new main method that runs the improved calculator, a redefinition of the method handleUnknownOpException, and anything else new or redefined that you need. A sample interaction with the user is shown next. Your program need not produce identical output, but it should be similar and just as clear or even clearer.

```
Calculator on:
result = 0.0
+ 4
result + 4.0 = 4.0
updated result = 4.0
/ 2
result / 2.0 = 2.0
updated result = 2.0
result saved in memory
result = 0.0
+ 99
result + 99.0 = 99.0
updated result = 99.0
/ 3
result / 3.0 = 33.0
updated result = 33.0
recalled memory value = 2.0
result = 33.0
+ 2
result + 2.0 = 35.0
updated result = 35.0
End of program
```

3. Write a program that converts dates from numerical month-day format to alphabetic month-day format. For example, input of 1/31 or 01/31 would produce January 31 as output. The dialogue with the user should be similar to that shown in Programming Project 2. You should define two exception classes, one called MonthException and another called DayException. If the user enters anything other than a legal month number (integers from 1 to 12), your program should throw and catch a MonthException. Similarly, if the user enters anything other than a valid day number (integers from 1 to either 29, 30, or 31,

- depending on the month), your program should throw and catch a DayException. To keep things simple, assume that February always has 28 days.
- 4. Modify the driver program from Practice Program 3 in Chapter 8 to use three exception classes called CylinderException, LoadException, and TowingException. The number of cylinders must be an integer from 1 to 12, the load capacity must be a number from 1 to 10 (possibly with a fractional part), and the towing capacity must be a number from 1 to 20 (possibly with a fractional part). Anything other than numbers in these ranges should cause your program to throw and catch the appropriate exception. You also need to define the classes CylinderException, LoadException, and TowingException.
- 5. Define an exception class called DimensionException to use in the driver program from Programming Project 4 in Chapter 8. Modify that driver program to throw and catch a DimensionException if the user enters something less than or equal to zero for a dimension.
- VideoNote
  Defining an exception class
- 6. Write a program to enter employee data, including Social Security number and salary, into an array. The maximum number of employees is 100, but your program should also work for any number of employees less than 100. Your program should use two exception classes, one called SSNLengthException for when the Social Security number entered without dashes or spaces—is not exactly nine characters and the other called SSNCharacterException for when any character in the Social Security number is not a digit. When an exception is thrown, the user should be reminded of what she or he entered, told why it is inappropriate, and asked to reenter the data. After all data has been entered, your program should display the records for all employees, with an annotation stating whether the employee's salary is above or below average. You will also need to define the classes Employee, SSNLengthException, and SSNCharacterException. Derive the class Employee from the class Person in Listing 8.1 of Chapter 8. Among other things, the class Employee should have input and output methods, as well as constructors, accessor methods, and mutator methods. Every Employee object should record the employee's name (as defined in Person), salary, and Social Security number, as well as any other data you need or think is appropriate.
- 7. Create a JavaFX application that implements a short survey. The first question should ask the user for his or her favorite color and present the choices "red", "orange", "blue", and "green" in radio buttons. The second question should ask the user for his or her age and present the choice in a spinner with the range 10–100. The third and final question should ask the user to select his or her favorite programming language from the choices "Java", "C++", "Python", and "C#" presented in a

**Graphics** 

choice box. Add a button, that when clicked, summarizes the user's selections.

**Graphics** 

8. Modify the Bouncing Ball example from Listing 9.18, except instead of animating a red circle, animate an image of your choice.

Graphics

- 9. Write a JavaFX program that moves an image toward the location of the mouse. The image shouldn't jump directly to the mouse coordinates (which is what happens in Listing 9.16) but should move a few pixels toward the mouse location every time cycle. You can choose the time cycle to control the speed of the animation.
- 10. Suppose that you are in charge of customer service for a certain business. As phone calls come in, the name of the caller is recorded and eventually a service representative returns the call and handles the request. Write a class ServiceRequests that keeps track of the names of callers. The class should have the following methods:
  - addName(name)—adds a name to the list of names. Throws a ServiceBackUpException if there is no free space in the list.
  - removeName(name)—removes a name from the list. Throws a NoServiceRequestException if the name is not in the list.
  - getName(i)—returns the ith name in the list.
  - getNumber—returns the current number of service requests.

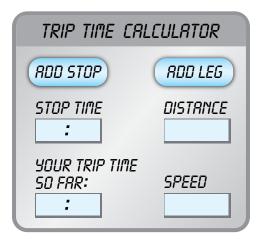
Write a program that uses an object of type ServiceRequests to keep track of customers that have called. It should have a loop that, in each iteration, attempts to add a name, remove a name, or print all names. Use an array of size 10 as the list of names.

**Graphics** 

- 11. Write an application that implements a trip-time calculator. Define and use a class TripComputer to compute the time of a trip. TripComputer should have the private attributes
  - totalTime—the total time for the trip
  - restStopTaken—a boolean flag that indicates whether a rest stop has been taken at the end of the current leg

and the following methods:

- computeLegTime(distance, speed)—computes the time for a leg of the trip having a given distance in miles and speed in miles per hour. If either the distance or the speed is negative, throws an exception.
- takeRestStop(time)—takes a rest stop for the given amount of time. If the time is negative, throws an exception. Also throws an exception if the client code attempts to take two rest stops in a row.
- getTripTime—returns the current total time for the trip.
- Here is one possible configuration of the labels, buttons, and text fields required by the trip-time calculator:



#### **Answers to Self-Test Questions**

 Try block entered. Exception: Time Limit Exceeded. After catch block.

Try block entered. Leaving try block. After catch block.

3. An exception is an object. For example, in the following code, Exception is a constructor for the class Exception:

```
throw new Exception("Time Limit Exceeded.");
The expression
new Exception("Time Limit Exceeded.");
creates an exception object.
```

- 4. Yes, it is perfectly valid, although it is unlikely that you would ever have a good reason to use it.
- 5. The behavior would not change. The new code is equivalent to the old code it replaces.
- 6. throw new Exception("Time Limit Exceeded.");

Note that the following is an if statement, not a throw statement, even though it contains a throw statement:

```
if (waitTime> 30)
    throw new Exception("Time Limit Exceeded.");
```

7. When a throw statement is executed, the enclosing try block ends; no other statements in the try block are executed. Control passes to the subsequent catch block whose parameter matches the exception object in type. Execution continues with the statements in that catch block.

- 10. e is the catch-block parameter.
- 11. No. The catch-block parameter e is just a place holder and can be replaced by any other valid identifier, such as messenger.

13. Yes, they are perfectly legal, although you would be more likely to write the following instead:

```
throw new IOException("Hello Houston!");
```

In practice, this throw statement would typically be included in some branching statement, such as an if statement.

14. Yes, it is legal.

```
super("Message Too Long!");
}
public MessageTooLongException(String message)
{
    super(message);
}
```

17. ExerciseException invoked with an argument.

Do Be Do

- 18. Wow, Crazy exception thrown! Crazy exception thrown! Message is Crazy exception thrown!
- 19. try block entered:
   DoubleException thrown! DoubleException thrown!
   End of code.
- 20. The output would not change at all. The modified program is completely equivalent to the original program.
- 21. The output would change to the following:

```
try block entered:
Leaving try block.
End of code.
```

22. 42
IntException thrown!

- 23. An exception class can be a derived class of any exception class, predefined or programmer defined. In particular, you can derive an exception class from the predefined class IOException.
- 24. Add the throws clause to the method's heading, as follows: public void doStuff(int n) throws Exception
- 25. Since the code evidently has compiled, we must assume that the method declares the exception in a throws clause. If you did not handle the exception by enclosing the method invocation within a try block and writing an appropriate catch block, the method invocation ends immediately after the exception is thrown. If the method invocation is inside a try block, the exception is thrown to a corresponding catch block, if there is one. If there is no catch block that corresponds to the exception, you have an uncaught exception, and the method invocation ends as soon as that exception is thrown.
- 26. It might be caught either in method B or, if not there, in method A or, if not in A, outside of method A.
- 27. Second catch. End of code.

- 28. First catch. End of code.
- 29. Hello! End of code.
- 30. Trying
  Starting sampleMethod.
  Catching
  From sampleMethod with love.
- 31. Yes. However, it would probably be better to place the inner try and catch blocks within a method definition and invoke the method within the larger try block.
- 32. Yes. However, it would probably be better to place the inner try and catch blocks within a method definition and invoke the method within the larger catch block.
- 33. Output for argument 99 is

```
In finally block.
Caught in main.
```

Output for argument -99 is

Caught in sampleMethod. In finally block. After finally block.

Output for argument 0 is

```
No exception.
Still in sampleMethod.
In finally block.
After finally block.
```

```
34. public double getPrecision()
{
        return precision;
}
public void setPrecision(double newPrecision)
{
        precision = newPrecision;
}
```

- 35. The program would end as soon as an UnknownOpException was thrown.
- 36. Radio buttons, choice box, or a spinner can be used to select one option.
- 37. The radio buttons will not be exclusive. You can select all three of the radio buttons.
- 38. The Pane class supports absolute positioning.

# Streams, File I/O, and Networking

## 10.1 AN OVERVIEW OF STREAMS AND FILE I/O 787

The Concept of a Stream 787 Why Use Files for I/O? 788 Text Files and Binary Files 788

#### **10.2 TEXT-FILE I/O** 790

Creating a Text File 790

Appending to a Text File 796

Reading from a Text File 798

## **10.3 TECHNIQUES FOR ANY FILE** 801

The Class File 801

Programming Example: Reading a File Name from the Keyboard 801

Using Path Names 803

Methods of the Class File 804

Defining a Method to Open a Stream 806

Case Study: Processing a Comma-Separated Values File 808

#### 10.4 BASIC BINARY-FILE I/O 811

Creating a Binary File 811
Writing Primitive Values to a Binary File 813
Writing Strings to a Binary File 816
Some Details About writeUTF 817
Reading from a Binary File 818
The Class EOFException 824
Programming Example: Processing a File of Binary Data 826

# 10.5 BINARY-FILE I/O WITH OBJECTS AND ARRAYS 831

Binary-File I/O with Objects of a Class 831 Some Details of Serialization 835 Array Objects in Binary Files 836

# 10.6 NETWORK COMMUNICATION WITH STREAMS 839

#### 10.7 GRAPHICS SUPPLEMENT 845

Programming Example: A JavaFX GUI for Manipulating Files 845

-WILLIAM SHAKESPEARE, Henry VI, Part II

I/O refers to program input and output. Input can be taken from the keyboard or from a file. Similarly, output can be sent to the screen or to a file. In this chapter, we explain how you can write your programs to take input from a file and send output to a file. By doing so, you will be able to retain your data and objects long after your program ends its execution.

#### **OBJECTIVES**

After studying this chapter, you should be able to

- Describe the concept of an I/O stream
- Explain the difference between text files and binary files
- Save data, including objects, in a file
- Read data, including objects, from a file
- Transmit data over a network

## **PREREQUISITES**

You will need some knowledge of exception handling, as described in Chapter 9, to understand this chapter. Having some knowledge of inheritance will also be helpful. Only Section 10.5 and the Case Study in Section 10.3 of this chapter actually require that you know about arrays, interfaces, and inheritance (covered in Chapters 7 and 8). You can, of course, skip this section until you learn about these topics. You may cover Section 10.3 after Section 10.4 and 10.5 if you wish. Many readers may choose to skip the coverage of binary files. Only selected Programming Projects in the rest of this book require knowledge of anything covered in this chapter.

Details of the prerequisites are as follows:

Section	Prerequisite					
10.1 An Overview of Streams and File I/O	Chapters 1 through 6.					
10.2 Text-File I/O	Sections 9.1 and 10.1. Also some knowledge of inheritance from Chapter 8.					
10.3 Techniques for Any File	Section 10.2 and Chapter7 for the Case Study.					
10.4 Basic Binary-File I/O	Sections 9.2 and 10.2. You do not need Section 10.3.					

10.5 Binary-File I/O with Objects and Arrays	Section 10.4 and Chapters 7 and 8. You do not need Section 10.3.				
10.6 Network Communication with Streams	Sections 9.1, 10.1, and 10.2.				
10.7 Graphics Supplement	Sections 9.4 and 10.3.				

## 10.1 AN OVERVIEW OF STREAMS AND FILE I/O

Fish say, they have their Stream and Pond, But is there anything Beyond?

—RUPERT BROOKE, Heaven

In this section, we give you a general introduction to file I/O. In particular, we explain the difference between text files and binary files. The Java syntax for file I/O statements is given in subsequent sections of this chapter.

# The Concept of a Stream

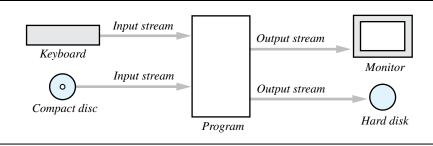
You are already using files to store your Java classes and programs, your music, your pictures, and your videos. You can also use files to store input for a program or to hold output from a program. In Java, file I/O, as well as simple keyboard and screen I/O, is handled by streams. A **stream** is a flow of data. The data might be characters, numbers, or bytes consisting of binary digits. If the data flows *into your program*, the stream is called an **input stream**. If the data flows *out of your program*, the stream is called an **output stream**. For example, if an input stream is connected to the keyboard, the data flows from the keyboard into your program. If an input stream is connected to a file, the data flows from the file into your program. Figure 10.1 illustrates some of these streams.

In Java, streams are implemented as objects of special stream classes. Objects of the class Scanner, which we have been using for keyboard input, are input streams. The object System.out is an example of an output stream

Files can store programs, music, pictures, video, and so on

A stream is a flow of data into or out of a program

FIGURE 10.1 Input and Output Streams



that we have also used. In this chapter, we discuss streams that connect your program to files instead of to the keyboard or display.

#### **RECAP Streams**

A stream is an object that either

- Delivers data from your program to a destination, such as a file or the screen, or
- Takes data from a source, such as a file or the keyboard, and delivers the data to your program.

# Why Use Files for I/O?

The keyboard input and screen output we have used so far deal with temporary data. When the program ends, the data typed at the keyboard and left on the screen go away. Files provide you with a way to store data permanently. The contents of a file remain until a person or program changes the file.

An input file can be used over and over again by different programs, without the need to type the data again for each program. Files also provide you with a convenient way to deal with large quantities of data. When your program takes its input from a large input file, it receives a lot of data without user effort.

# **Text Files and Binary Files**

All of the data in any file is stored as binary digits (bits)—that is, as a long sequence of 0s and 1s. However, in some situations, we do not think of a file's contents as a sequence of binary digits. Instead, we think of them as a sequence of characters. Files that are thought of as sequences of characters, and that have streams and methods to make the binary digits look like characters to your program and your text editor, are called **text files**. All other files are called **binary files**. Each kind of file has its own streams and methods to process them.

Your Java programs are stored in text files. Your music files and picture files are binary files. Since text files are sequences of characters, they usually appear the same on all computers, so you can move your text files from one computer to another with few or no problems. The contents of binary files are often based on numbers. The structure of some binary files is standardized so that they can also be used on a variety of platforms. Many picture files and music files fall into this category.

Java programs can create or read both text files and binary files. Writing a text file and writing a binary file require similar steps. Likewise, reading a text file is similar to reading a binary file. The kind of file, however, determines which classes we use to perform the input and output.

Data in a file remains after program execution ends

Two kinds of files: text files and binary files The one big advantage of text files is that you can create, look at, and edit them by using a text editor. You have already done this when writing a Java program. With binary files, all the reading and writing must normally be done by a special program. Some binary files must be read by the same type of computer and with the same programming language that originally created them. However, Java binary files are platform independent; that is, with Java, you can move your binary files from one type of computer to another, and your Java programs will still be able to read the binary files.

Each character in a text file is represented as 1 or 2 bytes, depending on whether the system uses ASCII or Unicode. When a program writes a value to a text file, the number of characters written is the same as if they were written to a display using System.out.println. For example, writing the int value 12345 to a text file places five characters in the file, as shown in Figure 10.2. In general, writing an integer places between 1 and 11 characters in a text file.

Binary files store all values of the same primitive data in the same format. Each is stored as a sequence of the same number of bytes. For example, all int values occupy 4 bytes each in a binary file, as Figure 10.2 also illustrates. A Java program interprets these bytes in very much the same way that it interprets a data item, such as an integer, in the computer's main memory. That is why binary files can be handled so efficiently.

## FAQ Should I use a text file or a binary file?

Use a text file if you want a text editor to either create a file that a program will read or read a file that a program created. In other cases, consider a binary file, as it usually occupies less space.

# **REMEMBER** Input and Output Terminology

The word *input* means that data moves into your program, not into the file. The word *output* means that data moves out of your program, not out of the file.

FIGURE 10.2 Text File and a Binary File Containing the Same Values

A text file													
	1	2	3	4	5		_	4	0	2	7	8	•••
A binary file													
	123	345	-40	72	8		• • •						



## **SELF-TEST QUESTIONS**

- 1. Why would anybody write a program that sends its output to a file instead of to the screen?
- 2. When we discuss input, are we referring to data moving from the program to a file or from a file to the program?
- 3. What is the difference between a text file and a binary file?

#### **10.2** TEXT-FILE I/O

Proper words in proper places, make the true definition of a style.

—JONATHAN SWIFT, Letter to a Young Clergyman (January 9,1720)

In this section, we give a description of the most common ways to perform text-file I/O in Java.

# Creating a Text File

The class PrintWriter in the Java Class Library defines the methods that we will need to create and write to a text file. This class is the preferred one for writing to a text file. It is in the package java.io, so we will need to begin our program with an import statement. Actually, we will be using other classes as well, so we will import them also, as you will see soon.

Before we can write to a text file, we must connect it to an output stream. That is, we **open** the file. To do this, we need the name of the file as a string. The file has a name like out.txt that the operating system uses. We also must declare a variable that we will use to reference the stream associated with the actual file. This variable is called the **stream variable**. Its data type in this case is PrintWriter. We open a text file for output by invoking PrintWriter's constructor and passing it the file name as its argument. Since this action can throw an exception, we must place the call to the constructor within a try block.

The following statements will open the text file out.txt for output:

```
String fileName = "out.txt";//Could read file name from user
PrintWriter outputStream = null;
try
{
    outputStream = new PrintWriter(fileName);
}
catch(FileNotFoundException e)
{
    System.out.println("Error opening the file " + fileName);
    System.exit(0);
}
```

Opening a file connects it to a stream

The class FileNotFoundException must also be imported from the package java.io.

File name versus stream variable

Note that the name of the file, in this case out.txt, is given as a String value. Generally, we would read the name of the file instead of using a literal. We pass the file name as an argument to the PrintWriter constructor. The result is an object of the class PrintWriter, which we assign to our stream variable outputStream.

When you connect a file to an output stream in this way, your program always starts with an empty file. If the file out.txt already exists, its old contents will be lost. If the file out.txt does not exist, a new, empty file named out.txt will be created.

Because the PrintWriter constructor might throw a FileNotFoundException while attempting to open the file, its invocation must appear within a try block. Any exception is caught in a catch block. If the constructor throws an exception, it does not necessarily mean that the file was not found. After all, if you are creating a new file, it doesn't already exist. In that case, an exception would mean that the file could not be created because, for example, the file name was already being used for a folder (directory) name.

After we open the file—that is, connect the file to the stream—we can write data to it. The method println of the class PrintWriter works the same for writing to a textfile as the method System.out.println works for writing to the screen. PrintWriter also has the method print, which behaves just like System.out.print, except that the output goes to a text file.

Now that the file is open, we always refer to it by using the stream variable, not its name. Our stream variable outStream references the output stream—that is, the PrintWriter object—that we created, so we will use it when we invoke println. Notice that outStream is declared outside of the try block so that it is available outside of the block. Remember, anything declared in a block—even within a try block—is local to the block.

Let's write a couple of lines to the text file. The following statements would come after the previous statements that opened the file:

```
outputStream.println("This is line 1.");
outputStream.println("Here is line 2.");
```

Rather than sending output to a file immediately, PrintWriter waits to send a larger packet of data. Thus, the output from a println statement, for example, is not sent to the output file right away. Instead, it is saved and placed into an area of memory called a **buffer**, along with the output from other invocations of print and println. When the buffer is too full to accept more output, its contents are written to the file. Thus, the output from several println statements is written at the same time, instead of each time a println executes. This technique is called **buffering**; it allows faster file processing.

After we finish writing the entire text file, we disconnect the stream from the file. That is, we **close** the stream connected to the file by writing

```
outputStream.close();
```

Closing a file disconnects it from a stream

Closing the stream causes the system to release any resources used to connect the stream to the file and to do some other housekeeping. If you do not close a stream, Java will close it for you when the program ends. However, it is safest to close the stream by explicitly calling the method close. Recall that when you write data to a file, the data might not immediately reach its destination. Closing an output stream forces any pending output to be written to the file. If you do not close the stream and your program terminates abnormally, Java might not be able to close it for you, and data can be lost. The sooner you close a stream, the less likely it is that this will happen.

If your program writes to a file and later reads from the same file, it must close the stream after it is through writing to the file and then reopen the file for reading. (Java does have a class that allows a file to be open for both reading and writing, but we will not cover that class in this book.) Note that all stream classes, such as PrintWriter, include a method named close.

The calls to println and close need not be within a try block, as they do not throw exceptions that must be caught. Listing 10.1 contains a simple but complete program that creates a text file from data read from the user. Notice that the lines shown in the resulting text file look just as they would if we wrote them to the screen. We can read this file either by using a text editor or by using another Java program that we will write a little later.

LISTING 10.1 Writing Output to a Text File (part 1 of 2)

```
import java.io.PrintWriter;
import java.io.FileNotFoundException;
import java.util.Scanner;
public class TextFileOutputDemo
    public static void main(String[] args)
    {
        String fileName = "out.txt"; //The name could be read from
                                     //the kevboard.
        PrintWriter outputStream = null;
        try
        {
            outputStream = new PrintWriter(fileName);
        catch(FileNotFoundException e)
            System.out.println("Error opening the file" +
                                 fileName):
            System.exit(0);
        }
                                                          (continued)
```

# LISTING 10.1 Writing Output to a Text File (part 2 of 2)

```
System.out.println("Enter three lines of text:");
Scanner keyboard = new Scanner(System.in);
for (int count = 1; count <= 3; count++)
{
    String line = keyboard.nextLine();
    outputStream.println(count + " " + line);
}
outputStream.close();
System.out.println("Those lines were written to " +
    fileName);
}</pre>
```

#### Sample Screen Output

```
Enter three lines of text:
A tall tree
in a short forest is like
a big fish in a small pond.
Those lines were written to out.txt
```

# Resulting file

```
1 A tall tree
2 in a short forest is like
3 a big fish in a small pond.

You can use a text editor to read this file.
```

# **RECAP** Creating a Text File

#### **SYNTAX**

```
// Open the file PrintWriter
Output_Stream_Name = null;
try
{
    Output_Stream_Name = new PrintWriter(File_Name);
}
catch(FileNotFoundException e)
{
    Statements_Dealing_With_The_Exception
}
(continued)
```

```
// Write the file using statements of either or both of the
// following forms:
Output_Stream_Name.println(...);
Output_Stream_Name.print(...);
// Close the file
Output_Stream_Name.close();
EXAMPLE
See Listing 10.1.
```

# PROGRAMMING TIP A Program Should Not Be Silent

A program that creates a file should inform the user when it has finished writing the file. Otherwise, you will have written a **silent program**, and the user will wonder whether the program has succeeded or has encountered a problem. This advice applies to both text files and binary files.

### **REMEMBER** A File Has Two Names in a Program

Every file used by a program, whether for input or for output, appears to have two names: the actual file name used by the operating system and the name of the stream that is connected to the file. The file name is used when connecting the file to a stream. The stream name is used thereafter to work with the file. The stream name does not exist after the program ends its execution, but the actual file name persists. Note that, since a stream variable can have aliases, a file actually can have more than two names. However, distinguishing between a file name and a stream name is what is important here.

#### **FAQ** What are the rules for naming files?

The rules for how you spell file names depend on your operating system, not on Java. When you pass a file name to a Java constructor for a stream, you are not giving the constructor a Java identifier. You are giving the constructor a string corresponding to the file name. Most common operating systems allow you to use letters, digits, and the dot symbol when spelling file names. Many operating systems allow other characters as well, but letters, digits, and the dot symbol are enough for most purposes. A suffix, such as .txt in out.txt, has no special meaning to a Java program. We are using the suffix to indicate a text file, but that is just a common convention. You can use any file names that are allowed by your operating system, but you should be aware that some operating systems will hide the suffix by default.

## **GOTCHA** A try Block Is a Block

Look again at the program in Listing 10.1. It is not an accident or a minor stylistic concern that caused us to declare the variable outputStream outside the try block. Suppose we were to move that declaration inside the try block, like this:

```
try
{
    PrintWriter outputStream = new PrintWriter(fileName);
}
```

This replacement looks innocent enough, but it makes outputStream a local variable in the try block. Thus, we would not be able to use outputStream outside the try block. If we did, we would get an error message saying that outputStream is an undefined identifier.

Chapter 8 suggested that you define a method toString in your classes. This method returns a string representation of the data in an instance of the class. The methods print and println of System.out invoke toString automatically when given an object as an argument. This is also true for print and println of an object of PrintWriter.

For example, we could add a toString method to the class Species in Chapter 5. Recall that this class defines three instance variables: name, population, and growthRate. Thus, we could define toString, as follows:

Overriding to String in the class Species

```
public String toString()
        return ("Name = " + name + "\n" +
                 "Population = " + population + "\n" +
                 "Growth rate = " + growthRate + "%");
    }
Now, if we write the statements
    Species oneRecord = new Species("Calif. Condor", 27, 0.02);
    System.out.println(oneRecord.toString());
in a program, they will produce the output
    Name = Calif. Condor
    Population = 27
    Growth rate = 0.02\%
We also know that
    System.out.println(oneRecord);
will invoke automatically, and so it will produce the same output.
   The same is true if we were to write to a text file. Either of the statements
```

outputStream.println(oneRecord.toString());

or

```
outputStream.println(oneRecord);
```

will write the previously shown output to the text file attached to the stream outputStream.

Extra code on the Web

The program in the file TextFileSpeciesOutputDemo, which is in the source code available on the book's Web site, illustrates this fact.

# PROGRAMMING TIP Define the Method toString for Your Classes

Since the methods print and println automatically invoke the method toString, regardless of whether they belong to the object System.out or to an object of an output stream, it is a good idea to define toString for your classes.

# **GOTCHA** Overwriting a File

When you open a text file or a binary file for output, you always begin with an empty file. If no existing file has the given name, the constructor that you invoke will create an empty file with that name. But if an existing file has the given name, all of its data will be eliminated. Any new output will be written to this existing file. Section 10.3 shows how to test for the existence of a file so that you can avoid accidentally overwriting it.

# Appending to a Text File

The way we opened a text file for output in Listing 10.1 ensures that we always begin with an empty file. If the named file already exists, its old contents will be lost. Sometimes, however, that is not what we want. We may simply want to add, or **append**, more data to the end of the file. To append program output to the text file named by the String variable fileName, we would connect the file to the stream outputStream as follows:

```
outputStream =
    new PrintWriter(new FileOutputStream(fileName, true));
```

Since PrintWriter does not have an appropriate constructor for this task, we need some help from the class FileOutputStream, which we must import from the package java.io. The second argument (true) of FileOutputStream's constructor indicates that we want to add data to the file, if it exists already. So if the file already exists, its old contents will remain, and the program's output will be placed after those contents. But if the file does not already exist, Java will create an empty file of that name and append the output to the end of this empty file. The effect in this case is the same as in Listing 10.1.

Appending, or adding, data to the end of a file

When appending to a text file in this way, we would still use the same try and catch blocks as in Listing 10.1. A version of the program in Listing 10.1 that appends to the file out.txt is in the program AppendTextFile.java included with the source code for this book available on the Web.

Extra code on the Web

#### **RECAP** Opening a Text File for Appending

You can create a stream of the class PrintWriter that appends data to the end of an existing text file.

#### **SYNTAX**

```
PrintWriter Output_Stream_Name = new PrintWriter(new
FileOutputStream(File_Name, true));
```

#### **EXAMPLE**

```
PrintWriter outputStream = new PrintWriter(new
FileOutputStream("out.txt", true));
```

After this statement, you can use the methods println and print to write to the file, and the new text will be written after the old text in the file. (In practice, you might want to separate the declaration of the stream variable and the invocation of the constructor, as we did in Listing 10.1, so you can handle a FileNotFoundException that might be thrown when opening the file.)

# **SELF-TEST QUESTIONS**

- 4. Write some code that will create a stream named outStream that is an object of the class PrintWriter and that connects this stream to a text file named sam.txt so that your program can send output to the file. If the file sam.txt does not exist, create a new empty file. However, if a file named sam.txt already exists, erase its old contents so the program can start with an empty file with that name.
- 5. Repeat Question 4, but if the file sam.txt exists already, write the new data after the old contents of the file.
- 6. Repeat Question 4, but read the name of the file from the user.
- 7. What kind of exception might be thrown by the following statement, and what would be indicated if this exception were thrown?

```
PrintWriter outputStream = new PrintWriter("out.txt");
```

# Reading from a Text File

Listing 10.2 contains a simple program that reads data from a text file and writes it to the screen. The file out.txt is a text file that could have been created by either a person using a text editor or a Java program—such as the one in Listing 10.1—using the class PrintWriter. Notice that we use the class

## LISTING 10.2 Reading Data from a Text File

```
import java.util.Scanner;
import java.io.File;
import java.io.FileNotFoundException;
public class TextFileInputDemo
    public static void main(String[] args)
        String fileName = "out.txt";
        Scanner inputStream = null;
        System.out.println("The file " + fileName +
                            "\ncontains the following lines:\n");
        try
        {
            inputStream = new Scanner(new File(fileName));
        catch(FileNotFoundException e)
        {
            System.out.println("Error opening the file " +
                                 fileName);
            System.exit(0);
        }
        while (inputStream.hasNextLine())
            String line = inputStream.nextLine();
            System.out.println(line);
        inputStream.close();
    }
}
```

#### Screen Output

```
The file out.txt
contains the following lines;
1 A tall tree
2 in a short forest is like
3 a big fish in a small pond.
```

Scanner, the same class we have been using to read data from the keyboard. Recall that we passed System.in as an argument to Scanner's constructor.

Unfortunately, we cannot pass a file name to Scanner's constructor. Although Scanner does have a constructor that takes a string argument, the string is interpreted as data, and not the name of a file. Scanner, however, does have a constructor that accepts as an argument an instance of another standard class, File, and File has a constructor to which we can pass a file name. (The next section will describe the class File in more detail.) So a statement of the following form will open the file for input:

```
Scanner Stream_Name = new Scanner(new File(File_Name));
```

If your program attempts to open a file for reading, but there is no such file, Scanner's constructor will throw a FileNotFoundException. As you saw earlier in this chapter, a FileNotFoundException is also thrown in certain other situations.

Using Scanner to open a text file for input

Notice that the program in Listing 10.2 has some general similarities to the program in Listing 10.1 that created a text file. Each opens the file using try-catch blocks, does something with the file, and then closes the file. Let's look at the statements in Listing 10.2 that read and display the entire file:

```
while (inputStream.hasNextLine())
{
    String line = inputStream.nextLine();
    System.out.println(line);
}
```

Reading and displaying an entire text file

This loop reads and then displays each line in the file, one at a time, until the end of the file is reached. The screen output shown in Listing 10.2 assumes that the file out.txt is the one we created in Listing 10.1.

All the methods of Scanner that we have used before are still available to us and work in the same way. Some of these methods, including nextLine, are described in Figure 2.7 of Chapter 2. However, we have not used the method hasNextLine before. It returns true if another line in the file is available for input. Figure 10.3 summarizes this method and a few other analogous methods.

```
RECAP Reading a Text File

SYNTAX

// Open the file
    Scanner Input_Stream_Name = null;
    try
    {
        Input_Stream_Name = new Scanner(new File(File_Name));
    }
    (continued)
```



```
catch(FileNotFoundException e)
{
    Statements_Dealing_With_The_Exception
}
// Read the file using statements of the form:
    Input_Stream_Name.Scanner_Method();
// Close the file
    Input_Stream_Name.close();

EXAMPLE
See Listing 10.2.
```

# FIGURE 10.3 Additional Methods in the Class Scanner (See also Figure 2.7)

```
Scanner_Object_Name . hasNext()
Returns true if more input data is available to be read by the method next.

Scanner_Object_Name . hasNextDouble()
Returns true if more input data is available to be read by the method nextDouble.

Scanner_Object_Name . hasNextInt()
Returns true if more input data is available to be read by the method nextInt.

Scanner_Object_Name . hasNextLine()
Returns true if more input data is available to be read by the method nextInt.
```

# **SELF-TEST QUESTIONS**

- 8. Write some code that will create a stream named textStream that is an object of the class PrintWriter and that connects the stream to a text file named dobedo so that your program can send output to this file.
- 9. Suppose you run a program that writes to the text file dobedo, using the stream defined in the previous self-test question. Write some code that will create a stream named inputStream that can be used to read from this text file in the ways we discussed in this section.
- 10. What is the type of a value returned by the method next in the class Scanner? What is the type of a value returned by the method nextLine in the class Scanner?

# **10.3** TECHNIQUES FOR ANY FILE

An ounce of prevention is worth a pound of cure.

—COMMON SAYING

This section discusses some techniques that we can use with both text files and binary files, even though our examples here will involve text files. We begin by describing the standard class File, which we used in the previous section when reading from a text file.

#### The Class File

The class File provides a way to represent file names in a general way. A string such as "treasure.txt" might be a file name, but it has only string properties, and Java does not recognize it as a file name. On the other hand, if you pass a file name as a string to the constructor of the class File, it produces an object that can be thought of as the name of a file. In other words, it is a system-independent abstraction rather than an actual file. For example, the object

new File("treasure.txt")

is not simply a string. It is an object that "knows" it is supposed to name a file.

Although some stream classes have constructors that accept a string as the name of a file, some do not. Some stream classes have constructors that accept only a File object as an argument. We already saw in the previous section that when reading a text file, we cannot pass the file's name as a string to Scanner's constructor. Instead, we passed it an object of the class File. The class PrintWriter, which we used to write a text file, has a constructor that accepts a string as the name of a file, as well as a constructor that accepts an instance of File to specify a particular file.

Before we go on to describe some of File's methods, let's look at an example that reads the name of a file from the user. Although our example uses a text file, we can do something similar with binary files.

**PROGRAMMING EXAMPLE** 

Reading a File Name from the Keyboard

Thus far, we have assigned a quoted string to a String variable and used it as the file name in our programs. However, you might not know what the file name will be when you write a program, so you may want to have the user enter the file name at the keyboard when the program is run. This task is easy to do. Simply have the program read the file name into the String variable. This technique is illustrated in Listing 10.3. That program is just like the one in

A File object represents the name of a file

Let the user enter the file name at the keyboard Listing 10.2, but it replaces the assignment to filename with statements that read the file name from the keyboard.

#### LISTING 10.3 Reading a File Name and Then the File

```
import java.util.Scanner;
import java.io.File;
import java.io.FileNotFoundException;
public class TextFileInputDemo2
    public static void main(String[] args)
    {
        System.out.print("Enter file name: ");
        Scanner keyboard = new Scanner(System.in);
        String fileName = keyboard.next();
        Scanner inputStream = null;
        System.out.println("The file " + fileName + "\n" +
                            "contains the following lines:\n");
        try
        {
            inputStream = new Scanner(new File(fileName));
        catch(FileNotFoundException e)
        {
            System.out.println("Error opening the file " +
                                fileName");
            System.exit(0).
        while (inputStream.hasNextLine())
        {
            String line = inputStream.nextLine();
            System.out.println(line);
        inputStream.close();
    }
}
```

#### Sample Screen Output

```
Enter file name: out.txt
The file out.txt
contains the following lines:
1 A tall tree
2 in a short forest is like
3 a big fish in a small pond.
```

Notice that our new program reads input from two different places. The Scanner object named keyboard is used to read the name of the file from the keyboard. The Scanner object named inputStream is connected to the specified file and is used to read data from that file.

# **Using Path Names**

When writing a file name as an argument to a constructor for opening a file in any of the ways we have discussed, the file is assumed to be in the same directory (folder) as the one in which the program is run. However, we could specify the directory that contains the file, if it is different than the location of the program, by writing a path name instead of only the name of the file. A full path name, as the name suggests, gives a complete path name, starting from the root directory. A relative path name gives the path to the file, starting with the directory containing your program. The way you specify path names depends on your particular operating system, and we will discuss only some of the details here.

A path name specifies the folder containing a file

An example of a typical UNIX path name is

/user/smith/homework1/data.txt

To create an input stream connected to this file, we would write

Windows uses \ instead of / in path names. A typical Windows path name is

```
C:\homework\hw1\data.txt
```

To create an input stream connected to this file, we would write

Notice that we must use \\ in place of \, as Java will otherwise interpret a backslash paired with another character—for example, \h—as an escape character.

Although we normally must be careful about using a backslash in a quoted string, this problem does not occur when reading a name from the keyboard. Suppose we run a program like the one in Listing 10.3, and suppose part of the dialogue with the user is as follows:

```
Enter file name:
C:\homework\hw1\data.txt
```

This path name will be understood. The user need not type double backslashes, as in

```
C:\\homework\\hw1\\data.txt
```

In fact, the use of \\ in input might produce an incorrect reading of the file name. When the user enters input at the keyboard, Java "understands" that \h is the backslash character followed by an h and not an escape character, because everything the user types consists of characters.

One way to avoid these escape-character problems altogether is always to use UNIX conventions when writing path names. A Java program will accept a path name written in either Windows or UNIX format, even if it is run on a computer whose operating system does not match the format used. Thus, an alternative way to create an input stream connected to the Windows file

# Methods of the Class File

You can use methods of the class File to check properties of files. You can check things like whether an existing file either has a specified name or is readable.

Suppose you create a File object and name it fileObject using the following code:

```
File fileObject = new File("treasure.txt");
```

Recall that a File object is not a file. Rather, fileObject is a system-independent abstraction of a file's path name—treasure.txt, in this case.

After creating fileObject, you can then use the File method exists to test whether any existing file has the name treasure.txt. For example, you can write

```
if (!fileObject.exists())
    System.out.println("No file by that name.")
```

If there already is such a file, you can use the method canRead to see whether the operating system will let you read from the file. For example, you can write

```
if (!fileObject.canRead())
    System.out.println("Not allowed to read from that file.");
```

Most operating systems let you designate some files as not readable or as readable only by certain users. The method canRead provides a good way to check whether you or somebody else has made a file nonreadable—either inadvertently or intentionally.

We could add the following statements to the program shown in Listing 10.3 to check that we have a text file ready as input, right after we read the file's name:

A File object can check whether a file by that name exists or is readable

Files can be tagged as readable or not readable

```
File fileObject = new File(fileName);
boolean fileOK = false;
while (!fileOK)
{
    if (!fileObject.exists())
        System.out.println("No such file");
    elseif (!fileObject.canRead())
        System.out.println("That file is not readable.");
    else
        fileOK = true;
    if (!fileOK)
    {
        System.out.println("Enter file name again:");
        fileName = keyboard.next();
        fileObject = new File(fileName);
    }
}
```

We have made this change to the program in Listing 10.3 and saved it in the file FileClassDemo.java, which is included in the source code for this book on its Web site.

Extra code on the Web

The method canWrite is similar to canRead, except that the former checks to see whether the operating system will allow you to write to the file. Most operating systems let you designate some files as not writable or as writable only by certain users. Figure 10.4 lists these methods and some others that are in the class File.

#### **RECAP The Class** File

The class File represents file names. The constructor for the class File takes a string as an argument and produces an object that can be thought of as the file with that name. You can use the File object and methods of the class File to answer questions such as the following: Does the file exist? Does your program have permission to read the file? Does your program have permission to write to the file? Figure 10.4 summarizes some of the methods for the class File.

#### **EXAMPLE**

#### FIGURE 10.4 Some Methods in the Class File

#### public boolean canRead()

Tests whether the program can read from the file.

#### public boolean canWrite()

Tests whether the program can write to the file.

#### public boolean delete()

Tries to delete the file. Returns true if it was able to delete the file.

#### public boolean exists()

Tests whether an existing file has the name used as an argument to the constructor when the File object was created.

#### public String getName()

Returns the name of the file. (Note that this name is not a path name, just a simple file name.)

#### public String getPath()

Returns the path name of the file.

#### public long length()

Returns the length of the file, in bytes.

### FAQ What is the difference between a file and a File object?

A file is a collection of data stored on a physical device such as a disc. A File object is a system-independent abstraction of a file's path name.



# **SELF-TEST QUESTION**

11. Write a complete Java program that asks the user for a file name, tests whether the file exists, and—if the file does exist—asks the user whether or not it should be deleted and then does as the user requests.

# Defining a Method to Open a Stream

Imagine that we want to write a method that opens a file. We will use a text file here and open it for output, but the idea is applicable to any kind of file. Our method has a String parameter that represents the file name, which could be either a literal or a string read from the user, as shown earlier. The following method creates an output stream, connects it to the named text file, and returns the stream:

```
public static PrintWriter openOutputTextFile
    (String fileName) throws FileNotFoundException
{
    PrintWriter toFile = new PrintWriter(fileName);
    return toFile;
}
We could invoke this method as follows:
PrintWriter outputStream = null;
try
{
    outputStream = openOutputTextFile("data.txt");
}
<appropriate catch block(s)>
```

and go on to use outputStream to write to the file. A simple program demonstrating this technique is in the file OpenFileDemo.java included with the source code for this book available on the Web.

Extra code on the Web

What if we had written the method as a void method so that instead of returning an output stream, it had the stream as a parameter? The following method looks reasonable, but it has a problem:

```
// This method does not do what we want it to do.
public static void openFile(String fileName,
    PrintWriter stream) throws FileNotFoundException
{
    stream = new PrintWriter(fileName);
}
```

Let's consider, for example, the following statements that invoke the method:

```
PrintWriter toFile = null;
try
{
    openFile("data.txt", toFile);
}
```

After this code is executed, the value of toFile is still null. The file that was opened in the method openFile went away when the method ended. The problem has to do with how Java handles arguments of a class type. These arguments are passed to the method as memory addresses that cannot be changed. The state of the object at the memory address normally can be changed, but the memory address itself cannot be changed. Thus, you cannot change the value of toFile.

This applies only to arguments of methods. If the stream variable is either an instance variable or declared locally within the body of the method, you can open a file and connect it to the stream and this problem will not occur. Once a stream is connected to a file, you can pass the stream variable as an argument to a method, and the method can change the file.

# **CASE STUDY** Processing a Comma-Separated Values File

A comma-separated values or CSV file is a simple text format used to store a list of records. A comma is used as a delimiter to separate the fields (also referred to as columns) for each record. This format is commonly used to transfer data between a spreadsheet, database, or custom application program. As an example, consider a cash register that saves a log of the day's sales in a CSV file named Transactions.txt. The text file contains the following data:

```
SKU, Quantity, Price, Description
4039, 50, 0.99, SODA
9100, 5, 9.50, T-SHIRT
1949, 30, 110.00, JAVA PROGRAMMING TEXTBOOK
5199, 25, 1.50, COOKIE
```

The first line of the file is a header that identifies the fields. The first field is the SKU, or stock-keeping unit. This is a unique identifier associated with every product sold. The second field is the quantity of the SKU sold in the transaction. The third field is the price of one unit, and the last field is a description of the item sold. For example, the second line of the file indicates that 50 sodas were sold at a price of \$0.99 each and the SKU for the soda is 4039.

There are many ways we might process the data, but in this case study we present a simple strategy to read every field in the file, output each transaction in a more English-like format, and compute the total sales for the cash register. The general algorithm is as follows:

- 1. Read and skip the header line of the file
- 2. Repeat while we have not reached the end of the file
  - a. Read an entire line (one record) from the file as a String
  - b. Create an array of strings from the line where array[0] is the value of the first field, array[1] is the value of the second field, etc.
  - c. Convert any numeric fields from the array of strings to the appropriate numeric data type
  - d. Process the fields.

Step 2b of the algorithm might seem to be difficult. At this step we have just read a line from the file. For the first line of our example we will have read "4039,50,0.99,SODA" into a variable of type String. Since a comma is used to separate every field, we could search the string for the first comma, extract the substring from the beginning of the string to the comma to extract the first field, and repeat this process for every successive field. However, the split method associated with the String class does all this for us and is defined as follows:

```
public String[] split(String delimiter)
```

The method splits the string around matches of delimiter and returns an array of the strings separated by delimiter. The delimiter parameter is interpreted as a regular expression, which is a flexible way to match patterns. For our purposes we will simply use this as a string that contains our delimiter character of a comma. The following example illustrates the split method.

```
String line = "4039,50,0.99,SODA"
String[] ary = line.split(",");
System.out.println(ary[0]);  // Outputs 4039
System.out.println(ary[1]);  // Outputs 50
System.out.println(ary[2]);  // Outputs 0.99
System.out.println(ary[3]);  // Outputs SODA
```

Listing 10.4 applies the technique to the sales transaction scenario. All that remains is to read the file, parse the quantity into an integer, parse the price into a double, and add the business logic to compute total sales by accumulating the product of the quantity sold multiplied by the price of the item. In the program, we used System.out.printf to format the price and totals with two decimal places.

LISTING 10.4 Processing a Comma-Separated Values File Containing Sales Transactions (part 1 of 2)

```
import java.io.FileInputStream;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.io.File;
import java.util.Scanner;
public class TransactionReader
public static void main(String[] args)
    {
        String fileName = "Transactions.txt";
        try
        Scanner inputStream = new Scanner(new File(fileName));
        // Skip the header line by reading and ignoring it
        String line = inputStream.nextLine();
        // Total sales
        double total = 0:
        // Read the rest of the file line by line
        while (inputStream.hasNextLine())
        {
            // Contains SKU, Quantity, Price, Description
            line = inputStream.nextLine();
                                                          (continued)
```

#### LISTING 10.4 Processing a Comma-Separated Values File Containing Sales Transactions (part 2 of 2)

```
// Turn the string into an array of strings
                    String[] ary = line.split(",");
                    // Extract each item into an appropriate
                    // variable
                    String SKU = arv[0]:
                    int quantity = Integer.parseInt(ary[1]);
                    double price = Double.parseDouble(ary[2]);
                    String description = ary[3];
                    // Output item
                    System.out.printf("Sold %d of %s (SKU: %s) at "+
                        "$%1.2f each.\n",
                        quantity, description, SKU, price);
                    // Compute total
                    total += quantity * price;
                System.out.printf("Total sales: $%1.2f\n",total);
                inputStream.close( );
        catch(FileNotFoundException e)
        {
               System.out.println("Cannot find file " + fileName);
        catch(IOException e)
        {
               System.out.println("Problem with input from file " +
               fileName);
        }
   }
}
```

#### Sample Screen Output

```
Sold 50 of SODA (SKU: 4039) at $0.99 each.
Sold 5 of T-SHIRT (SKU: 9100) at $9.50 each.
Sold 30 of JAVA PROGRAMMING TEXTBOOK (SKU: 1949) at $110.00 each.
Sold 25 of COOKIE (SKU: 5199) at $1.50 each.
Total sales: $3434.50
```

## **10.4** BASIC BINARY-FILE I/O

The White Rabbit put on his spectacles. "Where shall I begin, please your Majesty?" he asked.

"Begin at the beginning," the King said, very gravely, "And go on till you come to the end: then stop."

-LEWIS CARROLL, Alice's Adventures in Wonderland

We will use the stream classes <code>ObjectInputStream</code> and <code>ObjectOutputStream</code> to read and write binary files. Each of these classes has methods to read or write data one byte at a time. These streams can also convert numbers and characters to bytes that can be stored in a binary file. They allow your program to be written as if the data placed in the file, or read from the file, were made up not just of bytes but of either items of any of Java's primitive data types—such as <code>int</code>, <code>char</code>, and <code>double</code>—or strings or even objects of classes you define, as well as entire arrays. If you do not need to access your files via a text editor, the easiest and most efficient way to read data from and write data to files is to use <code>ObjectOutputStream</code> to write to a binary file and <code>ObjectInputStream</code> to read from the binary file.

We begin by creating a binary file, and then discuss how to write primitivetype data and strings to the file. Later, we will investigate using other objects and arrays as data for input and output.

# Creating a Binary File

If you want to create a binary file to store values of a primitive type, strings, or other objects, you can use the stream class <code>ObjectOutputStream</code>. Listing 10.5 shows a program that writes integers to a binary file. Let's look at the details shown in that program.

Note that the substance of the program is in a try block. Any code that does binary-file I/O in the ways we are describing can throw an IOException. Your programs can catch any IOException that is thrown, so that you get an error message and the program ends normally.

We can create an output stream for the binary file numbers.dat as follows:

As with text files, this process is called opening the (binary) file. If the file numbers.dat does not already exist, this statement will create an empty file named numbers.dat. If the file numbers.dat already exists, this statement will erase the contents of the file, so that the file starts out empty. The situation is basically the same as what happens when opening a text file, except that we're using a different class here.

Note that the constructor for ObjectOutputStream cannot take a string argument, but the constructor for FileOutputStream can. Moreover, ObjectOutputStream does have a constructor that will accept an object of

Opening a binary file for output

LISTING 10.5 Using ObjectOutputStream to Write to a File (part 1 of 2)

```
import java.io.FileOutputStream;
import java.io.ObjectOutputStream;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Scanner;
public class BinaryOutputDemo
{
    public static void main(String[] args)
    {
        String fileName = "numbers.dat";
        try
        {
            ObjectOutputStream outputStream =
            new ObjectOutputStream(new
                         FileOutputStream(fileName));
            Scanner keyboard = new Scanner(System.in);
            System.out.println("Enter nonnegative integers.");
            System.out.println("Place a negative number at the "+
                                "end.");
            int anInteger;
            do
            {
                anInteger = keyboard.nextInt();
                outputStream.writeInt(anInteger);
            } while (anInteger >= 0);
            System.out.println("Numbers and sentinel value");
            System.out.println("written to the file " + fileName);
            outputStream.close(); -
                                         A binary file is closed in the same
                                         way as a text file.
        catch(FileNotFoundException e)
            System.out.println("Problem opening the file " +
            fileName);
        }
        catch(IOException e)
            System.out.println("Problem with output to file " +
            fileName);
        }
    }
}
```

# LISTING 10.5 Using ObjectOutputStream to Write to a File (part 2 of 2)

### Sample Screen Output

Enter nonnegative integers.

Place a negative number at the end.

1 2 3 -1

Number and sentinel value
written to the file numbers.dat

The binary file after the program is run:

This file is a binary file. You cannot read this file using a text editor.

1 2 3 -1

The -1 in this file is a sentinel value. Ending a file with a sentinel value is not essential, as you will see later.

FileOutputStream as its argument. So in much the same way that we passed a File object to the Scanner constructor when we read from a text file, we pass a FileOutputStream object to the constructor of ObjectOutputStream. Note that the ObjectOutputStream constructor can throw an IOException and the FileOutputStream constructor can throw a FileNotFoundException.

Exceptions are possible

# Writing Primitive Values to a Binary File

An object of the class <code>ObjectOutputStream</code> does not have a method named <code>println</code>, as objects do when writing to either a text file or the screen. However, it does have a method named <code>writeInt</code> that can write a single <code>int</code> value to a binary file, as well as other output methods that we will discuss shortly. So once we have the stream <code>outputStream</code> of the class <code>ObjectOutputStream</code> connected to a file, we can write integers to the file, as in the following statement from Listing <code>10.5</code>:

outputStream.writeInt(anInteger);

The method writeInt can throw an IOException.

Listing 10.5 shows the numbers in the file numbers.dat as if they were written in a human-readable form. That is not how they are actually written, however. A binary file has no lines or other separators between data items. Instead, items are written to the file in binary—each as a sequence of bytes—one immediately after the other. These encoded values typically cannot be read using an editor. Realistically, they will make sense only to another Java program.

You can use a stream from the class <code>ObjectOutputStream</code> to write values of any primitive type. Each primitive data type has a corresponding write method in the class <code>ObjectOutputStream</code>, such as writeLong, writeDouble, writeFloat, and writeChar.

Writing values of any primitive type to a binary file

The method writeChar can be used to write a single character. For example, the following would write the character 'A' to the file connected to the stream named outputStream:

```
outputStream.writeChar('A');
```

The method writeChar has one possibly surprising property: It expects its argument to be of type int. So if you have an argument of type char, the char value will be type cast to an int before it is given to the method writeChar. Thus, the previous invocation is equivalent to the following one:

```
outputStream.writeChar((int)'A');
//You can omit the type cast
```

After you finish writing to a binary file, you close it in the same way that you close a text file. Here, the statement

```
outputStream.close();
```

closes the binary file.

Figure 10.5 summarizes some methods in the class <code>ObjectOutputStream</code>, including those that we have not discussed as yet. Many of these methods can throw an <code>IOException</code>.

```
RECAP Creating a Binary File
SYNTAX
try
{
    // Open the file
    ObjectOutputStream Output_Stream_Name =
        new ObjectOutputStream(new FileOutputStream(File_Name));
    // Write the file using statements of the form:
    Output_Stream_Name.MethodName(Argument); // See Figure 10.5
    // Close the file
    Output_Stream_Name.close();
}
catch(FileNotFoundException e)
    Statements_Dealing_With_The_Exception
catch(IOException e)
    Statements_Dealing_With_The_Exception
}
EXAMPLE
See Listing 10.5.
```

#### FIGURE 10.5 Some Methods in the Class ObjectOutputStream (part 1 of 2)

```
public ObjectOutputStream(OutputStream streamObject)
 Creates an output stream that is connected to the specified binary file. There is no con-
 structor that takes a file name as an argument. If you want to create a stream by using
 a file name, you write either
   new ObjectOutputStream(new FileOutputStream(File_Name))
 or, using an object of the class File,
   new ObjectOutputStream(new FileOutputStream(
                              new File(File_Name)))
 Either statement creates a blank file. If there already is a file named File_Name, the old
 contents of the file are lost.
    The constructor for FileOutputStream can throw a FileNotFoundException.
 If it does not, the constructor for ObjectOutputStream can throw an IOException.
public void writeInt(int n) throws IOException
 Writes the int value n to the output stream.
public void writeLong(long n) throws IOException
 Writes the long value n to the output stream.
public void writeDouble(double x) throws IOException
 Writes the double value x to the output stream.
public void writeFloat(float x) throws IOException
 Writes the float value x to the output stream.
public void writeChar(int c) throws IOException
 Writes a char value to the output stream. Note that the parameter type of c is int.
 However, Java will automatically convert a char value to an int value for you. So the
 following is an acceptable invocation of writeChar:
    outputStream.writeChar('A');
public void writeBoolean(boolean b) throws IOException
 Writes the boolean value b to the output stream.
public void writeUTF(String aString) throws IOException
 Writes the string aString to the output stream. UTF refers to a particular method of
 encoding the string. To read the string back from the file, you should use the method
 readUTF of the class ObjectInputStream. These topics are discussed in the next
 section.
```

#### FIGURE 10.5 Some Methods in the Class ObjectOutputStream (part 2 of 2)

Writes anObject to the output stream. The argument should be an object of a serializable class, a concept discussed later in this chapter. Throws a NotSerializable-Exception if the class of anObject is not serializable. Throws an InvalidClass-Exception if there is something wrong with the serialization. The method writeObject is covered later in this chapter.

public void close() throws IOException Closes the stream's connection to a file.



# **SELF-TEST QUESTIONS**

- 12. Writesome Java code to create an output stream of type Object Output Stream that is named to File and is connected to a binary file named stuff.
- 13. Give three statements that will write the values of the three double variables x1, x2, and x3 to the file stuff.data. Use the stream toFile that you created for the previous question.
- 14. Give a statement that will close the stream toFile created for the previous two questions.
- 15. What import statement(s) do you use when creating a binary file?

# Writing Strings to a Binary File

Use writeUTF for strings

To write a string to a binary file, we use the method writeUTF. For example, if outputStream is a stream of type ObjectOutputStream, the following will write the string "Hi Mom" to the file connected to that stream:

```
outputStream.writeUTF("Hi Mom");
```

Of course, with any of the write methods, you can use a variable of the appropriate type (in this case, the type String) as an argument to the method, instead of using a literal.

You may write output of different types to the same binary file. For example, you may write a combination of int, double, and String values. However, mixing types in a binary file does require special care, so that later the values in the file can be read correctly. In particular, we need to know the

order in which the various types appear in the file, because, as you will see, we use a different method to read data of each different type.

#### FAQ What does UTF stand for?

To write an int to a stream of the class <code>ObjectOutputStream</code>, you use <code>writeInt</code>; to write a double, you use <code>writeDouble</code>; and so forth. However, to write a string, you use <code>writeUTF</code>. There is no method called <code>writeString</code> in <code>ObjectOutputStream</code>. Why this funny name <code>writeUTF</code>? UTF stands for Unicode Text Format. That is not a very descriptive name. Here is the full story:

Recall that Java uses the Unicode character set, which includes many characters used in languages whose character sets are very different from that of English. Most text editors and operating systems use the ASCII character set, which is the character set normally used for English and for typical Java programs. The ASCII character set is a subset of the Unicode character set, so the Unicode character set has many characters you do not need. For English-speaking countries, the Unicode way of encoding characters is not a very efficient scheme. The UTF coding scheme is an alternative scheme that codes all of the Unicode characters but favors the ASCII character set. It does so by giving short, efficient codes for ASCII characters but inefficient codes for the other Unicode characters. However, if you do not use the other Unicode characters, this is a good deal.

#### Some Details About writeUTF

The method writeInt writes integers into a file, using the same number of bytes—that is, the same number of 0s and 1s—to store any integer. Similarly, the method writeLong uses the same number of bytes to store each value of type long. However, these methods use different numbers of bytes. The situation is the same for all the other write methods that write primitive types to binary files. The method writeUTF, however, uses varying numbers of bytes to store different strings in a file. Longer strings require more bytes than shorter strings. This condition can present a problem to Java, because data items in a binary file have no separators between them. Java can make this approach work by writing some extra information at the start of each string. This extra information tells how many bytes are used to write the string, so that readUTF knows how many bytes to read and convert. (The method readUTF will be discussed a little later in this chapter, but as you may have already guessed, it reads a String value.)

The situation with writeUTF is even a little more complicated than we have just described, however. Notice that we said that the information at the start of the string code in the file tells how many bytes to read, not how many characters are in the string. These two figures are not the same. With the UTF way of encoding, different characters are encoded in different numbers of bytes. However, all the ASCII characters are stored in just one byte. If you are using only ASCII characters, therefore, this difference is more theoretical than real to you.

# Reading from a Binary File

If you write to a binary file by using <code>ObjectOutputStream</code>, you can read from that file by using the stream class <code>ObjectInputStream</code>. Figure 10.6 gives some of the most commonly used methods for this class. If you compare these methods with the methods for <code>ObjectOutputStream</code> given in Figure 10.5, you will see that each output method has a corresponding input method. For example, if you write an integer to a file by using the method <code>writeInt</code> of <code>ObjectOutputStream</code>, you can read that integer from the file by using the method <code>readInt</code> of <code>ObjectInputStream</code>. If you write a number to a file by using the method <code>writeDouble</code> of <code>ObjectOutputStream</code>, you can use the method <code>readDouble</code> of <code>ObjectInputStream</code> to read it from the file, and so on.

You open a binary file for reading using ObjectInputStream in a manner similar to what you have already seen for ObjectOutputStream. The program in Listing 10.6 opens a binary file and connects it to a stream named inputStream as follows:

```
ObjectInputStream inputStream =
    new ObjectInputStream(new FileInputStream(fileName));
```

Note that this statement is like the analogous one in Listing 10.5, except that here we use the classes <code>ObjectInputStream</code> and <code>FileInputStream</code> instead of <code>ObjectOutputStream</code> and <code>FileOutputStream</code>, respectively. Once again, the class that defines the methods we need does not have a constructor that accepts a string as an argument. In addition, the constructor for <code>FileInputStream</code> can throw a <code>FileNotFoundException</code>, which is a kind of <code>IOException</code>. If the <code>FileInputStream</code> constructor succeeds, the constructor <code>forObjectInputStream</code> can throw a different <code>IOException</code>.

ObjectInputStream allows you to read input of different types from the same file. So you may read a combination of, for example, int values, double values, and String values. However, if the next data item in the file is not of the type expected by the reading method, the result is likely to be unpleasant. For example, if your program writes an integer using writeInt, any program that reads that integer should read it using readInt. If you instead use readLong or readDouble, for example, your program will misbehave in unpredictable ways.

Opening a binary file for input

Reading multiple types

#### FIGURE 10.6 Some Methods in the Class ObjectInputStream (part 1 of 2)

#### ObjectInputStream(InputStream streamObject)

Creates an input stream that is connected to the specified binary file. There is no constructor that takes a file name as an argument. If you want to create a stream by using a file name, you use either

The constructor for FileInputStream can throw a FileNotFoundException. If it does not, the constructor for ObjectInputStream can throw an IOException.

```
public int readInt() throws EOFException, IOException
```

Reads an int value from the input stream and returns that int value. If readInt tries to read a value from the file that was not written by the method writeInt of the class ObjectOutputStream (or was not written in some equivalent way), problems will occur. If the read goes beyond the end of the file, an EOFException is thrown.

```
public long readLong() throws EOFException, IOException
```

Reads a long value from the input stream and returns that long value. If readLong tries to read a value from the file that was not written by the method writeLong of the class ObjectOutputStream (or was not written in some equivalent way), problems will occur. If the read goes beyond the end of the file, an EOFException is thrown.

Note that you cannot write an integer using writeLong and later read the same integer using readInt, or to write an integer using writeInt and later read it using readLong. Doing so will cause unpredictable results.

```
public double readDouble() throws EOFException, IOException
```

Reads a double value from the input stream and returns that double value. If read—Double tries to read a value from the file that was not written by the method write—Double of the class ObjectOutputStream (or was not written in some equivalent way), problems will occur. If the read goes beyond the end of the file, an EOFExcep—tion is thrown.

```
public float readFloat() throws E0FException, I0Exception

Peods a float value from the input streem and returns that float value If
```

Reads a float value from the input stream and returns that float value. If read—Float tries to read a value from the file that was not written by the method write—Float of the class ObjectOutputStream (or was not written in some equivalent way), problems will occur. If the read goes beyond the end of the file, an EOFExcep—tion is thrown.

Note that you cannot write a floating-point number using writeDouble and later read the same number using readFloat, or write a floating-point number using writeFloat and later read it using readDouble. Doing so will cause unpredictable results, as will other type mismatches, such as writing with writeInt and then reading with readFloat or readDouble. (continued)

#### FIGURE 10.6 Some Methods in the Class ObjectInputStream (part 2 of 2)

Public char readChar() throws EOFException, IOException
Reads a char value from the input stream and returns that char value. If readChar tries to read a value from the file that was not written by the method writeChar of the class ObjectOutputStream (or was not written in some equivalent way), problems will occur. If the read goes beyond the end of the file, an EOFException is thrown.

public boolean readBoolean() throws EOFException, IOException Reads a boolean value from the input stream and returns that boolean value. If readBoolean tries to read a value from the file that was not written by the method writeBoolean of the class ObjectOutputStream (or was not written in some equivalent way), problems will occur. If the read goes beyond the end of the file, an EOFException is thrown.

publicString readUTF() throws IOException, UTFDataFormatException
Reads a String value from the input stream and returns that String value. If
readUTF tries to read a value from the file that was not written by the method
writeUTF of the class ObjectOutputStream (or was not written in some equivalent
way), problems will occur. One of the exceptions UTFDataFormatException or
IOException can be thrown.

Object readObject() throws ClassNotFoundException,
InvalidClassException, OptionalDataException, IOException
Reads an object from the input stream. Throws a ClassNotFoundException if the
class of a serialized object cannot be found. Throws an InvalidClassException if
something is wrong with the serializable class. Throws an OptionalDataException
if a primitive data item, instead of an object, was found in the stream. Throws an IOException if there is some other I/O problem. The method readObject is covered in
Section 10.5.

public void close() throws IOException Closes the stream's connection to a file.

# LISTING 10.6 Using ObjectInputStream to Read from a File (part 1 of 2)

Assumes the program in Listing 10.4 was already run

```
import java.io.FileInputStream;
import java.io.ObjectInputStream;
import java.io.EOFException;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Scanner;
```

(continued)

## LISTING 10.6 Using ObjectInputStream to Read from a File (part 2 of 2)

```
public class BinaryInputDemo
    public static void main(String[] args)
        String fileName = "numbers.dat";
        try
        {
            ObjectInputStream inputStream =
                  new ObjectInputStream(new FileInputStream(fileName));
            System.out.println("Reading the nonnegative integers");
            System.out.println("in the file " + fileName);
            int anInteger = inputStream.(readInt);
            while (anInteger >= 0)
                System.out.ptintln(anInteger);
                anInteger = inputStream.readInt();
            System.out.println("End of reading from file.");
            inputStream.close();
        catch(FileNotFoundException e)
            System.out.println("Problem opening the file " + fileName);
        catch(EOFException e)
            System.out.println("Problem reading the file " + fileName);
            System.out.println("Reached end of the file.");
        }
        catch(IOException e)
            System.out.println("Problem reading the file " + fileName);
        }
    }
}
```

#### Screen Output

# **RECAP** Reading from a Binary File

#### **SYNTAX**

```
try
{
    // Open the file
    ObjectInputStream Input_Stream_Name =
          new ObjectInputStream(new FileInputStream
                               (File_Name));
    // Read the file using statements of the form:
    Input_Stream_Name.MethodName(Argument); // See Figure 10.6
    // Close the file
    Input_Stream_Name.close();
 catch(FileNotFoundException e)
    Statements_Dealing_With_The_Exception
 catch(EOFException e)
    Statements_Dealing_With_The_Exception
 catch(IOException e)
{
    Statements_Dealing_With_The_Exception
}
```

#### **EXAMPLE**

See Listing 10.6.

#### **RECAP** FileInputStream and FileOutputStream

In this book, we use the classes FileInputStream and FileOutputStream for their constructors and nothing else. Each of these two classes has a constructor that takes a file name as an argument. We use these constructors to produce arguments for the constructors for stream classes, such as ObjectInputStream and ObjectOutputStream, that do not take a file name as an argument. Following are examples of using FileInputStream and FileOutputStream:

(continued)

We used similar statements in Listing 10.6 and Listing 10.5, respectively.

The constructors for FileInputStream and FileOutputStream can throw an exception in the class FileNotFoundException.

A FileNotFoundException is a kind of IOException.

# GOTCHA Using ObjectInputStream to Read a Text File

Binary files and text files encode their data in different ways. Thus, a stream that expects to read a binary file, such as a stream in the class ObjectInputStream, will have problems reading a text file. If you attempt to read a text file using a stream in the class ObjectInputStream, your program will either read "garbage values" or encounter some other error condition. Similarly, if you attempt to use Scanner to read a binary file as if it were a text file, you will also get into trouble.

# **SELF-TEST QUESTIONS**

- 16. Write some Java code to create an input stream of type ObjectInputStream that is named from File and is connected to a file named stuff.data.
- 17. Give three statements that will read three numbers of type double from the file stuff.data. Use the stream from File that you created in the previous question. Declare three variables to hold the three numbers.
- 18. Give a statement that will close the stream fromFile that you created for the previous two questions.
- 19. Can you use writeInt to write a number to a file and then read that number using readLong? Can you read that number using readDouble?
- 20. Can you use readUTF to read a string from a text file?
- 21. Write a complete Java program that asks the user for the name of a binary file and writes the first data item in that file to the screen. Assume that the first data item is a string that was written to the file with the method writeUTF.

#### The Class EOFException

An EOFException can end a loop

Many of the methods that read from a binary file will throw an EOFException when they try to read beyond the end of a file. As illustrated by the program in Listing 10.7, the class EOFException can be used to test for the end of a file when you are using ObjectInputStream. In that sample program, the statements that read the file are placed within a while loop whose boolean expression is true. Although this loop appears to be "infinite," it does come to an end: When the end of the file is reached, an exception is thrown, ending the entire try block and passing control to the catch block.

#### LISTING 10.7 Using EOFException (part 1 of 2)

```
Assumes the program in
  Listing 10.4 was already
  run
import java.io.FileInputStream;
import java.io.ObjectInputStream;
import java.io.EOFException;
import java.io.FileNotFoundException;
import java.io.IOException;
   public class EOFExceptionDemo
        public static void main(String[] args)
        {
            String fileName = "numbers.dat";
            try
            {
                ObjectInputStream inputStream =
                      new ObjectInputStream(new
                      FileInputStream(fileName));
                System.out.println("Reading ALL the integers");
                System.out.printin("in the file " + fileName);
                try
                {
                                      The loop ends when an
                     while (true)
                                      exception is thrown.
                         int anInteger = inputStream.readInt();
                         System.out.println(anInteger);
                     }
                catch(E0FException e)
```

(continued)

#### LISTING 10.7 Using EOFException (part 2 of 2)

#### Screen Output

```
Reading ALL the integers
in the file numbers.dat

When you use EOFException
to end reading, you can read files
that contain any kind of integers,
including the -1 here, which is
treated just like any other integer.

End of reading from file.
```

It is instructive to compare the program in Listing 10.7 with the similar program in Listing 10.6. The one in Listing 10.6 checks for the end of a file by testing for a negative number. This approach is fine, but it means that you cannot store negative numbers in the file, except as a sentinel value. On the other hand, the program in Listing 10.7 uses EOFException to test for the end of a file. Thus, it can handle files that store any kind of integers, including negative integers.

#### **RECAP The EOFException Class**

When reading primitive data from a binary file using the methods listed in Figure 10.6 for the class <code>ObjectInputStream</code>, if your program attempts to read beyond the end of the file, an <code>EOFException</code> is thrown. This exception can be used to end a loop that reads all the data in a file.

The class EOFException is derived from the class IOException. So every exception of type EOFException is also of type IOException.

# PROGRAMMING TIP Always Check for the End of a File

Nothing good happens if your program reads beyond the end of a file. Exactly what occurs will depend on the details of your program: It might enter an infinite loop or end abnormally. Always be sure that your program checks for the end of a file and does something appropriate when it reaches that point. Even if you think your program will not read past the end of the file, you should provide for this eventuality, just in case things do not go exactly as you planned.

# **GOTCHA** Checking for the End of a File in the Wrong Way

Different file-reading methods—usually in different classes—check for the end of a file in different ways. Some throw an exception of the class EOFException when they try to read beyond the end of a file. Others return a special value, such as null. When reading from a file, you must be careful to test for the end of a file in the correct way for the method you are using. If you test for the end of a file in the wrong way, one of two things will probably happen: Either your program will go into an unintended infinite loop or it will terminate abnormally.

Not all methods in all classes will throw an EOFException when they try to read beyond the end of a file. For the classes discussed in this book, the rule is as follows: If your program is reading primitive data from a binary file, it will throw an EOFException. If, however, your program is reading from a text file, it will return some special value, such as null, at the end of the file, and no EOFException will be thrown.

### **RECAP** Detecting the End of Data in a Binary File

You can read all of the data in a binary file in one of two ways:

- By detecting a sentinel value written at the end of the file
- By catching an EOFException

# **PROGRAMMING EXAMPLE**

Processing a File of Binary Data

Listing 10.8 contains a program that does some simple processing of data. It asks the user for two file names, reads the numbers in the input file, doubles them, and writes the resulting numbers to the output file. This programming task is not very complicated, but it does employ many standard programming

# LISTING 10.8 Processing a File of Binary Data (part 1 of 3)

```
import java.io.FileInputStream;
import java.io.FileOutputStream;
import java.io.ObjectInputStream;
import java.io.ObjectOutputStream;
import java.io.EOFException;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Scanner;
public class Doubler
{
    private ObjectInputStream inputStream = null;
    private ObjectOutputStream outputStream = null;
     /**
    Doubles the integers in one file and puts them in another file.
     public static void main(String[] args)
    {
        Doubler twoTimer = new Doubler();
        twoTimer.connectToInputFile();
        twoTimer.connectToOutputFile();
        twoTimer.timesTwo();
        twoTimer.closeFiles();
        System.out.println("Numbers from input file");
        System.out.println("doubled and copied to output file.");
    }
    public void connectToInputFile()
        String inputFileName =
            getFileName("Enter name of input file:");
        try
        {
            inputStream = new ObjectInputStream(
                              new FileInputStream(inputFileName));
        }
        catch(FileNotFoundException e)
        {
            System.out.println("File " + inputFileName +
                                " not found.");
            System.exit(0);
        }
        catch(IOException e)
            System.out.println("Error opening input file" +
                                 inputFileName);
```

# LISTING 10.8 Processing a File of Binary Data (part 2 of 3)

```
System.exit(0);
    }
}
private String getFileName(String prompt)
    String fileName = null;
    System.out.println(prompt);
    Scanner keyboard = new Scanner(System.in);
    fileName = keyboard.next();
    return fileName;
}
public void connectToOutputFile()
{
    String outputFileName =
                      getFileName("Enter name of output file:");
    try
    {
        outputStream = new ObjectOutputStream(
                          new FileOutputStream(outputFileName));
    catch(IOException e)
        System.out.println("Erroropeningoutputfile" +
                              outputFileName);
        System.out.println(e.getMessage());
        System.exit(0);
    }
}
A class used in a real-life application
would usually transform the input data in
a more complex way before writing it to
the output file. Such a class likely would
have additional methods.
public void timesTwo()
{
    try
    {
        while (true)
             int next = inputStream.readInt();
             outputStream.writeInt(2 * next);
        }
    }
```

# LISTING 10.8 Processing a File of Binary Data (part 3 of 3)

```
catch(EOFException e)
    {
         //Do nothing. This just ends the loop.
    catch(IOException e)
    {
        System.out.println(
                        "Error: reading or writing files.");
        System.out.println(e.getMessage());
        System.exit(0);
    }
    public void closeFiles()
        try
        {
            inputStream.close();
            outputStream.close();
        catch(IOException e)
            System.out.println("Error closing files " +
                                 e.getMessage());
            System.exit(0);
        }
    }
}
```

techniques for handling file I/O. In particular, note that the variables for stream objects connected to the files are instance variables, and note that the task is divided into subtasks assigned to various methods.

We have made the try blocks small so that, when an exception is thrown, it is caught in a nearby catch block. If we had fewer—and larger—try blocks, it would have been harder to decide what part of the code had thrown an exception.



# **GOTCHA** Exceptions, Exceptions

Many situations involving a text file that do not throw exceptions during I/O do throw exceptions when a binary file is involved. So you will need to do more exception handling when working with binary files than when working with text files. For example, closing a text file connected to a stream of type PrintWriter does not cause an exception to be thrown. However, closing a binary-file stream of the types we have been discussing can cause an IOException to be thrown. When doing binary-file I/O as we have described

it, almost anything can cause an exception to be thrown. Also, the methods writeObject and readObject can throw a long list of exceptions, which you can see by checking Figures 10.5 and 10.6.



# **SELF-TEST QUESTIONS**

22. Suppose that you want to create an input stream and connect it to the binary file named mydata.dat. Will the following code work? If not how can you write something similar that does work?

```
ObjectInputStream inputStream = new
   ObjectInputStream("mydata.dat");
```

- 23. Does the class FileInputStream have a method named readInt? Does it have one named readDouble? Does it have one named readUTF?
- 24. Does the class FileOutputStream have a constructor that accepts a file name as an argument?
- 25. Does the class ObjectOutputStream have a constructor that accepts a file name as an argument?
- 26. When opening a binary file for output in the ways discussed in this chapter, might an exception be thrown? What kind of exception? What are the answers to these questions if we open a binary file for input instead of for output?
- 27. Suppose that a binary file contains exactly three numbers written to the file using the method writeDouble of the class ObjectOutputStream. Suppose further that you write a program to read all three numbers using three invocations of the method readDouble of the class ObjectInputStream. If your program invokes readDouble a fourth time, what will happen?
- 28. The following code appears in the program in Listing 10.7:

```
try
{
    while (true)
    {
        int anInteger = inputStream.readInt();
        System.out.println(anInteger);
    }
}
catch(EOFException e)
{
    System.out.println("End of reading from file.");
}
```

Why doesn't this code really include an infinite loop?

29. Write a complete Java program that will display all the numbers in a binary file named temperatures.dat on the screen, one per line. Assume that the entire file was written with the method writeDouble.

# 10.5 BINARY-FILE I/O WITH OBJECTS AND ARRAYS

In this section, we cover I/O for binary files involving objects of a class and arrays, which, you'll recall, are really objects. We will use the classes ObjectInputStream and ObjectOutputStream.

# Binary-File I/O with Objects of a Class

We have seen how to write primitive values and strings to a binary file, and how to read them again. How would we write and read objects other than strings? We could, of course, write an object's instance variables to a file and invent some way to reconstruct the object when we read the file. Since an instance variable could be another object that itself could have an object as an instance variable, however, completing this task sounds formidable.

Fortunately, Java provides a simple way—called **object serialization**—to represent an object as a sequence of bytes that can be written to a binary file. This process will occur automatically for any object that belongs to a class that is **serializable**. Making a class serializable is easy to do. We simply add the two words <code>implementsSerializable</code> to the heading of the class definition, as in the following example:

Objects of a serializable class can be written to a binary file

```
public class Species implements Serializable
```

Actually, we do need to worry about some details involving a class's instance variables, but since those details will not be relevant to our example, we will postpone discussing them until the next section. We will also discuss the meaning of serialization at that time.

Serializable is an interface in the Java Class Library within the package java.io. The interface is empty, so we have no additional methods to implement. Although an empty interface might seem useless, this one tells Java to make the class serializable. We make the interface available to our program by including the following import statement:

```
import java.io.Serializable;
```

In Listing 10.9, we have made the class Species, which we saw in Listing 5.17 of Chapter 5, serializable and added constructors and a toString method. Let's use the class Species to illustrate the reading and writing of objects to a binary file.

We can write objects of a serializable class to a binary file by using the method writeObject of the class ObjectOutputStream and then read those objects from the file by using the method readObject of the class ObjectInputStream. Listing 10.10 provides an example of this process. To

# LISTING 10.9 The Class Species Serialized for Binary-File I/O

This is a new, improved definition of the class **Species** and replaces the definition in Listing 5.19 of Chapter 5.

```
import java.io.Serializable;
import java.util.Scanner;
Serialized class for data on endangered species.
public class Species implements Serializable -
    private String name;
                                        These two words and the import
    private int population;
                                       statement make this class serializable.
    private double growthRate;
    public Species()
        name = null;
        population = 0;
        growthRate = 0;
    }
    public Species (String initial Name, int initial Population,
                    double initialGrowthRate)
    {
        name = initialName;
        if (initialPopulation >= 0)
            population = initialPopulation;
        else
        {
            System.out.println("ERROR: Negative population.");
            System.exit(0);
        }
        growthRate = initialGrowthRate;
    }
    public String toString()
        return ("Name = " + name + "\n" +
                 "Population = " + population + "\n" +
                 "Growth rate = " + growthRate + "%");
    }
        <Other methods are the same as those in Listing 5.19 of Chapter 5,
        but they are not needed for the discussion in this chapter.>
```

#### LISTING 10.10 File I/O of Class Objects (part 1 of 3)

```
import java.io.FileInputStream;
import java.io.FileOutputStream;
import java.io.IOException;
import java.io.ObjectInputStream;
import java.io.ObjectOutputStream;
public class ClassObjectIODemo
    public static void main(String[]args)
    {
        ObjectOutputStream outputStream = null;
        String fileName = "species.records";
        try
        {
            outputStream = new ObjectOutputStream(
                           new FileOutputStream(fileName));
        catch(IOException e)
            System.out.println("Error opening output file " +
                                 fileName + ".");
            System.exit(0);
        Species califCondor =
                    new Species("Calif. Condor", 27, 0.02);
        Species blackRhino =
                    new Species("Black Rhino", 100, 1.0);
        try
        {
            outputStream.writeObject(califCondor);
            outputStream.writeObject(blackRhino);
            outputStream.Close();
        }
        catch(IOException e)
            System.out.println("Error wring to file " +
                               fileName + ".");
            System.exit(0)
        }
        System.out.println("Records sent to file " +
                            fileName + ".");
        System.out.println(
              "Now let's reopen the file and echo " +
              "the records.");
```

#### LISTING 10.10 File I/O of Class Objects (part 2 of 3)

```
ObjectInputStream inputStream = null;
    try
    {
        inputStream = new ObjectInputStream(
                       new FileInputStream("species.records"));
    }
    catch(IOException e)
    {
        System.out.println("Error opening input file " +
                             fileName + ".");
        System.exit(0);
    Species readOne = null, readTwo = null;
    try
                                   Notice the type casts.
    {
        readOne = (Species)inputStream.readObject();
        readTwo = (Species)inputStream.readObject();
        inputStream.close();
    }
                                A separate catch block for each type of
                                exception would be better. We use only
    catch(Exception e) ←
                                one to save space.
    {
        System.out.println("Error reading from file " +
                             fileName + ".");
        System.exit(0);
    }
    System.out.println("The following were read\n" +
                         "from the file " + fileName + ".");
    System.out.println(readOne);
    System.out.println();
    System.out.println(readTwo);
    System.out.println("End of program.");
}
```

#### Sample Screen Output

}

```
Records sent to file species.records.

Now let's reopen the file and echo the records.

The following were read
from the file species.records.

Name = Calif. Condor

Population = 27

Growth rate = 0.02%
```

#### LISTING 10.10 File I/O of Class Objects (part 3 of 3)

Name = Black Rhino
Population = 100
Growth rate 1.0%
End of program.

write an object of the class Species to a binary file, we pass the object as the argument to the method writeObject, as in

outputStream.writeObject(oneSpecies);

where outputStream is a stream of type ObjectOutputStream and oneSpecies is of type Species.

### **REMEMBER** Writing Objects to a Binary File

You can write objects to a binary file using writeObject only if their class is serializable. When checking the documentation for predefined classes, see whether the class implements Serializable.

An object written to a binary file with the method writeObject can be read by using the method readObject of the stream class ObjectInputStream, as illustrated by the following example taken from Listing 10.10:

readObject recovers an object in a binary file

```
readOne = (Species)inputStream.readObject();
```

Here, inputStream is a stream of type ObjectInputStream that has been connected to a file that was filled with data using writeObject of the class ObjectOutputStream. The data consists of objects of the class Species, and the variable readOne is of type Species. Note that readObject returns its value as an object of type Object. If you want to use it as an object of type Species, you must type cast it to the type Species.

Before we leave this example, let's clarify a potential misconception. The class Species has a method toString. This method is needed so that output to the screen and output to a text file—using println—appears correctly. However, the method toString has nothing to do with object I/O to a binary file. Object I/O with a binary file would work fine even if a class did not override toString.

#### Some Details of Serialization

Our introduction to serialization in the previous section omitted some details that we must cover now, in order to arrive at a complete definition of a serializable class. Recall that we mentioned that an instance variable could be another object that itself could have an object as an instance variable. In fact, the class Species has a string as an instance variable. When a serializable class has

Properties of a serializable class

instance variables of a class type, the class for those instance variables should also be serializable, and so on for all levels of instance variables within classes.

Thus, a class is serializable if all of the following are true:

- The class implements the interface Serializable.
- Any instance variables of a class type are objects of a serializable class.
- The class's direct super class, if any, is either serializable or defines a default constructor.

For example, the class Species implements the interface Serializable and has a string as an instance variable. The class String is serializable. Since any subclass of a serializable class is serializable, a class derived from Species would also be serializable.

What is the effect of making a class serializable? In a sense, there is no direct effect on the class, but there is an effect on how Java performs file I/O with objects of the class. If a class is serializable, Java assigns a serial number to each object of the class that it writes to a stream of type <code>ObjectOutputStream</code>. If the same object is written to the stream more than once, after the first time, Java writes only the serial number for the object, rather than writing the object's data multiple times. This feature makes file I/O more efficient and reduces the size of the file. When the file is read using a stream of type <code>ObjectInputStream</code>, duplicate serial numbers are returned as references to the same object. Note that this condition means that, if two variables contain references to the same object, and you write the objects to the file and later read them from the file, the two objects that are read will be references to the same object. So nothing in the structure of your object data is lost when you write the objects to the file and later read them.

Some classes aren't serializable for security reasons

Serializability sounds great. So why aren't all classes made serializable? In some cases, it is for security reasons. The serial-number system makes it easier for programmers to get access to the object data written to secondary storage. In other cases, writing objects to secondary storage may not make sense, since they would be meaningless when read again later. For example, if the object contains system-dependent data, the data may be meaningless later.

# **Array Objects in Binary Files**

Arrays are objects, and so can be written to a binary file Since Java treats arrays as objects, you can use writeObject to write an entire array to a binary file, and you can use readObject to read it from the file. When doing so, if the array has a base type that is a class, the class should be serializable. This means that, if you store all your data for one serializable class in a single array, you can write all your data to a binary file using one invocation of writeObject.

For example, suppose that group is an array of Species objects. If toFile is an instance of ObjectOutputStream that is associated with a binary file, we can write the array to that file by executing the statement

toFile.writeObject(group);

After creating the file, we can read the array by using the statement

```
Species[] myArray = (Species[])fromFile.readObject();
```

where from File is an instance of ObjectInputStream that is associated with the file that we just created.

Note that the base-class type, Species, is serializable. Note also the type cast when reading the array from the file. Since readObject returns its value as an object of type Object, it must be type cast to the correct array type, Species[] in this case.

Listing 10.11 contains a sample program that writes and reads an array using a binary file. Notice that we declared the arrays oneArray and anotherArray outside of the try blocks so that they exist both outside and

#### LISTING 10.11 File I/O of an Array Object (part 1 of 2)

```
import java.io.FileInputStream;
import java.io.FileOutputStream;
import java.io.IOException;
import java.io.ObjectInputStream;
import java.io.ObjectOutputStream;
public class ArrayIODemo
    public static void main(String[] args)
    {
        Species[] oneArray = new Species[2];
        oneArray[0] = new Species("Calif. Condor", 27, 0.02);
        oneArray[1] = new Species("Black Rhino", 100, 1.0);
        String fileName = "array.dat";
        try
        {
            ObjectOutputStream outputStream =
                  new ObjectOutputStream(
                      new FileOutputStream(fileName));
            outputStream.writeobject(oneArray);
            outputStream.close();
        catch(IOException e)
        {
            System.out.println("Error writing to file " +
                                fileName + ".");
            System.exit(0);
        System.out.println("Array written to file " +
                            fileName + " and file is closed.");
```

#### LISTING 10.11 File I/O of an Array Object (part 2 of 2)

```
System.out.println("Open the file for input and " +
                               "echo the array.")
             Species[] anotherArray = null;
             try
             {
                ObjectInputStream inputStream =
Note the type cast.
                           new objectInputStream(
                               new FileInputStream(fileName));
                anotherArray = (Species[])inputStream.readobject();
                inputStream.close();
            would be better. We use only one to save space.
                System.out.println("Error reading file " +
                                    fileName + ".");
                System.exit(0);
             System.out.println("The following were read from " +
                                "the file " + fileName + ":");
             for (int i = 0; i < anotherArray.length; i++)
                System.out.println(anotherArray[i]);
                System.out.println();
            System.out.println("End of program.");
         }
     }
```

#### Sample Screen Output

```
Array written to file array.dat and file is closed.

Open the file for input and echo the array.

The following were read from the file array.dat:

Name = Calif. Condor

Population = 27

Growth rate = 0.02%

Name = black Rhino

Population = 100

Growth rate = 1.0%

End of program.
```

inside these blocks. Also note that anotherArray is initialized to null, not newSpecies[2]. Had we allocated a new array here, it would have been replaced by the subsequent call to readObject. That is, readObject creates a new array; it does not fill an existing one.





# **SELF-TEST QUESTIONS**

- 30. How do you make a class serializable?
- 31. What is the return type for the method readObject of the class ObjectInputStream?
- 32. What exception(s) might be thrown by the method writeObject of the class ObjectOutputStream? (Consult the documentation for the Java Class Library.)
- 33. What exception(s) might be thrown by the method readObject of the class ObjectInputStream? (Consult the documentation for the Java Class Library.)

#### **10.6** NETWORK COMMUNICATION WITH STREAMS

Since in order to speak, one must first listen, learn to speak by listening.

-MEVLANA RUMI

We have seen that the Scanner class can be used to read data from a file or from the keyboard. Amazingly, classes such as Scanner and PrintWriter can be used with any kind of data stream! To illustrate this flexibility, here we introduce communication over a network using streams. As you will see, the code is nearly identical to reading from or writing to a file except instead the program will be reading from or sending to a computer on the Internet. This level of abstraction is made possible thanks to the principle of polymorphism discussed in Chapter 8.

When computers want to communicate with one another over a network, each computer must speak the same language, or protocol. The most common protocol today is TCP/IP, or the Transmission Control Protocol and Internet Protocol. It is used as the basis for most Internet communications. TCP is a stream-based protocol in which packets of data are transmitted from the sender to the receiver. TCP is considered a reliable protocol because it guarantees that data from the sender is received in the same order in which it was sent. The program that is waiting for a connection is called the server and the program that initiates the connection is called the client. An alternate protocol is UDP, or the User Datagram Protocol. In UDP, packets of data are



transmitted but no guarantee is made regarding the order in which the packets are received or if they will even be received. Although Java provides support for UDP, we will only introduce TCP in this section.

Network programming is implemented in Java using sockets. A socket describes one end of the connection between two programs over the network. A socket consists of an address that identifies the remote computer and a port for both the local and remote computer. The port is assigned an integer value between 0 and 65,535 that is used to identify which program should handle data received from the network. Two applications may not bind to the same port. Typically, ports 0 to 1,024 are reserved for use by well-known services implemented by your operating system.

The process of client/server communication is shown in Figure 10.7. First, the server waits for a connection by listening on a specific port. When a client connects to this port, a new socket is created that identifies the remote

# FIGURE 10.7 Client/Server Network Communication via Sockets

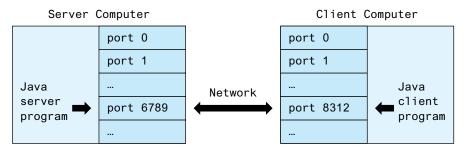
1. The Java server program listens and waits for a connection on port 6789. Different programs may be listening on other ports.

Server Computer

port 0
port 1

Java
server
program
port 6789

2. The Java client program connects to the server on port 6789. It uses a local port that is assigned automatically, in this case, port 8312.



3. The Java server program can now communicate over a socket bound locally to port 6789 and remotely to the client's address at port 8312, while the client communicates over a socket bound locally to port 8312 and remotely to the server's address at port 6789.

computer, the remote port, and the local port. A similar socket is created on the client. Once the sockets are created on both the client and the server, data can be transmitted using streams in the same way we read from and write to files.

Listing 10.12 shows how to create a simple server that listens on port 6789 for a connection. Once it receives a connection a new socket is returned by the accept() method. From this socket we create a Scanner and PrintWriter, just as if we were reading from a text file except the source of the stream comes from the socket. The ServerSocket and Socket classes are in the java.net package. Once the streams are created, the server expects the client to send a line of text. The server waits for the name with a call to nextLine() just like we would use to read from the keyboard or file, except this time the server waits for the text to come from the network. Once the text is received the server sends back a message. We should *flush* the stream when we want the data to be sent. Finally, the server closes the streams and sockets.

### LISTING 10.12 Network Server Program (part 1 of 2)

```
import java.util.Scanner;
import java.io.InputStreamReader;
import java.io.DataOutputStream;
import java.io.PrintWriter;
import java.net.Socket;
import java.net.ServerSocket;
public class SocketServer
 public static void main(String[] args)
 String s:
 Scanner inputStream = null;
 PrintWriter outputStream = null;
 ServerSocket serverSocket = null;
  try
        // Wait for connection on port 6789
        System.out.println("Waiting for a connection.");
        serverSocket = new ServerSocket(6789);
        Socket socket = serverSocket.accept();
        // Connection made, set up streams
        inputStream = new Scanner(new
          InputStreamReader(socket.getInputStream()));
        outputStream = new PrintWriter(new
          DataOutputStream(socket.getOutputStream()));
      // Read a line from the client
      s = inputStream.nextLine();
```

#### LISTING 10.12 Network Server Program (part 2 of 2)

After running the client program in Listing 10.13.

#### Screen Output

```
Waiting for a connection.
Closing connection from Java
```

Listing 10.13 shows how to create a client that connects to our server. First, we create a socket with the name of the computer running the server along with the corresponding port of 7654. If the server program and client program are running on the same computer then you can use *localhost* as the name of the machine. Otherwise, the hostname should be set to the name of the computer (e.g., my.server.com). After a connection is made, the client creates stream objects, sends its name, waits for a reply, and prints the reply.

# LISTING 10.13 Network Client Program (part 1 of 2)

#### LISTING 10.13 Network Client Program (part 2 of 2)

```
public static void main(String[] args)
 {
 String s;
 Scanner inputStream = null;
 PrintWriter outputStream = null;
 try
   // Connect to server on same machine, port 6789
   Socket clientSocket = new Socket("localhost",6789);
   // Set up streams to send/receive data
   inputStream = new Scanner(new
     InputStreamReader(clientSocket.getInputStream()));
   outputStream = new PrintWriter(new
     DataOutputStream(clientSocket.getOutputStream()));
   // Send "Java" to the server
   outputStream.println("Java");
   outputStream.flush(); // Sends data to the stream
   // Read everything from the server until no
   // more lines and output it to the screen
   while (inputStream.hasNextLine())
     s = inputStream.nextLine();
    System.out.println(s);
   }
   inputStream.close();
   outputStream.close();
 catch (Exception e)
   // If any exception occurs, display it
  System.out.println("Error " + e);
 }
}
}
```

After connecting to the server program in Listing 10.12.

#### Screen Output

```
Well,
Java is a fine programming language!
```

Note that the socket and stream objects throw checked exceptions. This means that their exceptions must be caught or declared in a throws block. If you run the server program in Listing 10.12 then you will notice that the server waits, or blocks, at the serverSock.accept() call until a client connects to it. The server also blocks at the nextLine() call if data from the socket is not yet available. This behavior makes it difficult for a server to handle connections with more than one client. After a connection is made with the first client, the server will not respond if a second client wishes to connect. The solution to this problem is to use threads. Threads allow a program to run concurrently, which is like multiple copies of a program running simultaneously. In a thread-based solution, each thread on the server program would handle communication with a different client that connects to it. Threads are not covered in this book but are discussed in more advanced texts.

As one final example to illustrate the flexibility of streams and the power of polymorphism, Java has an URL class that can read the contents of a website into a stream. To use the class, import java.net.URL, create the URL, and then use the stream when creating a Scanner object. From that point on, reading from the Scanner will read data from the URL. A code snippet is shown below that would output the HTML of www.wikipedia.org.

# **SELF-TEST QUESTIONS**

- 34. What is the purpose of a port in the context of a socket?
- 35. Modify the client so it sends two numbers, then reads a number and prints it. Modify the server so it reads two numbers, computes the sum, then sends the sum back to the client.

### **10.7** GRAPHICS SUPPLEMENT

The "real world" is the only world.

-GRAFFITI

Graphical user interfaces, or GUIs, are not just for cute little demonstrations. GUIs are meant to be interfaces for real application programs. This section provides one small example of a JavaFX GUI that manipulates files.

# **PROGRAMMING EXAMPLE**

A JavaFX GUI for Manipulating Files

The program in Listing 10.14 uses JavaFX to create a GUI that lets you do some housekeeping with your text files. The GUI has three buttons and two text fields. You can type a file name in the indicated text field. If you then click the Show first line button, the first line of the file is displayed in the other text field as a reminder of what is in the file. However, if the file does not exist or is not readable, you get a message explaining the situation instead. And if the file is not a text file, you will get gibberish.

# LISTING 10.14 A File Organizer GUI (part 1 of 5)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.FlowPane;
import javafx.scene.control.TextField;
import javafx.scene.control.Label;
import javafx.scene.control.Button;
import javafx.event.ActionEvent;
import javafx.event.EventHandler;
import java.io.File;
import java.io.FileNotFoundException;
import java.util.Scanner;
public class FileOrganizer extends Application
   private TextField fileNameField;
   private TextField firstLineField;
   public static void main(String[] args)
      launch(args);
   }
```

# LISTING 10.14 A File Organizer GUI (part 2 of 5)

```
@Override
public void start(Stage primaryStage) throws Exception
     final int WIDTH = 400;
     final int HEIGHT = 300;
     final int NUMBER_OF_PIXELS = 300;
   FlowPane root = new FlowPane();
  Button showButton = new Button("Show first line");
   root.getChildren().add(showButton);
   showButton.setOnAction(new EventHandler<ActionEvent>()
    {
        @Override
        public void handle(ActionEvent event)
            showFirstLine();
        }
   }
   );
  Button removeButton = new Button("Remove file");
   root.getChildren().add(removeButton);
   removeButton.setOnAction(new EventHandler<ActionEvent>()
    {
        @Override
        public void handle(ActionEvent event)
        {
            removeFile();
        }
   }
   );
  Button resetButton = new Button("Reset");
   root.getChildren().add(resetButton);
   resetButton.setOnAction(new EventHandler<ActionEvent>()
    {
        @Override
        public void handle(ActionEvent event)
        {
            resetFields();
        }
   }
   fileNameField = new TextField("Enter file name here.");
   fileNameField.setPrefWidth(NUMBER_OF_PIXELS);
   root.getChildren().add(fileNameField);
                                                       (continued)
```

# LISTING 10.14 A File Organizer GUI (part 3 of 5)

```
firstLineField = new TextField();
   firstLineField.setPrefWidth(NUMBER OF PIXELS);
   root.getChildren().add(firstLineField);
   Scene scene = new Scene(root, WIDTH, HEIGHT);
   primaryStage.setTitle("File Organizer");
   primaryStage.setScene(scene);
   primaryStage.show();
}
 private void showFirstLine( )
 {
    Scanner fileInput = null;
    String fileName = fileNameField.getText( );
    File fileObject = new File(fileName);
     if (!fileObject.exists( ))
         firstLineField.setText("No such file");
    else if (!fileObject.canRead( ))
         firstLineField.setText("That file is not readable.");
     else
     {
         try
         {
             fileInput = new Scanner(fileObject);
         catch(FileNotFoundException e)
         {
             firstLineField.setText("Error opening the file " +
                                      fileName);
         String firstLine = fileInput.nextLine( );
         firstLineField.setText(firstLine);
         fileInput.close( );
     }
 }
 private void resetFields()
 {
     fileNameField.setText("Enter file name here.");
    firstLineField.setText("");
 private void removeFile( )
    Scanner fileInput = null;
    String firstLine;
```

# LISTING 10.14 A File Organizer GUI (part 4 of 5)

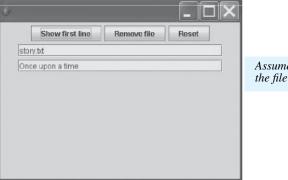
```
String fileName = fileNameField.getText();
File fileObject = new File(fileName);

if (!fileObject.exists())
    firstLineField.setText("No such file");
else if (!fileObject.canWrite())
    firstLineField.setText("Permission denied.");
else
{
    if (fileObject.delete())
        firstLineField.setText("File deleted.");
    else
        firstLineField.setText("Could not delete file.");
}
}
```

Screen Output Showing GUI's State Initially or After the Reset Button is Clicked



Screen Output After Entering the File Name and Clicking the Show first line Button



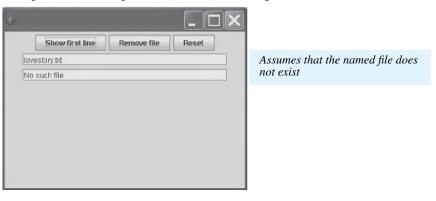
Assumes that the first line in the file is as shown

#### LISTING 10.14 A File Organizer GUI (part 5 of 5)

#### Screen Output After Entering the Remove line Button



#### Screen Output After Entering the File Name and Clicking the Show first line Button



If you want to delete a file, you type the file name in the text field and click the **Remove file** button. As long as the file exists and is writable, it is deleted and a confirmation message is displayed. If the file does not exist or is not writable—which normally also means you cannot delete it—an appropriate message appears instead. Finally, the **Reset** button restores the text fields to their original contents. Let's look at some code.

Within the constructor of our class, we define the three buttons and the two text fields. Having two text fields means that the file name can remain visible while any output is given in the other text field. To differentiate the text fields, we initialize the one for the file name as follows:

fileNameField.setText("Enter file name here.");

The button click event handlers take the appropriate action by calling one of three private methods within our class. The method showFirstLine retrieves the file name from the text field and, after checking that the file exists and is readable, opens the file for input. The method then reads the first line, displays it in the text field, and finally closes the file. The statements for these latter three steps are

```
String firstLine = fileInput.readLine();
firstLineField.setText(firstLine);
fileInput.close();
```

Before entering another file name, the user should click the Reset button, which sets the two text fields as follows:

```
fileNameField.setText("Enter file name here.");
firstLineField.setText("");
```

The second statement sets the text field contents to the empty string, which sets the field to blank. (The GUI will give correct answers even if the Reset button is not clicked, but the output will be clearer if it is clicked.) These two statements are in the private method resetFields that actionPerformed calls when the Reset button is clicked.

Finally, if the **Remove file** button is clicked, actionPerformed calls the private method removeFile. After checking that the file exists and is readable, removeFile deletes the file by using the following code:

```
if (fileObject.delete())
    firstLineField.setText("File deleted.");
else
    firstLineField.setText("Could not delete file.");
```

The invocation fileObject.delete() tries to delete the file. If delete is successful, it returns true; otherwise it returns false.

# PROGRAMMING TIP When to Define GUI Components as Instance Variables

When GUI components must be available to more than one method within a class, defining them as instance variables is more convenient than passing them as arguments to several methods. In Listing 10.14, for example, two text fields—fileNameField and firstLineField—are created and initialized by the start method and used in all of the other methods in the class except main. These text fields are defined as instance variables.

However, notice the buttons defined in the Start method. Since they are used only in the start method, they can be local to that method.

#### **CHAPTER SUMMARY**

- Files that are considered to be strings of characters and that look like characters to your program and to a text editor are called text files. All other files are called binary files.
- Your program can use the class PrintWriter to write to a text file and can use the class Scanner to read from a text file.
- When reading from a file, you should always check for the end of a file and do something appropriate if the end of the file is reached. The way you test for the end of a file depends on whether your program is reading from a text file or a binary file.
- You can read a file name from the keyboard into a variable of type String and use that variable in place of a file name.
- The class File can be used to see whether an existing file has a given name. It can also be used to see whether your program is allowed to read the file or write to the file.
- Your program can use the class ObjectOutputStream to write to a binary file and can use the class ObjectInputStream to read from a binary file.
- Your program can use the method writeObject of the class ObjectOutputStream to write class objects or arrays to a binary file. Objects or arrays can be read from a binary file using the method readObject of the class ObjectInputStream.
- In order to use the methods writeObject of the class ObjectOutputStream and readObject of the class ObjectInputStream, the class whose objects are written to a binary file must implement the Serializable interface.
- You can connect a PrintWriter or Scanner to a socket to read and write data over a network.

#### **Exercises**

- 1. Write a program that will write Pericles' Funeral Oration to a text file. Place each sentence on a separate line as a tabbed paragraph in the file.
- 2. Modify the program in the previous exercise so that it reads the name of the file entered by the user from the keyboard.
- 3. Write some code that asks the user to enter either of the words append or new. According to the user response, open either an existing text file to which data can be appended or a new, empty text file to which data can be written. In either case, the file's name is a string given by the variable fileName.

- 4. Write a program that will record the maximum marks of a question paper. For each question, read from the keyboard a question number, its subparts, and the marks allotted to each part. Compute the marks of each question (subparts times marks allotted) and write all this data to a text file. Also, display this information and the maximum marks of the total questions on the screen. After all questions have been entered, write the maximum marks to both the screen and the file. Since we want to remember all the questions entered, you should append new data to the end of the file.
- 5. Modify the class LapTimer, as described in Exercise 13 of Chapter 9, as follows:
  - Add an attribute for a file stream to which we can write the times
  - Add a constructor

```
LapTimer(n, person, fileName)
```

for a race having n laps. The name of the person and the file to record the times are passed to the constructor as strings. The file should be opened and the name of the person should be written to the file. If the file cannot be opened, throw an exception.

- 6. Write a class TelephoneNumber that will hold a telephone number. An object of this class will have the attributes
  - areaCode—a three-digit integer
  - exchangeCode—a three-digit integer
  - number—a four-digit integer

#### and the methods

- TelephoneNumber(aString)—a constructor that creates and returns a new instance of its class, given a string in the form xxx-xxx-xxxx or, if the area code is missing, xxx-xxxx. Throw an exception if the format is not valid. (*Hint*: To simplify the constructor, you can replace each hyphen in the telephone number with a blank. To accept a telephone number containing hyphens, you could process the string one character at a time or learn how to use Scanner to read words separated by a character—such as a hyphen—other than whitespace.)
- toString—returns a string in either of the two formats shown previously for the constructor.

Using a text editor, create a text file of several telephone numbers, using the two formats described previously. Write a program that reads this file, displays the data on the screen, and creates an array whose base type is TelephoneNumber. Allow the user to either add or delete one telephone number. Write the modified data on the text file, replacing its original contents. Then read and display the numbers in the modified file.

7. Write a class ContactInfo to store contact information for a person. It should have attributes for a person's name, business phone, home phone, cell phone, e-mail address, and home address. It should have a toString method that returns this data as a string, making appropriate replacements for any attributes that do not have values. It should have a constructor ContactInfo(aString) that creates and returns a new instance of the class, using data in the string aString. The constructor should use a format consistent with what the toString method produces.

Using a text editor, create a text file of contact information, as described in the previous paragraph, for several people. Write a program that reads this file, displays the data on the screen, and creates an array whose base type is ContactInfo. Allow the user to do one of the following: change some data in one contact, add a contact, or delete a contact. Finally, write over the file with the modified contacts.

- 8. Write a program that reads every line in a text file, removes the first word from each line, and then writes the resulting lines to a new text file.
- 9. Repeat the previous exercise, but write the new lines to a new binary file instead of a text file.
- 10. Write a program that will make a copy of a text file, line by line. Read the name of the existing file and the name of the new file—the copy—from the keyboard. Use the methods of the class File to test whether the original file exists and can be read. If not, display an error message and abort the program. Similarly, see whether the name of the new file already exists. If so, display a warning message and allow the user to either abort the program, overwrite the existing file, or enter a new name for the file.
- 11. Suppose you are given a text file that contains the subject choices of students. Unfortunately, the programmer who created the file of subject choices was careless and did not guarantee that each choice was on a single line of the file. Read this file of subjects and write them to a new text file, one choice of three subjects per line. For example, if the input file contains

English Geography History Philosophy Mathematics Music Law Architecture Engineering Economics Biology Physics Chemistry English History Music Philosophy Mathematics

the output file should be

English Geography History Philosophy Mathematics Music Law Architecture Engineering Economics Biology Physics Chemistry English History Music Philosophy Mathematics 12. Suppose that you have a binary file that contains numbers whose type is either int or double. You don't know the order of the numbers in the file, but their order is recorded in a string at the beginning of the file. The string is composed of the letters *i* (for int) and *d* (for double) in the order of the types of the subsequent numbers. The string is written using the method writeUTF.

For example, the string "iddiiddd" indicates that the file contains eight values, as follows: one integer, followed by two doubles, followed by two integers, followed by three doubles. Read this binary file and create a new text file of the values, written one to a line.

13. Suppose that we want to store digitized audio information in a binary file. An audio signal typically does not change much from one sample to the next. In this case, less memory is used if we record the change in the data values instead of the actual data values. We will use this idea in the following program.

Write a program StoreSignal that will read positive integers, each of which must be within 127 of the previous integer, from the keyboard (or from a text file, if you prefer). Write the first integer to a binary file. For each subsequent integer, compute the difference between it and the integer before it, cast the difference to a byte, and write the result to the binary file. When a negative integer is encountered, stop writing the file.

- 14. Write a program RecoverSignal that will read the binary file written by StoreSignal, as described in the previous exercise. Display the integer values that the data represents on the screen.
- 15. Even though a binary file is not a text file, it can contain embedded text. To find out if this is the case, write a program that will open a binary file and read it one byte at a time. Display the integer value of each byte as well as the character, if any, that it represents in ASCII.

Technical details: To convert a byte to a character, use the following code:

```
char[] charArray = Character.toChars(byteValue);
```

The argument byteValue of the method toChars is an int whose value equals that of the byte read from the file. The character represented by the byte is charArray[0]. Since an integer is four bytes, byteValue can represent four ASCII characters. The method toChars tries to convert each of the four bytes to a character and places them into a char array. We are interested in just the character at index 0. If a byte in the file does not correspond to a character, the method will throw an IllegalArgumentException. If the exception is thrown, display only the byte value and continue on to the next byte.

#### PRACTICE PROGRAMS

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

1. Write a program that searches a file of numbers and displays the largest number, the smallest number, and the average of all the numbers in the file. Do not assume that the numbers in the file are in any special order. Your program should obtain the file name from the user. Use either a text file or a binary file. For the text-file version, assume one number per line. For the binary-file version, use numbers of type double that are written using writeDouble.



- 2. Write a program that reads a file of numbers of type int and writes all the numbers to another file, but without any duplicate numbers. Assume that the numbers in the input file are already ordered from smallest to largest. After the program is run, the new file will contain all the numbers in the original file, but no number will appear more than once in the file. The numbers in the output file should also be sorted from smallest to largest. Your program should obtain both file names from the user. Use either a text file or a binary file. For the text-file version, assume one number per line. For the binary-file version, use numbers of type int that are written using writeInt.
- 3. The following is an old word puzzle: "Name a common word, besides tremendous, stupendous, and horrendous, that ends in dous." If you think about this for a while it will probably come to you. However, we can also solve this puzzle by reading a text file of English words and outputting the word if it contains "dous" at the end. The text file "words.txt" contains 87314 English words, including the word that completes the puzzle. This file is available online with the source code for the book. Write a program that reads each word from the text file and outputs only those containing "dous" at the end to solve the puzzle.



- 4. The Social Security Administration maintains an actuarial life table that contains the probability that a person in the United States will die (http://www.ssa.gov/OACT/STATS/table4c6.html). The death probabilities from this table for 2009 are stored in the file LifeDeathProbability.txt that is included with the book's source code. There are three values for each row the age, death probability for a male, and death probability for a female. For example, the first five lines are:
  - 0 0.006990 0.005728
  - 1 0.000447 0.000373
  - 2 0.000301 0.000241
  - 3 0.000233 0.000186
  - 4 0.000177 0.000150

This says that a 3-year-old female has a 0.000186 chance of dying that year.

Write a program that simulates how long you will live. The basic idea is to generate random numbers for each age until you "die." For example, if you are a 1-year-old male, then if a random number is <= 0.000447 then the simulation will say you will live to age 1. Otherwise if the random number is > 0.000447 then go to age 2 and generate another random number. If it is < 0.000301 then the simulation will say you will live to age 2, etc. The program should input your sex and age to determine which probabilities to use. The program should then simulate to what age you will live by starting with the death probability for the age and sex entered in the file. If the simulation reaches age 120 then stop and predict that the user will live to 120. This program is merely a simulation and will give different results each time it is run.

5. The following is a list of scores for a game. Enter them into a text file.

Write a program that opens this file, reads in each score as an integer, and remembers the highest score. After all the scores have been read, output the high score (65816 in this example, but it could be different if the file had different scores in it).

#### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

1. Write a program that checks a text file for several formatting and punctuation matters. The program asks for the names of both an input file and an output file. It then copies all the text from the input file to the output file, but with the following two changes: (1) any string of two or more blank characters is replaced by a single blank; (2) all sentences start with an uppercase letter. All sentences after the first one begin after either a period, a question mark, or an exclamation mark that is followed by one or more whitespace characters.

- 2. Write a program similar to the one in Listing 10.10 that can write an arbitrary number of Species objects to a binary file. (Species appears in Listing 5.19 of Chapter 5.) Read the file name and the data for the objects from a text file that you create by using a text editor. Then write another program that can search a binary file created by your first program and show the user the data for any requested endangered species. The user gives the file name and then enters the name of the species. The program either displays all the data for that species or gives a message if that species is not in the file. Allow the user to either enter additional species' names or quit.
- 3. Write a program that reads from a file created by the program in the previous programming project and displays the following information on the screen: the data for the species having the smallest population and the data for the species having the largest population. Do not assume that the objects in the file are in any particular order. The user gives the file name.
- 4. Programming Project 2 asks you, among other things, to write a program that creates a binary file of objects of the class Species. Write a program that reads from a file created by that program and writes the objects to another file after modifying their population figures as they would be in 100 years. Use the method predictPopulation of the class Species, and assume that you are given each species' growth rate.
- 5. Text messaging is a popular means of communication. Many abbreviations are in common use but are not appropriate for formal communication. Suppose the abbreviations are stored, one to a line, in a text file named abbreviations.txt. For example, the file might contain these lines:

lol :) iirc 4 u ttfn

Write a program that will read a message from another text file and surround each occurrence of an abbreviation with <> brackets. Write the marked message to a new text file.

For example, if the message to be scanned is

How are u today? Iirc, this is your first free day. Hope you are having fun! :)

the new text file should contain

How are <u> today? <lirc>, this is your first free day. Hope you are having fun! <:)>

- 6. Modify the TelephoneNumber class described in Exercise 6 so that it is serializable. Write a program that creates an array whose base type is TelephoneNumber by reading data from the keyboard. Write the array to a binary file using the method writeObject. Then read the data from the file using the method readObject and display the information to the screen. Allow the user to change, add, or delete any telephone number until he or she indicates that all changes are complete. Then write the modified telephone numbers to the file, replacing its original contents.
- 7. Revise the class Pet, as shown in Listing 6.1 of Chapter 6, so that it is serializable. Write a program that allows you to write and read objects of type Pet to a file. The program should ask the user whether to write to a file or read from a file. In either case, the program next asks for the file name. A user who has asked to write to a file can enter as many records as desired. A user who has asked to read from a file is shown all of the records in the file. Be sure that the records do not scroll by so quickly that the user cannot read them. (*Hint*: Think of a way to pause the program after a certain number of lines are displayed.)
- 8. Write a program that reads records of type Pet from a file created by the program described in the previous programming project and displays the following information on the screen: the name and weight of the heaviest pet, the name and weight of the lightest pet, the name and age of the youngest pet, and the name and age of the oldest pet.
- 9. The UC Irvine Machine Learning repository contains many datasets for conducting computer science research. One dataset is the Haberman's Survival dataset, available at http://archive.ics.uci.edu/ml/datasets/Haberman's+Survival and also included online with the source code for the book. The file "haberman.data" contains survival data for breast cancer patients in comma-separated value (CSV) format. The first field is the patient's age at the time of surgery, the second field is the year of the surgery, the third field is the number of positive axillary nodes detected, and the fourth field is the survival status. The survival status is 1 if the patient survived 5 years or longer and 2 if the patient died within 5 years.

Write a program that reads the CSV file and calculates the average number of positive axillary nodes detected for patients who survived 5 years or longer, and the average number of positive axillary nodes detected for patients who died within 5 years. A significant difference between the two averages suggests whether or not the number of positive axillary nodes detected can be used to predict survival time. Your program should ignore the age and year fields for each record.

10. In many races competitors wear a RFID tag on their shoes or bibs. When the racer crosses a sensor a computer logs the racer's number along with the current time. Sensors can be placed along the course to accurately calculate the racer's finish time or pace and also to verify that the racer crossed key checkpoints. Consider such a system in use for a half-marathon running race, which is 13.1 miles. In this problem there are only three sensors: at the start, at the 7-mile point, and at the finish line.

Here is sample data for three racers. The first line is the gun time in the 24-hour time format (HH MM SS). The gun time is when the race begins. Subsequent lines are recorded by sensors and contain the sensor ID (0=start, 1=midpoint, 2=finish) followed by the racer's number followed by the time stamp. The start time may be different than the gun time because sometimes it takes a racer a little while to get to the starting line when there is a large pack.

```
08 00 00

0,100,08 00 00

0,132,08 00 03

0,182,08 00 15

1,100,08 50 46

1,182,08 51 15

1,132,08 51 18

2,132,09 34 16

2,100,09 35 10

2,182,09 45 15
```

Create a text file with a sample race log. Write a program that reads the log data into an appropriate array structure. The program should then allow a user to enter a racer's number and it should output the racer's overall finish place, race split times in minutes/mile for each split (i.e., the time between sensors), and the overall race time and overall race pace. For a more challenging version modify your program so that it works with an arbitrary number of sensors placed at different locations along the course instead of just three locations. You will need to specify the mile marker for each sensor.

- 11. Based on the log file described in Programming Project 10 write a program to detect cheating. This could occur if:
  - A racer misses a sensor, which is a sign that the racer may have taken a shortcut.
  - A race split is suspiciously fast, which is a sign that the racer may have hopped in a vehicle. In this case, a race split faster than 4:30 per mile can be considered suspicious.

The output should be a list of suspected cheaters along with the reason for suspicion.

12. Write a Java program that serves as a primitive web browser. For this assignment it merely needs to input a server name and display the HTML that is sent by the web server. A web server normally listens on port 80.

Upon connection the server expects to be sent a string that identifies what web page to receive (use / for the root) and what protocol is used. The next line is the Host and then a blank line. For example, to get the default page on Wikipedia the Java program would connect to port 80 and send:

GET / HTTP/1.1
Host: www.wikipedia.org
(blank line)

The Wikipedia server would then send back the HTML for the site which your program should display in text. For a more challenging program, parse and render the HTML in a human-friendly format instead of printing out the raw HTML.

Graphics

13. Repeat any of the previous programming projects using a JavaFX graphical user interface.

**Graphics** 

14. Write a JavaFX application that uses a text field to get the name of a file, reads the file byte by byte, and displays the bytes as characters. (Exercise 15 describes how to convert a byte value to a character.) Display the first 20 characters in a label. If a byte does not correspond to a legal character, display a space instead. Clicking the Next button reads and displays the next 20 characters in the file. The GUI might look like the sketch in Figure 10.8.

Graphics

15. Write an application that implements a simple text editor. Use a text field and a button to get the file. Read the entire file as characters and display it in a TextArea. The user will then be able to make changes in the text area. Use a **Save** button to get the contents of the text area and write that over the original file.

Technical Details: Read each line from the file and then display the line in the text area using the method appendText(aString). The method getText will return all of the text in the text area in a string that then can be written to the file.

# FIGURE 10.8 GUI for Programming Project 14

•	_
File Name:	Get File
Characters in file: 112 abc 456 222 xxxxxx	Next

### **Answers to Self-Test Questions**

- If a program sends its output to the screen, the output goes away when (or soon after) the program ends. If your program sends its output to a file, the file will remain after the program has finished running. A program that sends its output to a file has preserved its output for use long after the program ends its execution. The contents of a file remain until a person or program changes the file.
- 2. From a file to the program.
- 3. All files contain binary data Text files can be thought of as a sequence of characters. You can write to and read a text file by using a text editor or your own Java program All other files are called binary files. Data in these files cannot conveniently be read using a text editor, but some standard binary files—such as certain music or picture files—can be created and read on any platform Java binary files are platform independent, but other binary files might depend on the programming language and type of computer used to create them.

```
4. PrintWriter outStream = new PrintWriter("sam.txt");
```

```
5. PrintWriter out Stream = new
    PrintWriter(new FileOutputStream("sam.txt", true));
```

```
6. System.out.print("Enter file name: ");
   Scanner keyboard = new Scanner(System.in);
   String fileName = keyboard.next();
   PrintWriter outStream = new PrintWriter(fileName);
```

- 7. A FileNotFoundException would be thrown if the file could not be opened because, for example, there is already a directory (folder) named out.txt. Note that if the file does not exist but can be created, no exception is thrown. If you answered IOException, you are not wrong, because a FileNotFoundException is an IOException. However, the better answer is the more specific exception class, namely, FileNotFoundException.
- 8. PrintWriter textStream = new PrintWriter("dobedo");
- 9. Scanner inputStream = new Scanner(new File("dobedo"));
- Both methods return a value of type String.
- 11. The code for the following program is included with the source code for this book available on the Web:

```
import java.io.File;
import java.util.Scanner;
public class Question11
{
    public static void main(String[] args)
    {
```

```
System.out.print("Enter a file name and I will ");
           System.out.println("tell you whether it exists.");
           Scanner keyboard = new Scanner(System.in);
           String name = keyboard.next();
           File fileObject = new File(name);
           if (fileObject.exists())
           {
               System.out.println("I found the file " + name);
               System.out.println("Delete the file?");
               String ans = keyboard.next();
               if (ans.equalsIgnoreCase("yes"))
           {
               System.out.println("If you delete the file " +
               name);
               System.out.println("all data in the file " + "will
               be lost.");
               System.out.println("Delete?");
               ans = keyboard.next();
               if (ans.equalsIgnoreCase("yes"))
               {
                    if (fileObject.delete())
                       System.out.println("File deleted.");
                   else
                       System.out.println("Can't delete.");
                    }
                   else
                       System.out.println("File not deleted.");
                    }
                    else
                       System.out.println("File not deleted.");
           }
           else
                   System.out.println("I cannot find " + name);
       }
   }
12. ObjectOutputStream toFile = new ObjectOutputStream(
     new FileOutputStream("stuff.data"));
13. toFile.writeDouble(x1);
   toFile.writeDouble(x2);
   toFile.writeDouble(x3);
14. toFile.close();
15. import java.io.FileOutputStream;
   import java.io.ObjectOutputStream;
   import java.io.FileNotFoundException;
   import java.io.IOException;
16. ObjectInputStream fromFile = new ObjectInputStream(
     new FileInputStream("stuff.data"));
```

```
17. double x1 = fromFile.readDouble();
  double x2 = fromFile.readDouble();
  double x3 = fromFile.readDouble();
```

- 18. fromFile.close();
- 19. No. If a number is written to a file using writeInt, it should be read only by readInt. If you use readLong or readDouble to read the number, something will go wrong.
- 20. You should not use readUTF to read a string from a text file. You should use readUTF only to read a string from a binary file. Moreover, the string should have been written to that file using writeUTF.
- 21. The following program is included with the source code for this book available on the Web:

```
import java.io.FileInputStream;
import java.io.FileNotFoundException;
import java.io.ObjectInputStream;
import java.io.IOException;
import java.util.Scanner;
public class Question21
   public static void main(String[] args)
        //To use fileName in a catch block,
        //declare it outside of the try block
        String fileName = null;
        try
        {
           System.out.println("Enter file name:");
           Scanner keyboard = new Scanner(System.in);
           fileName = keyboard.next();
           ObjectInputStream inputStream =
                          new ObjectInputStream(
                          new FileInputStream(fileName));
           System.out.println("The first thing in the file");
           System.out.println(fileName + " is");
           String first = inputStream.readUTF();
           System.out.println(first);
           inputStream.close();
        catch(FileNotFoundException e)
        {
            System.out.println("Problem opening the file "+
                               "fileName);
        catch(EOFException e)
```

22. It will not work because no constructor of <code>ObjectInputStream</code> has a parameter of type <code>String</code>. The correct way to accomplish the desired effect is by using

```
ObjectInputStream inputStream = new ObjectInputStream(
  new FileInputStream("mydata.dat"));
```

- 23. The class FileInputStream does not have any of the methods readInt, readDouble, or readUTF.
- 24. Yes.
- 25. No.
- 26. When opening a binary file for either output or input in the ways discussed in this chapter, a FileNotFoundException and other IOExceptions can be thrown.
- 27. An EOFException will be thrown.
- 28. Because when the end of the file is reached, an exception will be thrown, and that will end the entire try block.
- 29. The following program is included with the source code for this book available on the Web:

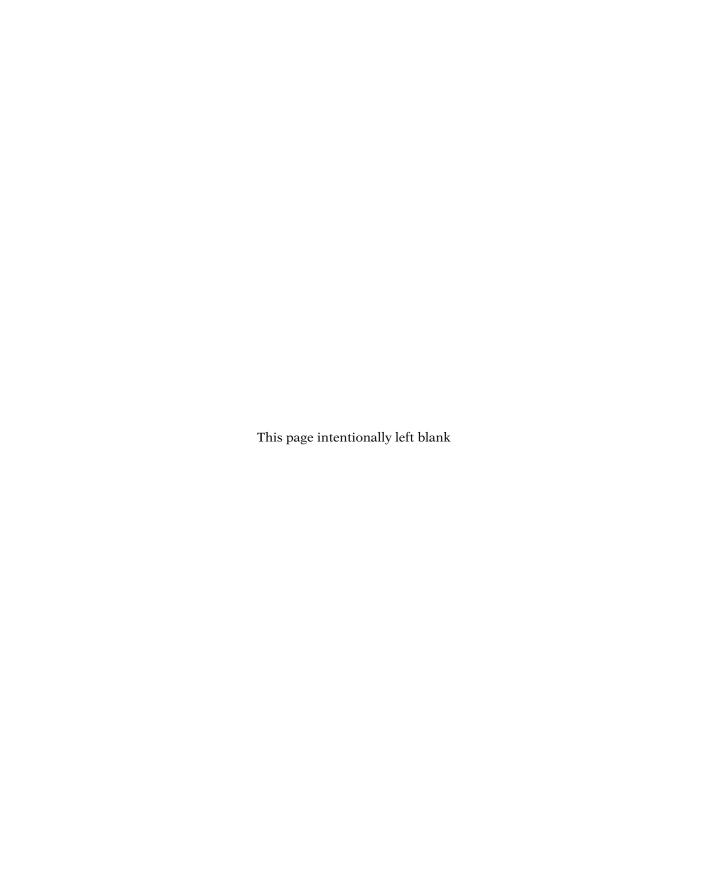
```
{
    while (true)
    {
        double number = inputStream.readDouble();
        System.out.println(number);
    }
}
catch(EOFException e)
{
    //Do nothing
}
System.out.println("End of reading from file.");
inputStream.close();
}
catch(IOException e)
{
    System.out.println("Problem reading from file.");
}
}
```

- 30. You add the two words implementsSerializable to the heading of the class definition. Any objects that are instance variables of the class must belong to a serializable class.
- 31. The return type is Object, which means that the returned value usually needs to be type cast to its "true" class.
- 32. InvalidClassException, NotSerializableException, and IOException.
- 33. ClassNotFoundException, InvalidClassException, StreamCorrupted Exception, OptionalDataException, and IOException.
- 34. The port identifies the program on the computer that should get data received by the computer over the network.
- 35. The relevant code on the client should look something like:

```
outputStream.println(3);
outputStream.println(4);
outputStream.flush();
int sum = inputstream.nextInt();
System.out.println(sum);
```

The relevant code on the client should look something like:

```
int i = inputstream.nextInt ();
int j = inputstream.nextInt ();
outputStream.println(i+j);
outputStream.flush();
```





#### 11.1 THE BASICS OF RECURSION 868

Case Study: Digits to Words 871

How Recursion Works 876

Infinite Recursion 880

Recursive Methods Versus Iterative Methods 882

Recursive Methods That Return a Value 884

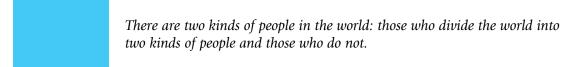
#### 11.2 PROGRAMMING WITH RECURSION 888

Programming Example: Insisting That User Input Be Correct 888

Case Study: Binary Search 890

Programming Example: Merge Sort—A Recursive
Sorting Method 898

## **11.3 GRAPHICS SUPPLEMENT** 902 Lambda Functions and Event Handlers 902



Many people believe that you should never define anything in terms of itself. That would be a kind of circularity, they say. However, there are situations in which it is both possible and useful to define a method in terms of itself. If you do it correctly, it need not even be circular. Java permits you to, in some sense, define a method in terms of itself. More precisely, a Java method definition can contain an invocation of the very method being defined. That is, a method can call itself. Such methods are the subject of this chapter.

#### **OBJECTIVES**

-ANONYMOUS

After studying this chapter, you should be able to

- Describe the concept of recursion
- Use recursion as a programming tool
- Describe and use the recursive form of the binary search algorithm to search an array for a particular element
- Describe and use the merge sort algorithm to sort an array
- Use a basic lambda function to handle an event

#### **PREREQUISITES**

Most of this chapter requires only Chapters 1 through 6. Only the case study "Binary Search" and the programming example "Merge Sort—A Recursive Sorting Method" require knowledge of any additional material. Those two sections require that you know about arrays, which are covered in Chapter 7.

### 11.1 THE BASICS OF RECURSION

```
TIARA

—TIARA is a recursive acronym.

The TTP Project

—DILBERT
```

It often turns out that a natural way to design an algorithm involves using the same algorithm on one or more subcases. For example, the following is an outline of an algorithm for searching for a name in a phone book: Open the

phone book to the middle of the book. If the name is on that page, you are done. If the name is alphabetically before that page, search the first half of the book. If the name is alphabetically after that page, search the second half of the book. Searching half of the phone book is a smaller version of the original task of searching the entire phone book.

Whenever an algorithm has one subtask that is a smaller version of the entire algorithm's task, it is said to be **recursive**. You can use a recursive algorithm to write a **recursive method** in Java. A recursive method contains an invocation of itself. That invocation is called a **recursive call**, or **recursive invocation**.

Of course, you must define a recursive method in the right way, or your Java code will cause problems, but the goal of this chapter is to show you the right way. The general topic of recursive methods is called **recursion**.

We begin with a simple example that illustrates recursion in Java. Given an integer variable num, we would like to output all of the numbers from num down to 1. If num is less than 1, then a new line should be printed. For example, if num is 3, then our program should output:

321

Such a program can obviously be written with a simple for loop. The for loop is the preferred method for this problem, but we will provide a recursive countDown method to illustrate how recursion works for a simple example. Later in this chapter, we will see other problems for which recursion is the more elegant and preferred solution.

First, consider the simplest instance of our problem. This is usually the case when the inputs to the problem are the simplest or smallest values possible and can generally be solved with a straightforward solution. In our problem, the simplest input possible is when the input num is less than 1. In this case, all we need to do is print a blank line. This case is called a **base case**, or **stopping case**—that is, a case containing no recursive calls. As we will see, when this case occurs recursion will end. Additionally, unless this simple case is made to work correctly, no other case will work correctly.

Code for a method implementing the base case for our countdown problem is simple:

```
public static void countDown(int num)
{
    if (num <= 0)
    {
        System.out.println();
    }
}</pre>
```

This method handles the base case, but not the more interesting case when num is 1 or more. To solve this recursively we have to break the problem up into a smaller version of the same problem. This means rephrasing the problem in terms of a method call back to countDown. Let's say that num equals 3. In other words, we have invoked countDown(3). We want to output "321".

A recursive method calls itself

A base or stopping case must be reached This is the same as outputting "3" followed by "21". But outputting "21" is what countDown(2) should output! Our algorithm to solve this becomes:

- Output 3
- Call countDown(2)—which is responsible for outputting 21

In turn, countDown(2) can repeat the same process:

- Output 2
- Call countDown(1)—which is responsible for outputting 1

In turn, countDown(1) can repeat the same process:

- Output 1
- Call countDown(0)—which is responsible for outputting a newline

When countDown(0) is invoked, this executes the base case which prints a newline and ends the recursive method calls.

For an arbitrary value in num the recursive solution becomes:

- Output num
- Call countDown(num-1)—which is responsible for counting from num-1 to 1

A complete program with the algorithm implemented in Java is shown in Listing 11.1.

#### LISTING 11.1 Recursive Countdown Method

```
public class RecursiveCountdown
{
    public static void main(String[] args)
    {
        countDown(3);
    }
    public static void countDown(int num)
    {
        if (num <= 0)
        {
            System.out.println();
        }
        else
        {
            System.out.print(num);
            countDown(num - 1);
        }
    }
}</pre>
```

#### Sample Screen Output

Recursion is possible because every call to countDown results in a distinct variable num that is local to the method for which it is invoked. Figure 11.1 illustrates the sequence of recursive calls and shows how num is passed from one method to the next.

#### **RECAP** Recursive Methods

A recursive method calls itself. That is, a recursive method is one whose definition contains an invocation of itself.

### **CASE STUDY** Digits to Words

In this case study, we will define a method that takes a single integer as an argument and displays the digits of that integer as words. For example, if the argument is the number 223, the method should display

```
two two three
The heading of our method can be

/**
Precondition: number >= 0
Displays the digits in number as words.
*/
public static void displayAsWords(int number)
```

If the number is only a single digit, you can use a long switch statement to decide which word to use for the digit; you don't need recursion. Let's delegate this task to a private method, getWordFromDigit, that displayAsWords can call. We can specify this private method as follows:

Single digits do not need recursion

```
// Precondition: 0 <= digit <= 9
// Returns the word for the argument digit.
private static String getWordFromDigit(int digit)</pre>
```

Thus, when digit is 0, getWordFromDigit returns "zero", when digit is 1, the method returns "one", and so forth.

If the number has more than one digit, we can break our task into subtasks in many ways. Some of these ways lend themselves to a solution that uses recursion, and some do not. One good way to decompose this task into two subtasks, so that you can solve one of the subtasks immediately, and so that the other lends itself to the use of recursion, is as follows:

Break the task into subtasks

- 1. Display all digits but the last one as words.
- 2. Display the last digit as a word.

The first subtask is a smaller version of the original problem. It is, in fact, the exact same problem as the one we started with, except that the number in

```
countDown(3); -
public static void countDown(int num)
      if (num <= 0)
            System.out.println();
      }
      else
            System.out.print(num);
            countDown(num - 1); -
      }
}
       public static void countDown(int num)
                                                                   Console Output
             if (num <= 0)
                                                                     3 2 1
             {
                    System.out.println();
             else
             {
                    System.out.print(num); -
                    countDown(num - 1); —
             }
       }
             public static void countDown(int num)
                   if (num <= 0)
                   {
                          System.out.println();
                   }
                   else
                   {
                          System.out.print(num);
                          countDown(num - 1); __
                   }
             }
                                                       0
                    public static void countDown(int num)
                           if (num <= 0)
                                 System.out.println();
                           }
                          else
                           {
                                 System.out.print(num);
                                 countDown(num - 1);
                           }
                    }
```

question is smaller—in particular, it contains fewer digits. Therefore, you can accomplish the first subtask by calling the very method we are defining. The second subtask is accomplished by a call to the private method getWordFromDigit. This scenario suggests the following refinement of our previous two steps:

#### Algorithm for displayAsWords(number)

- 1. displayAsWords (number after deleting its last digit);
- 2. System.out.print(getWordFromDigit(last digit of number) + " ");

How do we remove the last digit of a number so we can perform step 1 yet retain that digit for step 2? Let's consider an example. Suppose we choose a number that has more than one digit, like 987. We need to break this number into two parts, 98 and 7. We can use integer division by 10 to accomplish this task. For example, 987 / 10 is 98, and 987 % 10 is 7. Thus, our algorithm leads us to the following Java code:

A recursive subtask

```
displayAsWords(number / 10);
System.out.print(getWordFromDigit(number % 10) + " ");
```

Using these statements as the body of the method displayAsWords, we get the following definition:

```
public static void displayAsWords(int number)
//Not quite right
{
    displayAsWords(number / 10);
    System.out.print(getWordFromDigit(number % 10) + " ");
}
```

A recursive method, but it ignores the onedigit case

As the comment indicates, however, this method will not quite work.

The method is recursive and uses the right basic idea, but it has one big problem: The preceding definition assumes that the argument number is more than one digit long. You need to make a special case for numbers that are only one digit long. This observation leads us to revise the method definition as follows:

The correct recursive method

```
public static void displayAsWords(int number)
{
   if (number < 10)
       System.out.print(getWordFromDigit(number) + " ");
   else//number has two or more digits
   {
       displayAsWords(number / 10);
       System.out.print(getWordFromDigit(number % 10) + " ");
   }
}</pre>
```

A recursive call must solve a "smaller" problem

The recursive call displayAsWords(number / 10) has an argument whose value is smaller than number, the argument to the preceding call to displayAsWords. It is important that a recursive call within a method solve a "smaller" version of the original problem (using some intuitive notion of "smaller," which we will make clearer before the end of this chapter).

As you will see in the next section, the successful execution of a recursive method, such as displayAsWords, requires that the simplest (base) case not involve a recursive call. In the definition of displayAsWords, this base case is a one-digit number, which is handled as follows:

One case must not involve recursion

```
if (number < 10)
    System.out.print(getWordFromDigit(number) + " ");</pre>
```

No recursive call occurs in this case.

The definition of the method displayAsWords is now complete. Listing 11.2 shows the method embedded in a demonstration program.

## LISTING 11.2 A Demonstration of Recursion for Digits to Words (part 1 of 2)

```
import java.util.Scanner;
public class RecursionDemo
{
    public static void main(String[] args)
        System.out.println("Enter an integer:");
        Scanner keyboard = new Scanner(System.in);
        int number = keyboard.nextInt();
        System.out.println("The digits in that number are:")
        displayAsWords(number);
        System.out.println();
        System.out.println("If you add ten to that number,")
        System.out.println("the digits in the new number are:")
        number = number + 10;
        displayAsWords(number);
        System.out.println();
    Precondition: number >= 0
    Displays the digits in number as words.
    public static void displayAsWords(int number)
        if (number < 10)
            System.out.print(getWordFromDigit(number) + " ")
                                                          (continued)
```

## LISTING 11.2 A Demonstration of Recursion for Digits to Words (part 2 of 2)

```
else //number has two or more digits
    {
                                                 Recursive call
          displayAsWords(number / 10); 	←
          System.out.print(getWordFromDigit(number) + " ")
    }
}
// Precondition: 0 <= digit <= 9
// Returns the word for the argument digit.
private static String getWordFromDigit(int digit)
{
   String result = null;
    switch (digit)
          case 0: result = "zero";
                                       break;
          case 1: result = "one";
                                       break;
          case 2: result = "two";
                                       break;
          case 3: result = "three";
                                       break;
          case 4: result = "four";
                                       break;
          case 5: result = "five";
                                       break:
          case 6: result = "six";
                                       break:
          case 7: result = "seven";
                                       break;
          case 8: result = "eight";
                                       break:
          case 9: result = "nine";
                                       break;
          default:
              {
                  System.out.println("Fatal Error.");
                  System.exit(0);
              }
    return result;
}
```

#### Sample Screen Output

```
Enter an integer:
987
The digits in that number are:
nine eight seven
If you add ten to that number,
the digits in the new number are:
nine nine seven
```

#### **How Recursion Works**

Exactly how does the computer handle a recursive call? To see the details, consider the following invocation of the method displayAsWords:

```
displayAsWords (987);
```

Although the definition of displayAsWords in Listing 11.2 contains a recursive call, Java does nothing special to handle this or any other invocation of displayAsWords. The value of the argument 987 is copied into the method's parameter number and the resulting code executes. This code is equivalent to the following:

```
{//Code for invocation of displayAsWords(987)
    if (987 < 10)
        System.out.print(getWordFromDigit(987) + " ");
    else//987 has two or more digits
    {
        displayAsWords(987 / 10);
        System.out.print(getWordFromDigit(987 % 10) + " ");
    }
}</pre>
```

Because 987 is not less than 10, the compound statement after the else executes. This compound statement starts with the recursive call displayAsWords (987 / 10). The rest of the compound statement cannot execute until this recursive call is completed. Note that this would be true even if the method was calling another method, rather than calling itself recursively. So the execution of the code for displayAsWords (987) is suspended and waits for the execution of displayAsWords (987 / 10) to complete. When execution of the recursive call completes, the suspended computation resumes. That is, the rest of the compound statement executes.

The new recursive invocation, displayAsWords (987 / 10), is handled just like any other method invocation: The value of the argument 987 / 10 is copied into the parameter number, and the resulting code is executed. Since the value of 987 / 10 is 98, the resulting code is equivalent to the following:

```
{//Code for invocation of displayAsWords(98)
   if (98 < 10)
       System.out.print(getWordFromDigit(98) + " ");
   else//98 has two or more digits
   {
       displayAsWords(98 / 10);
       System.out.print(getWordFromDigit(98 % 10) + " ");
   }
}</pre>
```

Once again, the argument to the method—98 this time—is not less than 10, so the execution of this new code involves a recursive call, namely, displayAsWords (98 / 10). At that point, the preceding computation is

The effect of the original call to the method

The effect of the first recursive call

suspended and waits for this recursive call to complete. The value of the parameter number is the value of 98 / 10, or 9, and the following code begins execution:

The effect of the second recursive call

```
{//Code for invocation of displayAsWords(9)
   if (9 < 10)
        System.out.print(getWordFromDigit(9) + " ");
   else//9 has two or more digits
   {
        displayAsWords(9 / 10);
        System.out.print(getWordFromDigit(9 % 10) + " ");
   }
}</pre>
```

Because 9 is indeed less than 10, only the first part of the if-else statement,

```
System.out.print(getWordFromDigit(9) + " ");
```

is executed. This case is called a **base case**, or **stopping case**—that is, a case containing no recursive calls. A quick look at the definition of the method getWordFromDigit shows that the string "nine" is displayed on the screen. The invocation of displayAsWords (98 / 10) is now complete.

At this point, the suspended computation, shown here, can resume after the position indicated by the arrow:

```
stopping case
must be reached
```

A base or

Continuing execution after the last recursive call finishes

Thus, the statement

```
System.out.print(getWordFromDigit(98 % 10) + " ");
```

executes—causing the string "eight" to be displayed on the screen—and ends the invocation of the recursive call displayAsWords (98).

Stay with us, dear reader! The process is almost over. We have only one more suspended computation waiting to be completed, and it is shown in the code that follows:

Continuing execution after the next-to-last recursive call finishes

The computation resumes after the position indicated by the arrow, and the following code executes:

```
System.out.print(getWordFromDigit(987 % 10) + " ");
```

This statement causes "seven" to be displayed on the screen, and the entire process ends. The sequence of recursive calls is illustrated in Figure 11.2

#### FIGURE 11.2 Executing a Recursive Call

```
displayAsWords(987) is equivalent to executing:

{//Code for invocation of displayAsWords(987)
    if (987 < 10)
        System.out.print(getWordFromDigit(987) + " ");
    else //987 has two or more digits
    {
        displayAsWords(987 / 10);
        System.out.print(getWordFromDigit(987 % 10) + " ");
    }
}</pre>
```

```
displayAsWords(987/10) is equivalent to displayAsWords(98), which is
    equivalent to executing:

{//Code for invocation of displayAsWords(98)
    if (98 < 10)
        System.out.print(getWordFromDigit(98) + " ");
    else //98 has two or more digits
    {
        displayAsWords(98 / 10);
        System.out.print(getWordFromDigit(98 % 10) + " ");
    }
}</pre>
```

Note that nothing special happens when an invocation of a recursive method executes. Argument values are copied to parameters, and the code in the method definition executes, just as it would for any method invocation.

#### **REMEMBER** Keys to Successful Recursion

A definition of a method that includes a recursive invocation of the method itself will not behave correctly unless you follow some specific design guidelines. The following rules apply to most cases that involve recursion:

- The heart of the method definition must be an if-else statement or some other branching statement that leads to different cases, depending on some property of a parameter of the method.
- One or more of the branches should include a recursive invocation of the method. These recursive invocations must, in some sense, use "smaller" arguments or solve "smaller" versions of the task performed by the method.
- One or more branches must include no recursive invocations.
   These branches are the base cases, or stopping cases.



### **RECAP Base (Stopping) Cases**

Base cases must be designed so that they terminate every chain of recursive calls. A method invocation can produce a recursive invocation of the same method, and that invocation may produce another recursive invocation, and so forth for some number of recursive calls, but every such chain must eventually lead to a base case that ends with no recursive invocation. Otherwise, an invocation of the method might never end (or might not end until the computer runs out of resources).

A typical recursive method definition includes an if-else statement or other branching statement that chooses among one or more cases that each include a recursive call of the method and one or more cases that each end the method invocation without any recursive invocation. Every chain of recursive calls must eventually lead to one of those nonrecursive, or base, cases.

The most common way to ensure that a base case is always reached is to make all the recursive invocations of the method use a "smaller" argument. For example, consider the method displayAsWords given in Listing 11.2. Its parameter is number, and the parameter to the method's recursive invocation is the smaller value number / 10. In this way, the recursive invocations in a chain of recursive calls each have a smaller argument. Because the definition of this method has a base case for any one-digit argument, we know that, eventually, a base case is always reached.

#### **Infinite Recursion**

An example of infinite recursion

Consider the method displayAsWords defined in the previous section. Suppose we had been careless and had defined it as follows:

```
public static void displayAsWords(int number)//Not quite right
{
    displayAsWords(number / 10);
    System.out.print(getWordFromDigit(number % 10) + " ");
}
```

In fact, we almost did define it this way, until we noticed an omitted case. Suppose, however, that we did not notice the omitted case and used this shorter definition. Let's quickly trace the computation of the recursive call displayAsWords (987).

The method invocation displayAsWords (987) produces the recursive call displayAsWords (987 / 10),

which is equivalent to displayAsWords (98). The invocation of displayAsWords (98) produces the recursive call

```
displayAsWords(98 / 10),
```

which is equivalent to displayAsWords (9). Because our incorrect version of displayAsWords has no special case for one-digit numbers, the invocation of displayAsWords (9) produces the recursive call

```
displayAsWords(9 / 10),
```

which is equivalent to displayAsWords(0). The invocation of displayAsWords(0) produces the recursive call

```
displayAsWords(0 / 10),
```

which is equivalent to displayAsWords(0).

Now the problem becomes apparent: The invocation of displayAsWords (0) produces another invocation of displayAsWords (0), which produces yet another invocation of displayAsWords (0), and so forth forever—or until your computer runs out of resources. This situation is called **infinite recursion**.

Note that the preceding definition of displayAsWords is incorrect only in the sense that it performs the wrong computation. It is not illegal. The Java compiler will accept this definition of displayAsWords—and any similar recursive method definition that does not have a case to stop the series of recursive calls. However, unless your recursive definition ensures that a base case will, in fact, be reached, you will get an infinite chain of recursive calls, causing your program either to run forever or to end abnormally.

In order for a recursive method definition to work correctly and not produce an infinite chain of recursive calls, there must be one or more cases—the base cases—that, for certain values of the argument(s), will end without producing any recursive call. The correct definition of

displayAsWords, given in Listing 11.2, has one base case, which is highlighted in the following code:

```
public static void displayAsWords(int number)
{
    if (number < 10)
        System.out.print(getWordFromDigit(number) + " ");
    else //number has two or more digits
        {
            displayAsWords(number / 10);
            System.out.print(getWordFromDigit(number % 10) + " ");
        }
}</pre>
```

#### **GOTCHA** Stack Overflow

When a method invocation leads to infinite recursion, your program is likely to end with an error message that mentions a "stack overflow." The term **stack** refers to a data structure that is used to keep track of recursive calls—and other things as well.



The system maintains a record within the computer's memory of each recursive call. You can imagine these records as pieces of paper. The system "stacks" these papers one on top of the other. When this stack becomes too large for it to fit in the available memory, a **stack overflow** occurs.

### **SELF-TEST QUESTIONS**

1. What output will be produced by the following code?

2. What is the output produced by the following code?

```
public class Question2
{
    public static void main(String[] args)
    {
        methodB(3);
    }
    public static void methodB(int n)
    {
        if (n < 1)
            System.out.println('B');
        else
        {
             //The following two lines are in the reverse of
            //their order in Self-Test Question 1.
            System.out.println('R');
        methodB(n - 1);
        }
    }
}</pre>
```

3. Write a recursive definition for the following method:

```
/**
Precondition: n >= 1.
Displays the symbol '#' n times on one line
and then advances to the next line.
*/
public static void displaySharps(int n)
For example, the call displaySharps(3) is equivalent to
System.out.println("###");
```

If you have trouble writing this method, simplify it so that the output does not advance to the next line. For that simpler case, you need not worry about the distinction between print and println. In the simpler case, you use only print. After doing the simpler case, try to do the exercise as stated.

#### Recursive Methods Versus Iterative Methods

Any method definition that includes a recursive call can be rewritten so that it accomplishes the same task without using recursion. For example, Listing 11.3 contains a revision of the program in Listing 11.2 in which the definition of displayAsWords does not use recursion. Both versions of displayAsWords perform the exact same action—that is, they write the same output to the screen. As is the case here, the nonrecursive version of a method definition typically involves a loop instead of recursion. A nonrecursive repetitive process

is called **iteration**, <sup>1</sup> and a method that implements such a process is called an **iterative method**.

# methods that involve a loop are said to be

iterative

Processes or

#### LISTING 11.3 An Iterative Version of displayAsWords

```
import java.util.scanner;
public class IterativeDemo
    public static void main(String[] args)
    <The rest of main is the same as Listing 11.2.>
    Precondition: number >= 0
    Displays the digits in number as words.
    public static void displayAsWords(int number)
    {
        int divisor = getPowerOfTen(number);
        int next = number;
        while (divisor >= 10)
            System.out.print(getWordFromDigit(next / divisor) +
            next = next % divisor
            divisor = divisor / 10
        System.out.print(getWordFromDigit(next / divisor) + " ");
    }
    // Precondition: n \ge 0.
    // Returns 10 raised to the power n.
    private static int getPowerOfTen(int n)
    {
        int result = 1;
        while (n \ge 10)
        {
            result = result * 10;
            n = n / 10;
        result result;
    private static String getWordFromDigit(int digit)
   <The rest of getWordFromDigit is the same as in Listing 11.2.>
}
```

#### Screen Output

The output is exactly the same as in Listing 11.2.

<sup>&</sup>lt;sup>1</sup> Note that Chapter 4 defines an *iteration* as one repetition of a loop. The term also has the definition we introduce here.

A recursive method uses more storage space than an iterative version of the method, because of the overhead to the system that results from tracking the recursive calls and suspended computations. This overhead can make a recursive method run slower than a corresponding iterative one. Sometimes the extra time necessary for a particular recursive method is so large that recursion should not be used. For example, the Fibonacci numbers introduced in Programming Project 7 at the end of this chapter should never be computed recursively. In other situations, however, recursion is perfectly acceptable and can make your code easier to understand. Indeed, there are times when recursion can be a big aid in terms of program clarity.

#### Recursive Methods That Return a Value

A recursive method can be a void method, as you have seen, or it can be a method that returns a value. You design a recursive method that returns a value in essentially the same way that you design a recursive void method. That is, you follow the design guidelines on page 843 in the box titled "Keys to Successful Recursion." We can clarify the second guideline so that it accounts for returned values by adding the italicized words in the following:

One or more of the branches should include a recursive invocation of the method *that leads to the returned value*. These recursive invocations must, in some sense, use "smaller" arguments or solve "smaller" versions of the task performed by the method.

Facts that can be used to solve this problem recursively The recursive method getNumberOfZeros defined in Listing 11.4 returns a value. It returns the number of zeros in the integer given as an argument. For example, getNumberOfZeros(2030) returns 2, because 2030 contains two zero digits. Let's look at how this method works.

## LISTING 11.4 A Recursive Method That Returns a Value (part 1 of 2)

## LISTING 11.4 A Recursive Method That Returns a Value (part 2 of 2)

```
/**
Precondition: n >=0
Returns the number of zero digits in n.
*/
public static int getNumberOfZeros(int n)
{
    int result;
    if (n == 0)
        result = 1;
    else if (n < 10)
        result = 0; //n has one digit that is not 0
    else if (n % 10 == 0)
        result = getNumberOfZeros(n / 10) + 1;
    else //n % 10 !=0
        result = getNumberOfZeros(n / 10);
    return result;
}</pre>
```

#### Sample Screen Output

```
Enter a nonnegative number:
2008
2008 contains 2 zeros.
```

The definition of the method uses the following simple facts:

- If *n* contains only one digit, the number of zero digits in *n* is 1 if *n* is zero and 0 if *n* is not zero.
- If *n* contains two or more digits, let *d* be its last digit and *m* be the integer left after removing the last digit from *n*. The number of zero digits in *n* is the number of zeros in *m* plus 1 if *d* is zero.

For example, the number of zeros in 20030 is the number of zeros in 2003 plus 1 for the last zero. The number of zeros in 20035 is the number of zeros in 2003 without adding anything, because the extra digit is not zero. With this definition in mind, let's go through a simple computation using getNumberOfZeros.

First, consider the simple expression

```
getNumberOfZeros(0)
```

which might occur as the right-hand side of some assignment statement. When the method is called, the value of the parameter n is set equal to 0, and the code in the body of the method definition is executed. Because the value of n is equal to 0, the first case of the multiway if-else statement applies, and the value returned is 1.

Next, consider another simple expression:

```
getNumberOfZeros(5)
```

When the method is called, the value of the parameter n is set equal to 5, and the code in the body of the method definition is executed. Since the value of n is not equal to 0, the first case of the multiway if-else statement does not apply. The value of n is, however, less than 10, so the second branch of the multiway if-else statement applies, and the value returned is 0. As you can see, these two simple cases work out correctly.

Now let's look at an example that involves a recursive call. Consider the expression

```
getNumberOfZeros(50)
```

When the method is called, the value of n is set equal to 50, and the code in the body of the method definition is executed. Since this value of n is not equal to 0 and is not less than 10, neither of the first two branches of the multiway if-else statement applies. 50 % 10 is 0, so the third branch applies. Thus, the value returned is

```
getNumberOfZeros(n / 10) + 1
which in this case is equivalent to
  getNumberOfZeros(50 / 10) + 1
which, in turn, is equivalent to
  getNumberOfZeros(5) + 1
```

We saw earlier that getNumberOfZeros(5) returns 0, so the value returned by getNumberOfZeros(50) is 0 + 1, or 1, which is the correct value.

Larger numbers will produce longer chains of recursive calls. For example, consider the expression

```
getNumberOfZeros(2008)
```

A trace of recursive calls

The value of this expression is calculated as follows:

```
\label{eq:getNumberOfZeros(2008)} \mbox{ is getNumberOfZeros(200) } + 0 \\ \mbox{getNumberOfZeros(200) is getNumberOfZeros(20) } + 1 \\ \mbox{getNumberOfZeros(20) is getNumberOfZeros(2) } + 1 \\ \mbox{getNumberOfZeros(2) is 0 (a base case)} \\ \mbox{getNumberOfZeros(20) is getNumberOfZeros(2) } + 1, \mbox{ which is 0 } + 1, \\ \mbox{ or 1} \\ \mbox{getNumberOfZeros(200) is getNumberOfZeros(20) } + 1, \mbox{ which is 1 } + 1, \\ \mbox{ or 2} \\ \mbox{getNumberOfZeros(2008) is getNumberOfZeros(200) } + 0, \mbox{ which is 2 } + 0, \\ \mbox{ or 2} \\ \mbox{ } \end{array}
```

Note that when Java reaches the base case, getNumberOfZeros(2), three computations have been suspended. After calculating the value returned for the base case, the most recently suspended computation resumes, yielding the value of getNumberOfZeros(20). After that, each of the other suspended computations resumes and completes in turn. Each computed value is used in another suspended computation, until the computation for the original invocation, getNumberOfZeros(2008), completes. The suspended computations are completed in an order opposite to the order in which they were suspended. The final value returned is 2, which is correct, because 2008 has two zero digits.



#### **REMEMBER** Do Not Confuse Recursion and Overloading

Do not confuse recursion and overloading. When you overload a method name, you are giving two different methods the same name. If the definition of one of these two methods includes a call to the other, that is not recursion. In a recursive method definition, the definition of the method includes a call to the exact same method with the exact same definition, including the same number and types of parameters.

#### **SELF-TEST QUESTIONS**

4. What is the output of the following code?

```
public class Question4
{
    public static void main(String[] args)
    {
        System.out.println(getMysteryValue(3));
    }
    public static int getMysteryValue(int n)
    {
        if (n <= 1)
            return 1;
        else
            return getMysteryValue(n - 1) + n;
    }
}</pre>
```

5. Complete the definition of the following method. Your definition should be recursive.

```
/**
Precondition: n >= 0.
Returns 10 to the power n.
*/
public static int computeTenToThe(int n)
```

6. Complete the definition of the following method. Your definition should be recursive. Unlike the method in Question 5, this method does not restrict the sign or value of its argument. You can use the same technique you used for Question 5, but you should have one more recursive case for negative exponents. (*Hints*:  $10^n$  is  $1/10^{-n}$  for negative values of n. Also, if n is negative, -n is positive.)

```
/**
Precondition: n can be any int.
Returns 10 to the power n.
*/
public static int computeTenToThe(int n)
```

#### 11.2 PROGRAMMING WITH RECURSION

All short statements about programming techniques are false.

-ANONYMOUS

In this section, we present some programs that illustrate ways to use recursion.

### **PROGRAMMING EXAMPLE**

**Insisting That User Input Be Correct** 

The program in Listing 11.5 simply requests a positive integer and then counts down from that integer to zero. The method getCount reads the integer from the user. Notice that if the user enters a number that is not positive, the method getCount calls itself. This call starts the input process all over again from the beginning. If the user enters another incorrect number, another recursive call occurs, and the input process will start yet again. This procedure is repeated until the user enters a positive integer. Of course, in practice, not many recursive calls would be necessary, but they would take place as often as the user entered bad data. In general, this technique is not recommended because every invalid entry results in a recursive call. If the user kept making invalid entries, this would be similar to infinite recursion and could eventually result in a stack overflow.

### LISTING 11.5 Recursion for Starting Over (part 1 of 2)

#### LISTING 11.5 Recursion for Starting Over (part 2 of 2)

```
{
        CountDown countDowner = new CountDown();
        countDowner.getCount();
        countDowner.showCountDown();
    public void getCount()
        System.out.println("Enter a positive integer:");
        Scanner keyboard = new Scanner(System.in);
        count = keyboard.nextInt();
        if (count <= 0)
            System.out.println("Input must be positive.");
            System.out.println("Try again.");
            getCount();//start over
        }
    }
    public void showCountDown()
        System.out.println("Counting down:");
        for (int left = count; left >= 0; left--)
            System.out.print(left + ", ");
        System.out.println("Blast Off!");
    }
}
```

#### Sample Screen Output

```
Enter a positive integer:

O
Input must be positive.
Try again.
Enter a positive integer:

3
Counting down:
3, 2, 1, 0, Blast Off!
```

## SELF-TEST QUESTION

7. Revise the method getCount in Listing 11.5 so that it is iterative instead of recursive.

## **CASE STUDY** Binary Search



This case study assumes that you have already covered the basics about arrays given in Chapter 7. We will design a recursive method that tells whether a given number is or is not in an array of integers. If the sought-after number is in the array, the method will also give the index of the number's position in the array.

For example, suppose that the array contains a list of winning lottery tickets and you want to search the list to see whether you are a winner. Suppose another array contains the prize amounts for these tickets in an order that corresponds to the order of the tickets in the first array. Thus, if you know the index of a winning number, you can use this index to locate the amount of your winnings in the second array.

In Chapter 7, the section "Searching an Array" discussed a method for searching an array simply by checking every array position. The method we develop in this case study will be much faster than that simple sequential search. However, for this faster method to work, the array must be sorted. We will assume that the array is already sorted into ascending order and is completely filled. So if the array is named a, we know that

 $a[0] \le a[1] \le a[2] \le a[a.length-1]$ 

Recall that the sequential search does not have this requirement.

Let's design our method to return an integer that gives the index of the sought-after number. If the number is not in the array, the method will return -1. Before we worry about the exact setup of the class and methods and about connecting the method to an array, we first design some pseudocode to solve the search problem.

Because the array is sorted, we can rule out whole sections of the array that could not possibly contain the number we seek. For example, if we are looking for the number 7 and we know that a[5] contains 9, we know, of course, that 7 is not equal to a[5]. But we also know much more: Because the array is sorted, we know that

 $7 < a[5] \le a[i] \text{ for } i \ge 5$ 

So we know that 7 is not equal to a[i] for any value of i that is greater than or equal to 5. Thus, all the elements a[i] for  $i \ge 5$  need not be searched. We know that the sought-after value 7 is not among them without needing to check them. Similarly, if the sought-after number, 7, were greater than a[5]—for example, if a[5] were 3 instead of 9—we could rule out all the elements a[i] for  $i \le 5$ .

Let's express these observations as a first-draft algorithm, after replacing the index 5 in the preceding examples with m:

Assume a sorted array

Specify the method's behavior

First-draft algorithm

Algorithm to search a sorted array for the element target (draft 1)

- 1. m = an index between 0 and (a.length 1)
- 2. if(target == a[m])

```
    return m;
    else if (target < a[m])</li>
    return the result of searching a[0] through a[m - 1]
    else if (target > a[m])
    return the result of searching a[m + 1] through a[a.length - 1]
```

If a[m] is not the element we seek, we can ignore one part of the array and search only the other part. Our choice of m affects the size of these two parts. Since we do not know which part contains a[m], we might as well make the two parts as equal in size as we can. To do so, we choose m so that a[m] would be at or near the middle of the array. Thus, we replace step 1 of the previous pseudocode with

```
1. m = approximate midpoint between 0 and (a.length - 1)
```

To clarify our algorithm, we can rename the index m as mid.

Notice that each of the two else-if cases searches a segment of the array. This search is a smaller version of the very task we are designing. This observation suggests recursion. In fact, the segments of the array can be searched by using recursive calls to the algorithm itself. Although we need to write two recursive calls in our algorithm, only one of them will execute during a given search, because we will be searching only one half of the array. Thus, if a[mid] is not the element we seek, we would search either

```
a[0] through a[mid - 1], or a[mid + 1] through a[a.length - 1]
```

There is, however, one complication. (Isn't there always?) To implement these recursive calls, we need more parameters. These recursive calls specify that a subrange of the array is to be searched. In the first case, it is the elements indexed by 0 through mid - 1. In the second case, it is the elements indexed by mid + 1 through a.length - 1. Thus, we need two extra parameters to specify the first and last indices of the subrange of the array to be searched. Let's call these extra parameters first and last, respectively. We now can express the pseudocode more precisely as follows:

## Algorithm to search a [first] through a [last] of a sorted array for the element target (draft 2)

Second-draft algorithm

```
1. mid = approximate midpoint between first and last
```

```
2. if (target == a[mid])
```

3. return mid

```
4. else if (target < a[mid])
```

5. return the result of searching a[first] through a[mid - 1]

```
6. else if (target > a[mid])7. return the result of searching a[mid + 1] through a[last]
```

If we want to search the entire array, we would set first equal to 0 and last equal to a.length - 1 initially. But each recursive call will use some other values for first and last. For example, if the first recursive call made is the one in step 5, it will set first equal to 0 and last equal to mid - 1.

You should always ensure that any recursive algorithm you write will not produce an infinite recursion by checking whether every possible invocation of the algorithm will lead to a base case. Consider the three possibilities in the nested if-else statement. In the first case, the sought-after number is found in a[mid], and there is no recursive call, so the process terminates. We have reached the base case. In each of the other two possibilities, a smaller subrange of the array is searched by a recursive call. If the sought-after number is in the array, the algorithm will narrow the range down more and more until it finds the number. But what if the number is not anywhere in the array? Will the resulting series of recursive calls eventually lead to a base case if the number is not in the array? Unfortunately not.

Final algorithm for a binary search

The problem is not hard to fix, however. Note that in each recursive call, either the value of first is increased or the value of last is decreased. If these two indices ever pass each other in value and first actually becomes larger than last, we will know that there are no more indices left to check and that the number target is not in the array. If we add this test to our pseudocode, we get the following, more complete, pseudocode:

## Algorithm to search a [first] through a [last] of a sorted array for the element target (final version)

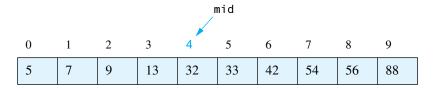
```
    mid = approximate midpoint between first and last
    if (first > last)
    return -1
    else if (target == a[mid])
    return mid
    else if(target < a[mid])</li>
    return the result of searching a[first] through a[mid - 1]
    else if(target > a[mid])
    return the result of searching a[mid + 1] through a[last]
```

This way of searching an array is called a **binary search**. While searching, the algorithm eliminates one half of the array, then half of what's left, and so on. Figure 11.3 provides an example of how this algorithm works.

#### FIGURE 11.3 A Binary Search Example

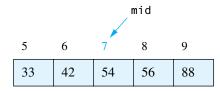
target is 33

Eliminate half of the array elements:



- 1. mid = (0 + 9)/2 (which is 4).
- 2. 33 > a[mid] (that is, 33 > a[4]).
- So if 33 is in the array, 33 is one of a [5],a [6],a [7],a [8],a [9].

Eliminate half of the remaining array elements:



- 1. mid = (5 + 9)/2 (which is 7).
- 2. 33 < a[mid] (that is, 33 < a[7]).
- 3. So if 33 is in the array, 33 is one of a[5], a[6].

Eliminate half of the remaining array elements:



- 1. mid = (5 + 6)/2 (which is 5).
- 2. 33 equals a[mid], so we found 33 at index 5.

33 found in a [5].

Now we need to translate this pseudocode algorithm into Java code. Let's name the method binarySearch and place it in a class called ArraySearcher. The class will have an instance variable to name the array, and the array to be searched will be given that name by the constructor. Since the method binarySearch has extra parameters, the user would always have to set them

The public method find calls the private method binarySearch

A binary search is fast

equal to 0 and a.length - 1 in order to specify that the entire array be searched. To avoid the need to worry about this detail, we add the method find, which simply calls the method binarySearch. It allows the user simply to specify the target value and not be concerned about indices. Since the method binarySearch is now just a helping method, we make it a private method.

The final code for the class ArraySearcher is shown in Listing 11.6. A simple program that demonstrates how this class works is given in Listing 11.7.

#### LISTING 11.6 A Binary Search Class (part 1 of 2)

```
Class for searching an already sorted array of integers.
public class ArraySearcher
     private int[] a;
    /**
     Precondition: the Array is full and is sorted
     from lowest to highest.
    public ArraySearcher(int[] theArray)
        a = theArray; //a is now another name for theArray.
     If target is in the array, returns the index of an occurrence
     of target. Returns -1 if target is not in the array.
    public int find(int target)
        return binarySearch(target, 0, a.length - 1);
    //Uses binary search to search for target in a[first] through
    //a[last] inclusive. Returns the index of target if target
    //is found. Returns -1 if target is not found.
    private int binarySearch(int target, int first, int last)
    {
        int result:
        if (first > last)
            result = -1;
        else
        {
```

(continued)

#### LISTING 11.6 A Binary Search Class (part 2 of 2)

```
int mid = (first + last)/2;
if (target == a[mid])
    result = mid;
else if (target < a[mid])
    result = binarySearch(target, first, mid - 1);
else //(target > a[mid])
    result = binarySearch(target, mid + 1, last);
}
return result;
}
```

#### LISTING 11.7 A Binary Search Demonstration (part 1 of 3)

```
import java.util.Scanner;
public class ArraySearcherDemo
    public static void main(String[] args)
    {
        int[] anArray = new int[10];
        Scanner keyboard = new Scanner(System.in);
        System.out.println("Enter 10 integers in increasing " +
                            "order,");
        System.out.println("one per line.");
        for (int i = 0; i < 10; i++)
             anArray[i] = keyboard.nextInt();
        System.out.println();
        for (int i = 0; i < 10; i++)
            System.out.print("a[" + i + "]=" + anArray[i] + " ");
        System.out.println();
        System.out.println();
        ArraySearcher finder = new ArraySearcher(anArray);
        String ans;
        do
        {
            System.out.println("Enter a value to search for:");
            int target = keyboard.nextInt();
            int result = finder.find(target);
            if (result < 0)</pre>
              System.out.println(target + "is not in the array.");
              System.out.println(target + "is at index" + result);
            System.out.println("Again?");
            ans = keyboard.next();
                                                          (continued)
```

#### LISTING 11.7 A Binary Search Demonstration (part 2 of 3)

#### Sample Screen Output

```
Enter 10 integers in increasing order,
one per line.
0
2
4
6
8
10
12
14
16
18
a[0]=0
a[1]=2 a[2]=4 a[3]=6 a[4]=8 a[5]=10 a[6]=12 a[7]=14
a[8]=16 \ a[9]=18
Enter a value to search for:
14
14 is at index 7
Again?
yes
Enter a value to search for:
0 is at index 0
Again?
yes
Enter a value to search for:
2 is at index 1
Again?
yes
```

### LISTING 11.7 A Binary Search Demonstration (part 3 of 3)

```
Enter a value to search for:

13

13 is not in the arrray.

Again?

no

May you find what you're searching for.
```

The binary search algorithm is extremely fast. It eliminates about half the array from consideration right at the start. It then eliminates another quarter of the array, then another eighth, and so forth. This process of elimination means that most of the array need not be searched at all, saving a lot of time. For example, for an array with 1000 elements, the binary search will need to compare only about 10 array elements with the target value. By comparison, a simple serial search could possibly compare all 1000 array elements with the target value; on average, it will make about 500 comparisons. Searching an array of 1 million items provides an even more impressive example. A binary search of 1 million items requires at most 20 comparisons, whereas a sequential search of the same array would take, on average, 500,000 comparisons and might even need 1 million comparisons.

#### PROGRAMMING TIP Generalize the Problem

When designing a recursive algorithm, you often need to solve a more general problem than the one you set out to solve. For example, consider the method binarySearch in the previous case study. We designed it to search not only the entire array but also any subrange of the array. This design was necessary to be able to express the recursive subcases. It is often true that, when you are designing a recursive algorithm, you must make the problem a bit more general so that you can easily express the recursive subcases.



### **SELF-TEST QUESTIONS**

- 8. Will the binary search algorithm work if the array is not sorted?
- 9. Will the binary search work for an array that has repeated values, or do all the values need to be different?
- 10. Suppose you want the class ArraySearcher to work for arrays whose values are sorted in descending order instead of ascending order. How would you change the definition of ArraySearcher?

### **PROGRAMMING EXAMPLE**

## Merge Sort—A Recursive Sorting Method

Some of the most efficient sorting algorithms are easiest to state as recursive algorithms. One such example is the **merge sort** algorithm for sorting an array. In this example, we present a method that implements the merge sort algorithm to sort an array of int values from smallest to largest. With minor changes, you can obtain a method to sort an array of items of any type that can be ordered. Some examples of these changes are discussed in the self-test questions.

Merge sort is an example of a divide-and-conquer algorithm. The array to be sorted is divided in half, and the two halves of the array are sorted by recursive calls. That process produces two smaller sorted arrays. The two sorted arrays are then merged to form a single sorted array with all the elements from the two smaller arrays. In outline form, the algorithm is as follows:

#### Merge sort algorithm to sort the array a

- 1. If the array a has only one element, do nothing (base case). Otherwise, do the following (recursive case):
- 2. Copy the first half of the elements in a to a smaller array named firstHalf.
- 3. Copy the rest of the elements in the array a to another smaller array named lastHalf.
- 4. Sort the array firstHalf using a recursive call.
- 5. Sort the array lastHalf using a recursive call.
- 6. Merge the elements in the arrays firstHalf and lastHalf into the array a.

It is straightforward to implement most of the details of this algorithm as Java code. However, the merging of the two arrays firstHalf and lastHalf into a single sorted array a does require some explanation.

The basic idea of the merging algorithm is as follows: The arrays firstHalf and lastHalf are both sorted from smallest to largest. So the smallest element in the array firstHalf is firstHalf[0], and the smallest element in the array lastHalf is lastHalf[0]. Therefore, the smallest of all the elements in both arrays is the smaller of firstHalf[0] and lastHalf[0]. Move that smallest element to a[0].

For example, let's say that the smaller element is lastHalf[0], so that element gets moved to a[0]. The smallest of the elements left to move to a is the smaller of firstHalf[0] and lastHalf[1]. Move that element to a[1], and continue with this process.

The Java code for the merging process will look something like the following:

```
int firstHalfIndex = 0, lastHalfIndex = 0, aIndex = 0;
while (Some_Condition)
{
    if (firstHalf[firstHalfIndex] < lastHalf[lastHalfIndex])</pre>
```

Merging two sorted arrays into one sorted array

```
{
    a[aIndex] = firstHalf[firstHalfIndex];
    aIndex++;
    firstHalfIndex++;
}
else
{
    a[aIndex] = lastHalf[lastHalfIndex];
    aIndex++;
    lastHalfIndex++;
    }
}
```

Now, what is the condition for the while loop? Note that the loop does not make sense unless both of the arrays firstHalf and lastHalf have elements left to move. So rather than looping until the array a is full, we must loop until all the elements in one of the arrays firstHalf or lastHalf have been completely moved to a. Hence, the while loop condition can be

```
while ((firstHalfIndex < firstHalf.length) &&
    (lastHalfIndex < lastHalf.length))</pre>
```

When this while loop ends, one of the arrays firstHalf or lastHalf has had all of its elements moved to the array a, and the other might have—in fact, probably will have—elements left to move to a. These elements are sorted and are all larger than the elements already moved to a. So all we need to do is move the elements remaining in the array firstHalf or lastHalf to a.

Listing 11.8 gives the complete Java implementation of the merge sort algorithm, including the method merge. Listing 11.9 contains a demonstration program that uses the MergeSort class from Listing 11.8.

After the loop, one array will be entirely moved

### LISTING 11.8 The MergeSort Class (part 1 of 3)

(continued)

### LISTING 11.8 The MergeSort Class (part 2 of 3)

```
{
            int halfLength = a.length / 2;
            int[] firstHalf = new int[halfLength];
            int[] lastHalf = new int[a.length - halfLength];
            divide(a, firstHalf, lastHalf);
            sort(firstHalf);
            sort(lastHalf);
            merge(a, firstHalf, lastHalf);
    }
     //else do nothing. a.length == 1, so a is sorted.
//Precondition: a.length = firstHalf.length + lastHalf.length.
//Postcondition: All the elements of a are divided
//between the arrays firstHalf and lastHalf.
private static void divide(int[] a, int[] firstHalf,
                                      int[] lastHalf)
{
    for (int i = 0); i < firstHalf.length; i++)</pre>
        firstHalf[i] = a[i];
    for (int i = 0; i < lastHalf.length; i++)</pre>
        lastHalf[i] = a[firstHalf.length + i];
}
//Precondition: Arrays firstHalf and lastHalf are sorted from
//smallest to largest; a. length = firstHalf.length +
//lastHalf.length.
//Postcondition: Array a contains all the values from firstHalf
//and lastHalf and is sorted from smallest to largest.
private static void merge(int[] a, int[] firstHalf,
                                     int[] lastHalf)
{
    int firstHalfIndex = 0, lastHalfIndex = 0, aIndex = 0;
    while ((firstHalfIndex < firstHalf.length) &&</pre>
            (lastHalfIndex < lastHalf.length))</pre>
    {
        if (firstHalf[firstHalfIndex] < lastHalf[lastHalfIndex])</pre>
        {
             a[aIndex] = firstHalf[firstHalfIndex];
             firstHalfIndex++;
        }
        else
          a[aIndex] = lastHalf[firstHalfIndex];
          lastHalfIndex++;
        }
        aIndex++;
}
                                                       (continued)
```

### LISTING 11.8 The MergeSort Class (part 3 of 3)

```
//At least one of firstHalf and lastHalf has been
    //completely copied to a.
    //Copy rest of firstHalf, if any.
    while (firstHalfIndex < firstHalf.length)</pre>
        a[aIndex] = firstHalf[firstHalfIndex];
        aIndex++:
        firstHalfIndex++;
    }
    //Copy rest of lastHalf, if any.
    while (lastHalfIndex < lastHalf.length)</pre>
    {
       a[aIndex] = lastHalf[lastHalfIndex];
       aIndex++;
       lastHalfIndex++;
    }
 }
}
```

### LISTING 11.9 Demonstration of the MergeSort Class

```
public class MergeSortDemo
{
    public static void main(String[] args)
    {
        int[] anArray = {7, 5, 11, 2, 16, 4, 18, 14, 12, 30};
        System.out.println("Array values before sorting:");
        for (int i = 0; i < anArray.length; i++)
            System.out.print(anArray[i] + " ");
        System.out.println();
        MergeSort.sort(anArray);
        System.out.println("Array values after sorting:");
        for (int i = 0; i < anArray.length; i++)
            System.out.print(anArray[i] + " ");
        System.out.println();
    }
}</pre>
```

### Screen Output

```
Array values before sorting:
7 5 11 2 1 4 18 14 12 30
Array values after sorting:
2 4 5 7 11 12 14 16 18 30
```

A merge sort is fast

The merge sort algorithm is much more efficient than the selection sort algorithm we presented in Chapter 7. In fact, there is no sorting algorithm that is "orders of magnitude" more efficient than the merge sort algorithm. The details of what is meant by "orders of magnitude" are beyond the scope of this book, but we can hint at its meaning.

There are algorithms that, in practice, are more efficient than the merge sort algorithm. However, for very large arrays, any of these algorithms (including the merge sort algorithm) are so much faster than the selection sort algorithm that the improvement over selection sort is more dramatic than the differences between these various faster algorithms.



### **SELF-TEST QUESTIONS**

11. What Java statement will sort the following array, using the class MergeSort?

```
int[] myArray = {9, 22, 3, 2, 87, -17, 12, 14, 33, -2};
```

- 12. How would you change the class MergeSort so that it can sort an array of values of type double instead of type int?
- 13. How would you change the class MergeSort so that it can sort an array of values of type int into decreasing order, instead of increasing order?
- 14. If a value in an array of base type int occurs twice—for example, both b[0] and b[5] are 7—and you sort the array by using the method MergeSort.sort, will there be one or two copies of the repeated value after the array is sorted?

### 11.3 GRAPHICS SUPPLEMENT

This section introduces lambda expressions. **Lambda functions** are not limited to graphics and JavaFX, but we present them in the context of creating JavaFX event handlers. Lambda functions are useful in many other contexts, particularly for parallelizing operations to make a program run faster.

### Lambda Functions and Event Handlers

Functional programming with lambda expressions was introduced in Java 8. A lambda expression is a nameless function. In functional programming, a function is the same thing as a method. Related concepts include closures, anonymous functions, and function literals. As a nameless function, a lambda expression is essentially a little chunk of code that you can pass around as data but have it treated like a function with parameters. Lambda expressions

provide a neat way to implement a class that normally has only one function and to make it easy to modify methods on the spot rather than go through the work of defining a method to perform a specialized task. Additionally, lambda expressions help Java parallelize itself to run more efficiently on multi-core or parallel machines.

The format to define a lambda expression looks like this:

```
parameters -> body
```

The arrow separates the parameters from the body. In many cases, the body is short and just a single line of code. If it were longer, then a traditional method may make more sense. Here is a lambda expression with a function that takes no parameters and returns the number 44:

```
() -> { return 44; }
```

Here is a lambda expression that returns the sum of two integers x and y:

```
(int x, int y) -> { return (x+y); }
```

In many cases, Java can infer the type of the parameters, in which case we can leave the data type off. We can also simply provide an expression on the right side and it automatically becomes the return value without requiring the keyword return. The following is equivalent to the previous example:

```
(x, y) \rightarrow x+y
```

As an example to motivate the use of lambda functions, consider the anonymous inner class that we wrote for the button handlers of Listing 8.23. The handler for btnSunny was:

```
btnSunny.setOnAction(new EventHandler<ActionEvent>()
{
    @Override
    public void handle(ActionEvent event)
    {
        lblMessage.setText("It is sunny!");
    }
}
```



In this case, we need to create a new class to implement EventHandler<ActionEvent> and define the handle method. We can do the same thing in a much more compact format using lambda functions. The equivalent event handler becomes:

We even don't need to specify the ActionEvent data type for argument e because Java can infer it from the only type valid from the context from which we are calling setOnAction. The lambda format is the simplest of all and lets us directly insert the method where needed. Listing 11.10 is the JavaFX program from Listing 8.23 converted to use lambda functions.

### LISTING 11.10 Handling Events with Lambda Functions (part 1 of 2)

```
import javafx.application.Application;
import javafx.scene.Scene;
import javafx.stage.Stage;
import javafx.scene.layout.VBox;
import javafx.scene.control.Button;
import javafx.event.ActionEvent;
import javafx.event.EventHandler;
import javafx.scene.control.Label;
/**
Event handling with lambda functions. This program implements
Listing 8.23 using lambda functions.
* /
public class ButtonDemoLambda extends Application
   public static void main(String[] args)
    {
        launch(args);
    }
   @Override
   public void start(Stage primaryStage) throws Exception
        VBox root = new VBox();
        Button btnSunny;
        Button btnCloudy;
        Label lblMessage;
        btnSunny = new Button("Sunny");
        btnCloudy = new Button("Cloudy");
        lblMessage = new Label("Click a button.");
        btnSunny.setOnAction(e ->
               lblMessage.setText("It is sunny!");
           }
        );
        btnCloudy.setOnAction(e ->
           {
               lblMessage.setText("It is cloudy!");
           }
        );
```

(continued)

### LISTING 11.10 Handling Events with Lambda Functions (part 2 of 2)

```
root.getChildren().add(btnSunny);
root.getChildren().add(btnCloudy);
root.getChildren().add(lblMessage);

Scene scene = new Scene(root, 300, 100);
primaryStage.setTitle("Lambda Button Demo");
primaryStage.setScene(scene);
primaryStage.show();
}
```

### Program Output

The program output is identical to that of Listing 8.23 except for the window title.

These examples should give you an idea of what Java lambda expressions look like and what they can do. While there is definitely a learning curve, lambda expressions will allow you to write code that is more concise while enabling parallel processing. Java 8's new syntax supports both functional programming and object-oriented programming in a way that reaps the benefits of both styles.

### **SELF-TEST QUESTION**

15. Convert the following event handler to use the lambda style.

### **CHAPTER SUMMARY**

- If a method definition includes an invocation of the method itself, that invocation is known as a recursive call. Recursive calls are legal in Java and can sometimes make a method definition clearer.
- Whenever an algorithm has one subtask that is a smaller version of the entire algorithm's task, you can realize the algorithm as a Java recursive method.
- To avoid infinite recursion, a recursive method definition should contain two kinds of cases: one or more cases that include a recursive call and one or more base (stopping) cases that do not involve any recursive calls.
- Two good examples of recursive algorithms are the binary search algorithm and the merge sort algorithm.
- A lambda function is a nameless function that allows you to quickly implement a method.

#### **Exercises**

1. What output will be produced by the following code?

```
public class Demo
{
    public static void main(String[] args)
    {
        System.out.println("The output is:");
        foo(564);
        System.out.println();
    }
    public static void foo(int number)
    {
        if (number > 0)
        {
            foo(number / 3);
            System.out.print(number % 3);
        }
    }
}
```

2. What output will be produced by the following code?

```
public class Demo
{
    public static void main(String[] args)
    {
        System.out.println("The output is:");
        bar(123456);
        System.out.println();
    }
}
```

```
public static void bar(int number)
{
    if (number > 0)
    {
        int d = number % 10;
        boolean even = (number / 10) % 2 == 0;
        bar(number / 10);
        if (even)
            System.out.print(d / 2 + 4);
        else
             System.out.print(d / 2 + 3);
    }
}
```

- 3. Write a recursive method that will compute the number of even digits in a number.
- 4. Write a recursive method that will compute the product of the digits in a positive number.
- 5. Complete a recursive definition of the following method:

```
/**
Precondition: n >= 0.
Returns 2 to the power n.
*/
public static int computeTwoToThe(int n)
Use the following facts about x^n:x
x^n = (x^{n/2})^2 \text{ when } n \text{ is even and positive } x^n = x(x^{(n-1)/2})^2 \text{ when } n \text{ is odd and positive } x^0 = 1
```

- 6. Write a recursive method that will compute the product of all the values in an array.
- 7. Write a recursive method that will find and return the smallest value in an array of integers. (*Hint*: Split the array in half and recursively find the smallest value in each half. Return the larger of those two values.)
- 8. Write a recursive ternary search algorithm that splits the array into three parts instead of the two parts used by a binary search.
- 9. Write a recursive method that will compute cumulative products in an array. To find the cumulative products, multiply to each value in the array the product of the values that precede it in the array. For example, if the values in the array are [2, 3, 1, 5, 6, 2, 7], the result will be [2, (2) \* 3, (2 \* 3) \* 1, (2 \* 3 \* 1) \* 5, (2 \* 3 \* 1 \* 5) \* 6, (2 \* 3 \* 1 \* 5 \* 6) \* 2, (2 \* 3 \* 1 \* 5 \* 6 \* 2) \* 7] or [2, 6, 6, 30, 180, 360, 2520]. (*Hint:* The parenthesized products in the previous example are the results of a recursive call.)

- 10. Suppose we want to compute the amount of money in a bank account with compound interest. If the amount of money in the account is m, the amount in the account at the end of the month will be 1.005m. Write a recursive method that will compute the amount of money in an account after t months with a starting amount of m.
- 11. Suppose we have a satellite in orbit. To communicate to the satellite, we can send messages composed of two signals: dot and dash. Dot takes 2 microseconds to send, and dash takes 3 microseconds to send. Imagine that we want to know the number of different messages, M(k), that can be sent in k microseconds that completely fills the k microseconds.
  - If k is 0 or 1, we can send 1 message (the empty message).
  - If k is 2 or 3, we can send 1 message (dot or dash, respectively).
  - If k is larger than 3, we know that the message can start with either dot or dash. If the message starts with dot, the number of possible messages is M(k-2). If the message starts with dash, the number of possible messages is M(k-3). Therefore the number of messages that can be sent in k microseconds is M(k-2) + M(k-3).

Write a program that reads a value of k from the keyboard and displays the value of M(k), which is computed by a recursive method.

- 12. Write a recursive method that will count the number of special characters in a string. (*Hint*: Each time you make a recursive call, use the String method substring to construct a new string consisting of the second through last characters. The final call will be when the string contains no characters.)
- 13. Write a recursive method that will remove all the special characters from a given string and return what is left as a new string. (*Hint*: Use the + operator to perform string concatenation to construct the string that is returned.)
- 14. Write a recursive method that will triplicate each character in a string and return the result as a new string. For example, if "book" is the argument, the result would be "bbbooooookkk".
- 15. Write a recursive method that will reverse the order of the characters in a given string and return the result as a new string. For example, if "book" is the argument, the result would be "koob".

### PRACTICE PROGRAMS

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

1. Write a static recursive method that returns the number of digits in the integer passed to it as an argument of type int. Allow for both positive and negative arguments. For example, –120 has three digits. Do not count leading zeros. Embed the method in a program, and test it.

- 2. Write a static recursive method that returns the product of the integers in the array of int values passed to it as a single argument. You can assume that every indexed variable of the array has a value. Embed the method in a test program.
- 3. One of the most common examples of recursion is an algorithm to calculate the **factorial** of an integer. The notation n! is used for the factorial of the integer n and is defined as follows:

```
0! is equal to 1

1! is equal to 1

2! is equal to 2 \times 1 = 2

3! is equal to 3 \times 2 \times 1 = 6

4! is equal to 4 \times 3 \times 2 \times 1 = 24

...

n! is equal to n \times (n-1) \times (n-2) \times ... \times 3 \times 2 \times 1
```

An alternative way to describe the calculation of n! is the recursive formula  $n \times (n-1)!$ , plus a base case of 0!, which is 1. Write a static method that implements this recursive formula for factorials. Place the method in a test program that allows the user to enter values for n until signaling an end to execution.

4. An example of how a recursive formula is used would be to compute the greatest common divisor (GCD) of two numbers. For example, GCD(204, 136) = 68. The recursive formula for GCD of two positive integers p and q, such that p > q, can be expressed as GCD(p, q) = GCD(q, p % q).

Write a static method that implements this recursive formula to compute the GCD of two positive integers. Place the method in a test program that allows the user to enter the values of p and q until signaling an end to execution. Also implement the same with a nonrecursive method.

### **PROGRAMMING PROJECTS**

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

1. A **palindrome** is a string that reads the same forward and backward, such as "radar". Write a static recursive method that has one parameter of type String and returns true if the argument is a palindrome and false otherwise. Disregard spaces and punctuation marks in the string, and consider upperand lowercase versions of the same letter to be equal. For example, the following strings should be considered palindromes by your method:



```
"Straw? No, too stupid a fad, I put soot on warts."
"xyzcZYx?"
```

Your method need not check that the string is a correct English phrase or word. Embed the method in a program, and test it. For an additional challenge, use your palindrome-checking method with the file of English words described in Programming Project 11 in Chapter 10 to find the word with the longest palindrome.

2. A **geometric progression** is defined as the product of the first *n* integers and is denoted as

geometric(n) = 
$$\prod_{i=1}^{n} i$$

where this notation means to multiply the integers from 1 to *n*. A **harmonic progression** is defined as the product of the inverses of the first *n* integers and is denoted as

$$harmonic(n) = \prod_{i=1}^{n} \frac{1}{i}$$

Both types of progression have an equivalent recursive definition:

geometric(n) = 
$$n \times \prod_{i=1}^{n-1} i$$

$$\operatorname{harmonic}(n) = \frac{1}{n} \times \prod_{i=1}^{n-1} \frac{1}{i}$$

Write static methods that implement these recursive formulas to compute geometric(n) and harmonic(n). Do not forget to include a base case, which is not given in these formulas, but which you must determine. Place the methods in a test program that allows the user to compute both geometric(n) and harmonic(n) for an input integer n. Your program should allow the user to enter another value for n and repeat the calculation until signaling an end to the program. Neither of your methods should use a loop to multiply n numbers.

3. The **Fibonacci sequence** occurs frequently in nature as the growth rate for certain idealized animal populations. The sequence begins with 0 and 1, and each successive Fibonacci number is the sum of the two previous Fibonacci numbers. Hence, the first ten Fibonacci numbers are 0, 1, 1, 2, 3, 5, 8, 13, 21, and 34. The third number in the series is 0 + 1, which is 1; the fourth number is 1 + 1, which is 2; the fifth number is 1 + 2, which is 3; and so on.

Besides describing population growth, the sequence can be used to define the form of a spiral. In addition, the ratios of successive Fibonacci numbers in the sequence approach a constant, approximately 1.618, called the "golden mean." Humans find this ratio so aesthetically pleasing that it is often used to select the length and width ratios of rooms and postcards.

Use a recursive formula to define a static method to compute the *n*th Fibonacci number, given *n* as an argument. Your method should not use a loop to compute all the Fibonacci numbers up to the desired one, but should be a simple recursive method. Place this static recursive method in a program that demonstrates how the ratio of Fibonacci numbers converges. Your program will ask the user to specify how many Fibonacci numbers it should calculate. It will then display the Fibonacci numbers, one per line. After the first two lines, it will also display the ratio of the current and previous Fibonacci numbers on each line. (The initial ratios do not make sense.) The output should look something like the following if the user enters 5:

Fibonacci #1 = 0 Fibonacci #2 = 1 Fibonacci #3 = 1; 1/1 = 1 Fibonacci #4 = 2; 2/1 = 2 Fibonacci #5 = 3; 3/2 = 1.5

4. Imagine a candy bar that has k places where it can be cut. You would like to know how many different sequences of cuts are possible to divide the bar into pieces. For example, if k is 3, you could cut the bar at location 1, then location 2, and finally at location 3. We indicate this sequence of cuts by 123. So if k is 3, we have six ways to divide the bar: 123, 132, 213, 231, 312, or 321. Notice that we have k possibilities for making the first cut. Once we make the first cut we have k-1 places where a cut must be made. Recursively, this can be expressed as

$$C(k) = kC(k-1)$$

Let's make this a bit more interesting by adding a restriction. You must always cut the leftmost pieces that can be cut. Now if *k* is 3, we can cut the bar at locations 123, 132, 213, 312, or 321. A cutting sequence of 231 would not be allowed, because after the cut at 2 we would have to make the cut at location 1, since it is the leftmost piece. We still have *k* possibilities for making the first cut, but now we have to count the number of ways to cut two pieces and multiply. Recursively, this can be expressed as

$$D(k) = \sum_{j=1}^{k} D(i-1)D(k-i)$$

When k is 3, we would compute

$$D(3) = \sum_{i=1}^{3} D(i-1)D(3-i) = D(0)D(2) + D(1)D(1) + D(2)D(0)$$

$$D(2) = \sum_{i=1}^{2} D(i-1)D(2-i) = D(0)D(1) + D(1)D(0)$$

$$D(1) = \sum_{i=1}^{1} D(i-1)D(1-i) = D(0)D(0)$$

For both recursive formulas, if k = 0, there is exactly one way to divide the bar.

Develop a program that will read a value of k from the keyboard and then display C(k) and D(k). (D(k) is interesting because it turns out to be the number of ways that we can parenthesize an arithmetic expression that has k binary operators.)

5. Once upon a time in a kingdom far away, the king hoarded food and the people starved. His adviser recommended that the food stores be used to help the people, but the king refused. One day a small group of rebels attempted to kill the king but were stopped by the adviser. As a reward, the adviser was granted a gift by the king. The adviser asked for a few grains of wheat from the king's stores to be distributed to the people. The number of grains was to be determined by placing them on a chessboard. On the first square of the chessboard, he placed one grain of wheat. He then placed two grains on the second square, four grains on the third square, eight grains on the fourth square, and so forth.

Compute the total number of grains of wheat that were placed on k squares by writing a recursive method getTotalGrains(k, grains). Each time getTotalGrains is called, it "places" grains on a single square; grains is the number of grains of wheat to place on that square. If k is 1, return grains. Otherwise, make a recursive call, where k is reduced by 1 and grains is doubled. The recursive call computes the total number of grains placed in the remaining k-1 squares. To find the total number of grains for all k squares, add the result of the recursive call to grains and return that sum.

6. There are *n* people in a room, where *n* is an integer greater than or equal to 2. Each person shakes hands once with every other person. What is the total number of handshakes in the room? Write a recursive method to solve this problem with the following header:

```
public static int handshake(int n)
```

where handshake(n) returns the total number of handshakes for n people in the room. To get you started, if there are only one or two people in the room, then:

```
handshake(1) = 0
handshake(2) = 1
```

7. Given the definition of a 2D array such as the following:

write a recursive program that outputs all combinations of each subarray in order. In the above example, the desired output (although it doesn't have to be in this order) is:

```
A 1 XX
A 1 YY
A 1 ZZ
A 2 XX
A 2 YY
A 2 ZZ
B 1 XX
B 1 YY
B 1 ZZ
B 2 XX
B 2 YY
B 2 ZZ
```

Your program should work with arbitrarily sized arrays in either dimension. For example, the following data:

should output:

```
A 1 2 XX
A 1 2 YY
```

8. The word ladder game was invented by Lewis Carroll in 1877. The idea is to begin with a start word and change one letter at a time until arriving at an end word. Each word along the way must be an English word.

For example, starting from FISH you can make a word ladder to MAST through the following ladder:

```
FISH, WISH, WASH, MASH, MAST
```

Write a program that uses recursion to find the word ladder given a start word and an end word, or determines if no word ladder exists. Use the file words.txt that is available online with the source code for the book as your dictionary of valid words. This file contains 87314 words. Your program does not need to find the shortest word ladder between words, any word ladder will do if one exists.

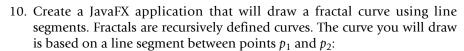
9. A description of the File class is available on Oracle's Java Web site at http://docs.oracle.com/javase/7/docs/api/java/io/File.html. To use this

Graphics

class you must import java.io.File. For this program the relevant methods of the File class are described below:

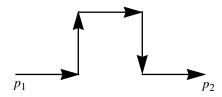
File(String pathname)	The constructor takes a pathname and
	creates a File object corresponding to
	the file or directory with that pathname.

Write the static recursive method String searchForFile(File currentFolder, String filename). The first parameter should be a File object that specifies the root folder to search for the file named filename. The method should recursively search all subfolders for the file and return the complete pathname to the first match. For example, if currentFolder is set to C:\ and filename is "foo.txt" then it might return "C:\Code\ Stuff\foo.txt" if that is a valid pathname for the file. If there is no file with a matching name within the currentFolder then the method should return a blank string, "".





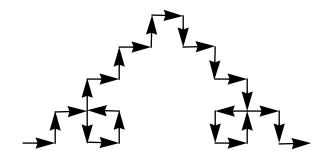
To draw the curve from  $p_1$  to  $p_2$ , you first split the segment into thirds. Then add two segments and offset the middle segment to form part of a square, as shown in the following picture:





Note that you would not draw the arrowheads, but we use them here to indicate the direction of drawing. If the order of  $p_1$  and  $p_2$  were reversed, the square would be below the original line segment.

This process is recursive and is applied to each of the five new line segments, resulting in the following curve:



The fractal is given by repeating this recursive process an infinite number of times. Of course, we will not want to do that and will stop the process after a certain number of times.

To draw this curve, use a recursive method drawFractal (p1x, p1y, p2x, p2y, k). If k is zero, just draw a line from  $p_1$  to  $p_2$ . Otherwise, split the line segment into five segments, as described previously, and recursively call drawFractal for each of these five segments. Use k-1 for the last argument in the recursive calls. For convenience, you may assume that the segments are either vertical or horizontal.

The initial call should be drawFracta1 (50, 800, 779, 800, 5). Set the size of the window to 1000 by 1000.

- 11. Do Programming Project 17 from Chapter 4, the Edoc calculator, except use a recursive function to calculate or help you calculate the maximum amount of experience points you can earn.
- 12. Do Programming Project 9 from Chapter 8 using lambda functions to implement the button click events.

### **Answers to Self-Test Questions**

1. B

R

R

R

Note that the 'B' is the first output, not the last output.

```
2. R
  R
  R
  В
  Note that the 'B' is the last output.
3. /**
  Precondition: n \ge 1.
  Displays the symbol '#' n times on one line
  and then advances to the next line.
  */
  public static void displaySharps(int n)
       if (n <= 1)
          System.out.println('#');
      else
       {
          System.out.print('#');
          displaySharps(n - 1);
  }
4. 6
5. /**
  Precondition: n \ge 0
  Returns 10 to the power n.
  public static int computeTenToThe(int n)
  {
       if (n \le 0)
          return 1;
          return computeTenToThe(n - 1) * 10;
  }
6. /**
  Precondition: n can be any int.
  Returns 10 to the power n.
  public static int computeTenToThe(int n)
  {
      if (n == 0)
          return 1;
      else if (n > 0)
          return computeTenToThe(n - 1) * 10;
      else//n < 0
          return 1 / computeTenToThe(-n);
  }
```

```
7. public void getCount()
    {
            System.out.println("Enter a positive integer:");
            Scanner keyboard = new Scanner(System.in);
            int count = keyboard.nextInt();
            while (count <= 0)
            {
                  System.out.println("Input must be positive.");
                 System.out.println("Try again.");
                  count = keyboard.nextInt();
            }
        }
}</pre>
```

- 8. No.
- 9. The array can have repeated values, as long as the array is sorted.
- 10. The multiway if-else statement in the method binarySearch needs to have two comparison operators changed so that it reads as follows:

```
if (target == a[mid])
    result = mid;
else if (target > a[mid])//Changed from <to>
    result = search(target, first, mid - 1);
else if (target < a[mid])//Changed from > to <
    result = search(target, mid + 1, last);</pre>
```

No other changes are needed, but the comments should be revised to reflect the fact that the array is sorted from largest to smallest.

- 11. MergeSort.sort(myArray);
- 12. Change the types for the array elements to double. For example, you would replace

13. Replace the < with > in the following line of the definition of merge:

```
if (firstHalf[firstHalfIndex] < lastHalf[lastHalfIndex])</pre>
```

14. If an array of base type int has a value that occurs twice, and you sort the array by using the method MergeSort.sort, the repeated value will occur twice in the sorted array.

# Dynamic Data Structures and Generics

### 12.1 ARRAY-BASED DATA STRUCTURES 921

The Class ArrayList 922
Creating an Instance of ArrayList 922
Using the Methods of ArrayList 924
Programming Example: A To-Do List 928
Parameterized Classes and Generic Data Types 931

### 12.2 THE JAVA COLLECTIONS FRAMEWORK 931

The Collection Interface 931
The Class HashSet 932
The Map Interface 934
The Class HashMap 934

### **12.3 LINKED DATA STRUCTURES** 937

The Class LinkedList 937 Linked Lists 938 Implementing the Operations of a Linked List 941 A Privacy Leak 948
Inner Classes 949
Node Inner Classes 950
Iterators 950
The Java Iterator Interface 962
Exception Handling with Linked Lists 962
Variations on a Linked List 964
Other Linked Data Structures 966

### **12.4 GENERICS** 967

The Basics 967

Programming Example: A Generic Linked List 970

### 12.5 GRAPHICS SUPPLEMENT 975

Building JavaFX Applications with the Scene Builder 975 Where to Go from Here 981 As Chapter 5 noted, an abstract data type, or ADT, specifies a set of data and the operations on that data. It describes what the operations do but not how to implement them or store the data. Basically, an ADT specifies a particular data organization. You can express the specifications of an ADT by writing a Java interface, as described in Chapter 8. You know that a class can implement an interface in various ways. Thus, you implement an ADT by defining a Java class. In doing so, you use various data structures. A data structure is a construct, such as a class or an array, within a programming language.

This chapter focuses on data structures. In particular, we discuss two kinds of data structures whose size can grow or shrink while your program is running. Such structures are said to be **dynamic**. One kind of dynamic structure is based on an array. As an example, we will introduce the class ArrayList, which is available in the Java Class Library. The other kind links its data items to one another, so that one data item "knows" where the next one is. Although there are many different kinds of linked data structures, we will emphasize one simple but useful linked data structure known as a linked list. In the process of covering linked lists, we will introduce inner classes, which are a kind of class definition within another class definition.

Starting with version 5.0, Java allows class definitions to have parameters for the data types they use. These parameters are known as **generic types**. In Section 12.1 we show you how to use one such definition—ArrayList—which is in the Java Class Library. Section 12.3 shows you how to write class definitions that have generic data types.

#### **OBJECTIVES**

After studying this chapter, you should be able to

- Define and use an instance of ArrayList
- Describe the general idea of linked data structures and how to implement them in Java
- Manipulate linked lists
- Use inner classes in defining linked data structures
- Describe, create, and use iterators
- Define and use classes that have generic types
- Understand how the Scene Builder can help you create a JavaFX Application

### **PREREQUISITES**

You should read Section 12.1 before Section 12.2. Section 12.3 stands on its own but you should read Sections 12.1 through 12.3 before Section 12.4. Chapters 1 through 7 are needed to fully understand this chapter. Some familiarity with basic inheritance and basic exception handling will be helpful. The details are as follows:

Section	Prerequisite
12.1 Array-Based Data Structures	Chapters 1 through 7 and Section 9.1
12.2 The Java Collections Framework	Section 12.1
12.3 Linked Data Structures (excluding "Exception Handling with Linked Lists")	Chapters 1 through 7
The subsection of Section 12.3 entitled "Exception Handling with Linked lists"	Chapters 1 through 7 and Chapter 9
12.4 Generics	Sections 12.1 through 12.3 up to, but not including, "Exception Handling with Linked Lists"

### 12.1 ARRAY-BASED DATA STRUCTURES

"Well, I'll eat it," said Alice, "and if it makes me grow larger, I can reach the key; and if it makes me grow smaller, I can creep under the door; so either way I'll get into the garden."

-LEWIS CARROLL, Alice's Adventures in Wonderland

In Java, you can read the length of an array as data when the program is running, but once your program creates an array of that length, it cannot change the length of the array. For example, suppose you write a program to record customer orders for a mail-order house, and suppose you store all the items ordered by one customer in an array order of objects of a class called OrderItem. You could ask the user for the number of items in an order, store the number in a variable called numberOfItems, and then create the array order, using the following statement:

OrderItem[] order = new OrderItem[numberOfItems];

But suppose the customer enters number Of Items items and then decides to order another item? There is no way to actually increase the size of the array order. However, we can simulate increasing its size: We create a new and larger array, copy the elements from the original array to the new array, and

An array of a certain size

then rename the new array order. For example, the following statements effectively double the size of our array:

```
OrderItem[] largerArray = new OrderItem[2 * numberOfItems];
for (int index = 0; index < numberOfItems; index++)
    largerArray[index] = order[index];
order = largerArray;</pre>
```

Doubling the size of an array

### The Class ArrayList

Instead of worrying about changing the size of the array order, we can use an instance of the class ArrayList, which is in the package java.util of the Java Class Library. Such an instance can serve the same purpose as an array, except that it can change in length while the program is running. An ArrayList object could handle the customer's extra order without any problems.

ArrayList versus an array

If we can simply use ArrayList to overcome the main disadvantage of using an array, why did we study arrays? Why don't we always use ArrayList? It often seems that every silver lining has a cloud, and that is true here as well. There are two main drawbacks when using ArrayList:

- Using an instance of ArrayList is less efficient than using an array.
- An instance of ArrayList can store only objects; it cannot contain values of a primitive type, such as int, double, or char.

The implementation of ArrayList uses arrays. In fact, to expand the capacity of its underlying array, it uses the same technique we used to expand our array order. Using ArrayList instead of an array in your program will require more computer time, but that might or might not be significant. You would need to analyze your situation before making a choice. The second drawback can be addressed as follows: Instead of storing int values, for example, you could store Integer values, where Integer is the wrapper class whose objects simulate int values. Automatic boxing and unboxing—as discussed in Chapter 6—makes using a wrapper class convenient. But using one does add to the time overhead of a program.

The ADT list

Note that ArrayList is an implementation of an ADT called a **list**. The ADT list organizes data in the same way that you do when you write a list in everyday life. Lists of tasks, address lists, gift lists, and grocery lists are all examples of familiar lists. In each case, you can add entries to the list—at the beginning, at the end, or between items—delete entries, look at entries, and count entries. These are the same kinds of operations that an object of ArrayList can perform.

### Creating an Instance of ArrayList

Using an instance of ArrayList has similarities to using an array, but there are some important differences. First, the definition of the class ArrayList is not provided automatically. The definition is in the package <code>java.util</code>, and any code that uses the class ArrayList must contain the following statement at the start of the file:

```
import java.util.ArrayList;
```

You create and name an instance of ArrayList in the same way that you create and name objects of any class, except that you specify the base type using a different notation. For example,

ArrayList is in the package java.util

```
ArrayList<String>list = new ArrayList<String>(20);
```

This statement makes list the name of an object that stores instances of the class String. The type String is the base type. An object of the class ArrayList stores objects of its base type, just as an array stores items of its base type. The difference here is that the base type of ArrayList must be a class type; you cannot use a primitive type, such as int or double, as the base type.

Our object list has an initial capacity of 20 items. When we say that an ArrayList object has an initial capacity, we mean that it has been allocated memory for that many items, but if it needs to hold more items, the system will automatically allocate more memory. By carefully choosing the initial capacity, you can often make your code more efficient. If you choose an initial capacity that is large enough, the system will not need to reallocate memory too often, and as a result, your program should run faster. On the other hand, if you make your initial capacity too large, you will waste storage space. No matter what capacity you choose, it has no effect on how many items an ArrayList object can hold. Note that if you omit the initial capacity, you will invoke ArrayList's default constructor, which assumes a capacity of ten.

An object of ArrayList stores objects of a specified base type

An object of ArrayList can increase its capacity

### **RECAP Creating and Naming an Instance of ArrayList**

An object of the class ArrayList is created and named in the same way as any other object, except that you specify a base type.

#### **SYNTAX**

The Base\_Type must be a class type; it cannot be a primitive type such as int or double. When a number Capacity is given as an argument to the constructor, that number determines the initial capacity of the list. Omitting an argument results in an initial capacity of ten.

#### **EXAMPLES**

```
ArrayList<String>aList = new ArrayList<String>();
ArrayList<Double>bList = new ArrayList<Double>(30);
```

# PROGRAMMING TIP Newer Versions of Java Require the Base Type Only Once

Prior to JDK version 7, the syntax to create an object of the class ArrayList required the base type to be repeated in the constructor.

```
ArrayList<Base_Type> Variable = new ArrayList<Base_Type>();
```

For example:

```
ArrayList<String> aList = new ArrayList<String>();
```

Starting with JDK version 7 the format does not require the base type to be repeated in the constructor. The syntax is:

```
ArrayList<Base_Type> Variable = new ArrayList<>();
```

For example:

```
ArrayList<String> aList = new ArrayList<>();
```

This saves a bit of typing over the old version and can make code more readable for more complex base types. The base type is no longer required in the constructor due to a feature called **type inference**. The compiler is able to infer the base type from the variable declaration. Programmers have been using the earlier format for many years, so you are likely to see it in existing code.

### Using the Methods of ArrayList

An object of ArrayList can be used like an array, but you must use methods instead of an array's square-bracket notation. Let's define an array and an object of ArrayList and give them the same capacity:

Creating an array and an object of ArrayList

```
String[] anArray = new String[20];
ArrayList<String> aList = new ArrayList<String>(20);
```

Objects of ArrayList are indexed in the same way as an array: The index of the first item is 0. So if you would use

```
anArray[index] = "Hi Mom!";
```

for the array anArray, the analogous statement for the object aList would be

```
aList.set(index, "Hi Mom!");
```

If you would use

```
String temp = anArray[index];
```

to retrieve an element from the array anArray, the analogous statement for aList would be

```
String temp = aList.get(index);
```

An array and an object of ArrayList use the same indexing The two methods set and get give objects of ArrayList approximately the same functionality that square brackets give to arrays. However, you need to be aware of one important point: The method invocation

The methods set and get

```
aList.set(index, "Hi Mom!");
```

is not always completely analogous to

```
anArray[index] = "Hi Mom!";
```

The method set can replace any *existing* element, but you cannot use set to put an element at just any index, as you would with an array. The method set is used to change the value of existing elements, not to set them for the first time.

To set an element for the first time, you use the method add. This method adds elements at index positions 0, 1, 2, and so forth, in that order. An ArrayList object must always be filled in this order. The method add has two forms; that is, it is overloaded. When given one argument, add adds an element immediately after the last currently occupied position. Given two arguments, the method adds the element at the indicated position, assuming that the indicated position is not after an unoccupied position. For example, if aList contains five elements, either

```
aList.add("Caboose");
or
aList.add(5, "Caboose");
```

adds "Caboose" as the sixth—and last—element. But notice that for a list of five items, the statement

```
aList.add(6, "Caboose");
```

would cause an IndexOutOfBoundsException exception. Because the list contains five items, the index of the last item is 4. Attempting to add an item at index 6 before placing one at index 5 is illegal.

After adding elements to aList, you also can use add to insert an element before or between existing elements. The statement

The method add

```
aList.add(0, "Engine");
```

adds (inserts) a string before all other elements in aList. Existing elements are shifted to make room for the new element. So the original string at index 0 is not replaced, but rather is shifted to index position 1. Likewise,

```
aList.add(4, "BoxCar");
```

inserts "BoxCar" as the element at index 4. Elements at indices before 4 remain in place, while those originally after it are shifted to the next higher index position. When you use the method add to insert a new element at an index position, all the elements that were at that index position or higher

have their index increased by 1 so that there is room to insert the new element without losing any of the older elements. Unlike the procedure for inserting into an array, this process happens automatically, and you need not write any extra code to move elements. Clearly, using ArrayList is much easier than using an array.

You can find out how many elements have already been added to aList by using the method size. The expression aList.size() returns the number of elements stored in aList. The indices of these elements range from 0 to aList.size() minus 1.

The method size

Figure 12.1 describes a selection of the methods in the class ArrayList.

### FAQ Why are some parameters of type Base\_Type and others of type Object?

Look at the table of methods in Figure 12.1. In some cases, when a parameter is naturally an object of the base type, the parameter type is the base type, but in other cases it is the type <code>Object</code>. For example, the method add has a parameter of the base type, but the method contains has a parameter of type <code>Object</code>. Why the difference in parameter types? For <code>ArrayList</code>, it makes sense to add only an element of the base type, so add does not accommodate objects of other types. However, contains is more general. Since its parameter's type is <code>Object</code>, it can test whether an object of any type is on the list. An object whose type is not the base type cannot possibly be on the list, so if it is passed to contains, the method will return false.

### **RECAP Arrays Versus Objects of the Class ArrayList**

With arrays, the square brackets and the instance variable length are the only tools automatically provided for a programmer. If you want to use arrays for other things, you must write code to manipulate the arrays. ArrayList, on the other hand, comes with a large selection of powerful methods that can do many of the things that you must do for yourself when using an array. For example, the class ArrayList has a method—add—that inserts a new element between two existing elements.

### **SELF-TEST QUESTIONS**

1. Suppose aList is an object of the class ArrayList<String>. How do you add the string "Hello" to the end of aList?

### FIGURE 12.1 Some Methods in the Class ArrayList

### public ArrayList<Base\_Type>(int initialCapacity)

Creates an empty list with the specified <code>Base\_Type</code> and initial capacity. The <code>Base\_Type</code> must be a class type; it cannot be a primitive type such as <code>int</code> or <code>double</code>. When the list needs to increase its capacity, the capacity doubles.

```
public ArrayList<Base_Type>()
```

Behaves like the previous constructor, but the initial capacity is ten.

```
public boolean add(Base_Type newElement)
```

Adds the specified element to the end of this list and increases the list's size by 1. The capacity of the list is increased if that is required. Returns true if the addition is successful.

```
public void add(int index, Base_Type newElement)
```

Inserts the specified element at the specified index position of this list. Shifts elements at subsequent positions to make room for the new entry by increasing their indices by 1. Increases the list's size by 1. The capacity of the list is increased if that is required. Throws IndexOutOfBoundsException if index < 0 or index > size().

```
public Base_Type get(int index)
```

Returns the element at the position specified by index. Throws

IndexOutOfBoundsException if index < 0 or index  $\ge$  size().

```
public Base_Type set(int index, Base_Type element)
```

Replaces the element at the position specified by index with the given element. Returns the element that was replaced. Throws IndexOutOfBoundsException if index < 0 or index  $\ge size()$ .

```
public Base_Type remove(int index)
```

Removes and returns the element at the specified index. Shifts elements at subsequent positions toward position index by decreasing their indices by 1. Decreases the list's size by 1. Throws IndexOutOfBoundsException if index < 0 or index  $\geq$  size().

```
public boolean remove(Object element)
```

Removes the first occurrence of element in this list, and shifts elements at subsequent positions toward the removed element by decreasing their indices by 1. Decreases the list's size by 1. Returns true if element was removed; otherwise returns false and does not alter the list.

```
public void clear()
```

Removes all elements from this list.

```
public int size()
```

Returns the number of elements in this list.

```
public boolean contains(Object element)
```

Returns true if element is in this list; otherwise, returns false.

```
public int indexOf(Object element)
```

Returns the index of the first occurrence of element in this list. Returns -1 if element is not on the list.

```
public boolean isEmpty()
```

Returns true if this list is empty; otherwise, returns false.

- 2. Suppose instruction is an object of the class ArrayList<String> that contains the string "Stop" at index position 5. How do you change the string at index position 5 to "Go"?
- 3. Can you use the method set to place an element in a list at any index you want?
- 4. Can you use the method add to place an element in a list at any index you want?
- 5. Can you use the method add to insert an element at a position for which you cannot use set?
- 6. If aList is an object of the class ArrayList<String> that contains seven elements, why does aList.add(7, "Red truck") place a new string as the eighth element of aList?
- 7. Suppose aList is an object of the class ArrayList<String> that contains the four strings: "red", "blue", "green", and "yellow". What strings are on the list after aList.add(2, "orange") executes?
- 8. If you create a list using the statement

```
ArrayList<Double> aList = new ArrayList<Double>(20);
can the list contain more than 20 elements?
```

9. Suppose aList is an object of the class ArrayList<String>. Write Java statements that will display all the elements in aList on the screen.

### PROGRAMMING EXAMPLE A To-Do List

Listing 12.1 contains an example of using ArrayList to maintain a list of everyday tasks. The user can enter as many tasks as desired, and then the program will display the list.

### LISTING 12.1 Using ArrayList to Maintain a List (part 1 of 2)

```
import java.util.ArrayList;
import java.util.Scanner;
public class ArrayListDemo
    public static void main(String[] args)
                                                          (continued)
```

### LISTING 12.1 Using ArrayList to Maintain a List (part 2 of 2)

```
{
        ArrayList<String> toDoList = new ArrayList<String>();
        System.out.println("Enter items for the list, when "+
                   "prompted.");
        boolean done = false;
        Scanner keyboard = new Scanner(System.in);
        while (!done)
        {
            System.out.println("Type an entry:");
            String entry = keyboard.nextLine( );
            toDoList.add(entry);
            System.out.print("More items for the list? ");
            String ans = keyboard.nextLine( );
            if (!ans.equalsIgnoreCase("yes"))
                done = true;
        }
        System.out.println("The list contains:");
        int listSize = toDoList.size( );
        for (int position = 0; position < listSize;</pre>
            position++)
                System.out.println(toDoList.get(position));
    }
}
```

### Sample Screen Output

```
Enter items for the list, when prompted.
Type an entry:
Buy milk
More items for the list? yes
Type an entry:
Wash car
More items for the list? yes
Type an entry:
Do assignment
More items for the list? no
The list contains:
Buy milk
Wash car
Do assignment
```

### PROGRAMMING TIP Use a For-Each Loop to Access All Elements in an Instance of ArrayList

The last loop in Listing 12.1, which displays all the elements in an instance of ArrayList, can be replaced by the following for-each loop:

```
for (String element : toDoList)
    System.out.println(element);
```

This loop is much simpler to write than the original one when you want to access all of the elements in a collection such as an ArrayList object.

### ■ PROGRAMMING TIP Use TrimTosize to Save Memory

ArrayList objects automatically double their capacity when your program needs them to have additional capacity. However, the new capacity may be more than your program requires. In such cases, the capacity does not automatically shrink. If the capacity of your expanded list is much larger than you need, you can save memory by using the method trimToSize. For example, if aList is an instance

### **ASIDE Early Versions of ArrayList**

Versions of Java before version 5.0 had a class named ArrayList that was not parameterized and was used just like any other class. For example,

This older class is still available in recent versions of Java and is approximately equivalent to the class ArrayList<0bject>. So the previous line of code is approximately equivalent to

```
ArrayList<Object>aList = new
ArrayList<Object>(10);
```

The class ArrayList<0bject> and the older class ArrayList are not completely equivalent, but for simple applications they can be considered equivalent. The differences between these classes become relevant only when you are dealing with issues related to type casting or subtyping. This older class is in the package java.util, as is the newer parameterized ArrayList. Knowing about the older class is relevant if you have a program written in earlier versions of Java.

of ArrayList, the invocation aList.trimToSize() will shrink the capacity of aList down to its actual size, leaving it with no unused capacity. Normally, you should use trimToSize only when you know that you will not soon need the extra capacity.

## **GOTCHA** Using an Assignment Statement to Copy a List

As was true for objects of other classes, as well as for arrays, you cannot make a copy of an instance of ArrayList by using an assignment statement. For example, consider the following code:

```
ArrayList<String>aList = new
    ArrayList<String>();
<Some code to fill aList>
ArrayList<String>anotherName = aList;
//Defines an alias
```

This code simply makes another Name another name for aList so that you have two names but only one list. If you want to make an identical copy of aList so that you have two separate copies, you use the method clone. So instead of the previous assignment statement, you would write

```
ArrayList<String> duplicateList =
    (ArrayList<String>)aList.clone();
```

For lists of objects other than strings, using the method clone can be more complicated and can lead to a few pitfalls. Appendix 10, explains more about this method.

### Parameterized Classes and Generic Data Types

The class ArrayList is a parameterized class. That is, it has a parameter, which we have been denoting <code>Base\_Type</code>, that can be replaced with any class type to obtain a class that stores objects having the specified base type. <code>Base\_Type</code> is called a <code>generic</code> data type. You already know how to use parameterized classes, since you know how to use <code>ArrayList</code>. Section 12.3 will outline how to define such a class yourself.



### **SELF-TEST QUESTIONS**

- 10. Can you have a list of ints?
- 11. Suppose list is an instance of ArrayList. What is the difference between the capacity of list and the value of list.size()?
- 12. Suppose list is an instance of ArrayList that was defined with an initial capacity of 20. Imagine that we add 10 entries to list. What will be the values of the elements at indices 10 through 19? Garbage values? A default value? Something else?

### **12.2** THE JAVA COLLECTIONS FRAMEWORK

Any idea is a generalization, and generalization is a property of thinking. To generalize something means to think it.

—GEORG WILHELM FRIEDRICH HEGEL, Elements of the Philosophy of Right, (1820)

The Java Collections Framework is a collection of interfaces and classes that may be used to manipulate groups of objects. The classes implemented in the Java Collections Framework serve as reusable data structures and include algorithms for common tasks such as sorting or searching. The framework uses parameterized classes so you can use them with the classes of your choice. Utilizing the framework can free the programmer from lots of low-level details if they aren't the focus of the program. This section is just enough for you to use a few common components of the Java Collections Framework.

### The Collection Interface

The Collection interface is the highest level of Java's framework for collection classes and it describes the basic operations that all collection classes should implement. Selected methods for the Collection interface are

### FIGURE 12.2 Selected Methods in the Collection Interface

```
public boolean add(Base_Type newElement)
   Adds the specified element to the collection. Returns true if the collection is changed
   as a result of the call.
public void clear()
   Removes all of the elements from the collection.
public boolean remove(Object o)
   Removes a single instance of the specified element from the collection if it is present.
   Returns true if the collection is changed as a result of the call.
public boolean contains(Object o)
   Returns true if the specified element is a member of the collection.
public boolean isEmpty()
   Returns true if the collection is empty.
public int size()
   Returns the number of elements in the collection.
public Object[] to Array()
   Returns an array containing all of the elements in the collection. The array is of a type
   Object so each element may need to be type cast back into the original base type.
```

given in Figure 12.2. The methods support basic operations such as adding, removing, or checking to see if an object exists in the collection. The Collection interface takes a base type that allows you to create a collection of objects of your choice. Note that the toArray method returns an array of type Object. You may need to type cast elements of the array to the appropriate class or abstract data type.

You may have noticed that many of the methods from Figure 12.2 look the same as those in Figure 12.1, the listing of methods for the ArrayList class. This is no coincidence. The ArrayList class implements the Collection interface, so it must have the same methods. Other classes that implement the Collection interface must also have the same methods, but of course the implementation of the methods may differ. Additionally, classes can add their own methods not specified by the interface. For example, the get and set methods for the ArrayList class are specified not in the Collection interface but by a derived interface, List, that in turn is implemented by ArrayList. While these methods provide specialized functionality, an understanding of the Collection interface is enough to give you a basic understanding of how to use any class that implements it.

### The Class HashSet

The HashSet class is used to store a set of objects. Like the ArrayList, the HashSet class also implements the Collection interface. However, the HashSet stores a set rather than a list of items. This means that there can be no duplicate elements, unlike an ArrayList, which can have many duplicates.

The HashSet class stores a set of objects

The class is named HashSet because the algorithm used to implement the set is called a hash table. A description of how the hash table algorithm works is beyond the scope of this text, but in summary it provides a fast and efficient way to look up items. Listing 12.2 demonstrates how to use the HashSet class to store and manage a set of integers. The base type is the wrapper class Integer (described in Section 6.2) rather than int because primitive types are not allowed as a base type. Only objects may be stored in any collection. The example uses only the methods specified in the Collection interface.

It is important to note that if you intend to use the HashSet<T> class with your own class as the parameterized type T then your class T must override the following methods:

```
public int hashCode();
public boolean equals(Object obj);
```

The hashCode() method should return a numeric key that is ideally a unique identifier for each object in your class. It is always a good idea to override the

### LISTING 12.2 A HashSet Demonstration (part 1 of 2)

```
import java.util.HashSet;
public class HashSetDemo
    public static void main(String[] args)
        HashSet<Integer> intSet = new HashSet<Integer>();
        intSet.add(2);
        intSet.add(7);
        intSet.add(7);
                                        Ignored since 7 is already in the set
        intSet.add(3);
        printSet(intSet);
        intSet.remove(3);
        printSet(intSet);
        System.out.println("Set contains 2: " +
            intSet.contains(2));
        System.out.println("Set contains 3: " +
            intSet.contains(3));
    public static void printSet(HashSet<Integer> intSet)
        System.out.println("The set contains:");
        for (Object obj : intSet.toArray())
        {
            Integer num = (Integer) obj;
            System.out.println(num.intValue());
        }
    }
}
```

### LISTING 12.2 A HashSet Demonstration (part 2 of 2)

### Sample Screen Output

```
The set contains:
2
3
7
The set contains:
2
7
Set contains 2: true
Set contains 3: false
```

equals() method for any class you write, but you must override it in this scenario. Java will use the hash code to index the object and then use the equals() method to check if an object exists in the set. If the hash code for two different objects is identical they will still be indexed correctly as long as equals() indicates they are unique. However, the identical hash codes will decrease performance.

### The Map Interface

The Map interface is also a top-level interface in the Java Collection Framework. The Map interface is similar in character to the Collection interface, except that it deals with collections of ordered pairs. Think of the pair as consisting of a key K (to search for) and an associated value V. For example, the key might be a student ID number and the value might be an object storing information about the student (such as the name, major, address, or phone number) associated with that ID number. Selected methods for the Map interface are given in Figure 12.3. The Map interface takes a base type for the key and a base type for the value. Use the put method to add a key/value pair to the collection and the get method to retrieve the value for a given key. Just like the Collection interface, the base types must be objects and cannot be primitive data types.

### The Class HashMap

The HashMap class implements the Map interface and is used to store a map from a key object to a value object. Like the HashSet, the class is called HashMap because it also uses the hash table algorithm. It can be used like a small database and is able to quickly retrieve the value object when given the key object. Listing 12.3 demonstrates how to use the HashMap class to map from the names of mountain peaks to their height in feet. The name of the mountain is the key and the height is the mapped value. The base type of the key is String and the base type of the value is Integer. We must use the wrapper class Integer rather than int because primitive data types are not allowed as a base type. The example uses only the methods specified in the Map interface to add several mappings, look up a mapping, modify a mapping, and remove a mapping.

The Map interface describes a mapping from a key object to a value object

The HashMap class implements the Map interface



### FIGURE 12.3 Selected Methods in the Map Interface

```
public Base_Type_Value put(Base_Type_Key k, Base_Type_Value v)
   Associates the value v with the key k. Returns the previous value for k or null if
   there was no previous mapping.
public Base_Type_Value get(Object k)
  Returns the value mapped to the key k or null if no mapping exists.
public void clear()
  Removes a single instance of the specified element from the collection if it is present.
  Returns true if the collection is changed as a result of the call.
public Base_Type_Value remove(Object k)
   Removes the mapping of key k from the map if present. Returns the previous value for
  the key k or null if there was no previous mapping.
public boolean containsKey(Object k)
  Returns true if the key k is a key in the map.
public boolean containsValue(Object v)
  Returns true if the value v is a value in the map.
public boolean hashCode()
  Returns the hash code value for the calling object.
public boolean isEmpty()
  Returns true if the map contains no mappings.
public int size()
  Returns the number of mappings in the map.
public Set <Base_Type_Key> keySet()
  Returns a set containing all of the keys in the map.
public Collection <Base Type Values> values()
  Returns a collection containing all of the values in the map.
```

### LISTING 12.3 A HashMap Demonstration (part 1 of 2)

### LISTING 12.3 A HashMap Demonstration (part 2 of 2)

```
System.out.println("Changing height of Denali.");
        mountains.put("Denali", 20320);
                                                    Overwrites the old
        printMap(mountains);
                                                    value for Denali
        System.out.println("Removing Kangchenjunga.");
        mountains.remove("Kangchenjunga");
        printMap(mountains);
   }
   public static void printMap(HashMap<String, Integer> map)
        System.out.println("Map contains:");
        for (String keyMountainName : map.keySet())
            Integer height = map.get(keyMountainName);
            System.out.println(keyMountainName + " --> " +
                height.intValue() + " feet.");
        System.out.println();
   }
}
```

### Sample Screen Output

```
Map contains:
K2 --> 28251 feet.
Denali --> 20355 feet.
Kangchenjunga --> 28169 feet.
Everest --> 29029 feet.
Denali in the map: true
Changing height of Denali.
Map contains:
K2 --> 28251 feet.
Denali --> 20320 feet.
Kangchenjunga --> 28169 feet.
Everest --> 29029 feet.
Removing Kangchenjunga.
Map contains:
K2 --> 28251 feet.
Denali --> 20320 feet.
Everest --> 29029 feet.
```



As with the HashSet<T> class, if you intend to use your own class as the parameterized type K in a HashMap<K,V> then your class must override the following methods:

```
public int hashCode();
public boolean equals(Object obj);
```

These methods are required for indexing and checking for uniqueness of the key.

# PROGRAMMING TIP Other Classes in the Java Collections Framework

There are many other methods, classes, and interfaces in the Java Collections Framework. You will be happy to know that the methods specified in either the Collection or Map interfaces provide a uniform interface for all classes in the framework. For example, there is a TreeSet class that stores data in a tree instead of a hash table like the HashSet class. The program in Listing 12.2 will produce identical output if the data type is changed to TreeSet. However, many classes have additional methods specific to the type of data structure or algorithm being implemented.

# **SELF-TEST QUESTIONS**

- 13. Define and invoke the constructor for a HashSet variable named colors capable of holding strings.
- 14. Given the variable colors defined in Question 13, write the code to add "red" and "blue" to the set, output if the set contains "blue", then remove "blue" from the set.
- 15. Define and invoke the constructor for a HashMap named studentIDs that holds a mapping of integers to strings.
- 16. Given the variable studentIDs defined in Question 15, write the code to map 5531 to "George", 9102 to "John", and print the name associated with ID 9102.

### **12.3** LINKED DATA STRUCTURES

Do not mistake the pointing finger for the moon.

-ZEN SAYING

A **linked data structure** is a collection of objects, each of which contains data and a reference to another object in the collection. We will confine most of our discussion of linked data structures to a simple but widely used kind known as a linked list.

A collection of linked objects

### The Class LinkedList

Instead of using the class ArrayList and worrying about allocating too much memory, we can use an instance of the class LinkedList, which is also in the

The class LinkedList implements a list package java.util of the Java Class Library. Like ArrayList, LinkedList is another implementation of the ADT list. Although the two classes do not have the same methods, both have the same basic list operations described in Figure 12.1, with the exception of the constructors and the last method, trimToSize. As you will see, LinkedList—as a linked data structure—allocates memory only as needed to accommodate new entries and deallocates memory when an entry is removed.

After importing LinkedList from the package java.util, you create a new instance of LinkedList by invoking its default constructor. For example, the following statement creates myList as a list of strings:

LinkedList<String> myList = new LinkedList<String>();

You then can go on to use the methods of LinkedList—such as add, set, get, remove, and size—just as you did when using the class ArrayList.

It makes sense to use predefined classes such as LinkedList and ArrayList, since they were written by experts, are well tested, and will save you a lot of work. However, using LinkedList will not teach you how to implement linked data structures in Java. To do that, you need to see a simple example of building at least one linked data structure. A linked list is both a simple and a typical linked data structure. We will construct our own simplified example of a linked list so you can see how linked data structures work.

### PROGRAMMING TIP The Interface List

The Java Collections Framework contains the interface List, which specifies the operations for an ADT list. The methods listed in Figure 12.1 are a part of this interface. Both of the classes ArrayList and LinkedList implement the interface List.



## **SELF-TEST QUESTION**

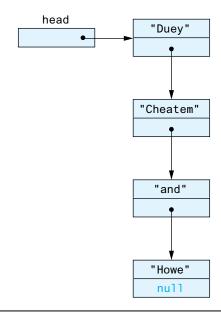
17. What changes would you make to the program in Listing 12.1 to use LinkedList instead of ArrayList?

#### **Linked Lists**

A linked list links nodes

A **linked list** is a dynamic data structure that links the items in a list to one another. Figure 12.4 shows a linked list in diagrammatic form. Like all linked data structures, a linked list consists of objects known as **nodes**. In the figure, the nodes are the boxes that are divided in half by a horizontal line. Each node has a place for some data and a place to hold a **link** to another node. The links are shown as arrows that point to the node they "link" to. In Java, the links are implemented as references to a node, and in practice they are instance variables of the node type. However, for your first look at a linked list, you can simply think of the links as arrows. In a linked list, each node contains only one link, and the nodes are arranged one after the other so as to form a list, as in Figure 12.4. In an intuitive sense, you or, more properly, your code moves from node to node, following the links.





The link marked head is not on the list of nodes; in fact, it is not even a node, but is a link that gets you to the first node. In implementations, head will contain a reference to a node, so head is a variable of the node type. Your program can easily move through the list in order, from the first node to the last node, by following the "arrows."

#### **RECAP Linked List**

A linked list is a data structure consisting of objects known as nodes. Each node can contain both data and a reference to one other node so that the nodes link together to form a list, as illustrated in Figure 12.4.

Now let's see exactly how we can implement a linked list in Java. Each node is an object of a class that has two instance variables, one for the data and one for the link. Listing 12.4 gives the definition of a Java class that can serve as the node class for linked lists like the one shown in Figure 12.4. In this case, the data in each node consists of a single String value.<sup>1</sup> As noted in Listing 12.4, we will later make this node class private.

<sup>&</sup>lt;sup>1</sup> Technically speaking, the node does not contain the string, but only a reference to the string, as would be true of any variable of type String. However, for our purposes, we can think of the node as containing the string, since we never use this string reference as an "arrow."

### LISTING 12.4 A Node Class

```
public class ListNode
                                        Later in this chapter, we will hide
                                        this class by making it private.
    private String data;
    private ListNode link;
    public ListNode()
    {
        link = null;
        data = null;
    }
    public ListNode(String newData, ListNode linkValue)
        data = newData;
        link = linkValue;
    }
    public void setData(String newData)
        data = newData;
    public String getData()
    {
        return data;
    public void setLink(ListNode newLink)
        link = newLink;
    public ListNode getLink()
    {
        return link;
    }
}
```

### The class ListNode

Notice that the link instance variable of the class ListNode in Listing 12.4 is of type ListNode. This relationship sounds circular, and in a sense, it is. However, this kind of class definition is perfectly legal in Java. Recall that a variable of a class type holds a reference to an object of that class. So the link instance variable of an object of the ListNode class will contain a reference to another object of the class ListNode. Thus, as the arrows in the diagram in Figure 12.4 show, each node object of a linked list contains in its link instance variable a reference to another object of the class ListNode; this other object contains a reference to another object of the class ListNode, and so on, until the end of the linked list.

When dealing with a linked list, your code needs to be able to "get to" the first node, and you need some way to detect when the last node is reached. To get to the first node, you use a variable of type ListNode that contains a reference to the first node. As we noted earlier, this variable is not a node on the list. In Figure 12.4, the variable containing a reference to the first node is represented by the box labeled head. The first node in a linked list is called the head node, and it is common to use the name head for a variable that contains a reference to this first node. In fact, we call head a head reference.

A reference to the head (first) node is called the head reference

In Java, you indicate the end of a linked list by setting the link instance variable of the last node object to null, as shown in Figure 12.4. That way your code can test whether a node is the last node in a linked list by testing whether the node's link instance variable contains null. Recall that you check whether a variable contains null by using the operator ==. In contrast, the data instance variable in Listing 12.4 is of type String, and you normally check two String variables for equality by using the equals method.

head is null for an empty list

Linked lists usually start out empty. Since the variable head is supposed to contain a reference to the first node in a linked list, what value do you give head when there is no first node? You give head the value null in order to indicate an empty list. This technique is traditional and works out nicely for many algorithms that manipulate a linked list.

### REMEMBER Use null for the Empty List and to Indicate Its End

The head reference of an empty linked list contains null, as does the link portion of the last node of a nonempty linked list.

# Implementing the Operations of a Linked List

Listing 12.5 contains a definition of a linked-list class that uses the node class definition given in Listing 12.4. Note that this new class has only one instance variable, and it is named head. This head instance variable contains a reference to the first node in the linked list, or it contains null if the linked list is empty—that is, when the linked list contains no nodes. The one constructor sets this head instance variable to null, indicating an empty list.

Before we go on to discuss how nodes are added and removed from a linked list, let's suppose that a linked list already has a few nodes and that you want to display the contents of all the nodes to the screen. You can do so by writing the following statements:

```
ListNode position = head;
while (position != null)
{
    System.out.println(position.getData());
    position = position.getLink();
}
```

### LISTING 12.5 A Linked-List Class (part 1 of 2)

```
public class StringLinkedList
                                          We will give another definition of
                                          this class later in this chapter.
    private ListNode head;
    public StringLinkedList()
    {
        head = null;
    }
     /**
    Displays the data on the list.
    public void showList()
        ListNode position = head;
        while (position != null)
            System.out.println(position.getData());
            position = position.getLink();
        }
    }
    Returns the number of nodes on the list.
    public int length()
    {
        int count = 0.
        ListNode position = head;
        while (position != null)
        {
            count++;
            position = position.getLink();
        return count;
    }
    Adds a node containing the data addData at the
    start of the list.
    public void addANodeToStart(String addData)
        head = new ListNode(addData, head);
    }
```

### LISTING 12.5 A Linked-List Class (part 2 of 2)

```
/ * *
    Deletes the first node on the list.
    public void deleteHeadNode()
    {
        if (head != null)
            head = head.getLink();
        else
        {
            System.out.println("Deleting from an empty list.");
            System.exit(0);
        }
    }
    Sees whether target is on the list.
    public boolean onList(String target)
        return find(target) != null;
    //Returns a reference to the first node containing the
    //target data. If target is not on the list, returns null.
    private ListNode find(String target)
    {
        boolean found = false;
        ListNode position = head:
        while ((position != null) && !found)
        {
            String dataAtPosition = position.getData();
            if (dataAtPosition.equals(target))
                found = true;
            else
                position = position.getLink();
        }
        return position
    }
}
```

The variable named position contains a reference to one node. Initially, position contains the same reference as the head instance variable; thus, it starts out positioned at the first node. After we display the data in that node, the reference in position changes from one node to the next via the assignment

Stepping through a list

```
position = position.getLink();
```

This process is illustrated in Figure 12.5.

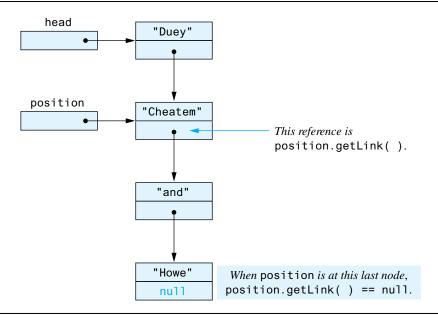


FIGURE 12.5 Moving Down a Linked List

To see that this assignment "moves" the position variable to the next node, note that position contains a reference to the node pointed to by the position arrow in Figure 12.5. So position is a name for that node, and position.link is a name for the link portion of that node. Thus, position.link references the next node. The value of link is produced by calling the accessor method getLink. Therefore, a reference to the next node in the linked list is position.getLink(). You "move" the position variable by giving it the value of position.getLink().

The previous loop continues to move the position variable down the linked list, displaying the data in each node as it goes along. When position reaches the last node, it displays the data in that node and again executes

```
position = position.getLink();
```

If you study Figure 12.5, you will see that position's value is set to null at this point. When this occurs, we want to stop the loop, so we iterate the loop while position is not null.

The method showList contains the loop that we just discussed. The method length uses a similar loop, but instead of displaying the data in each node, length just counts the nodes as the loop moves from node to node. When the loop ends, length returns the number of entries on the list. By the way, a process that moves from node to node in a linked list is said to **traverse** the list. Both showList and length traverse our list.

Next, let's consider how the method addANodeToStart adds a node to the start of the linked list so that the new node becomes the first node of the list.

This operation is performed by the single statement

head = new ListNode(addData, head);

Adding a node at the beginning of the list

In other words, the variable head is set equal to a reference to a new node, making the new node the first node in the linked list. To link this new node to the rest of the list, we need only set the link instance variable of the new node equal to a reference to the old first node. But we have already done that: The new node produced by newListNode(addData, head) references the old first node, because head contains a reference to the old first node before it is assigned a reference to the new node. Therefore, everything works out as it should. This process is illustrated in Figure 12.6.

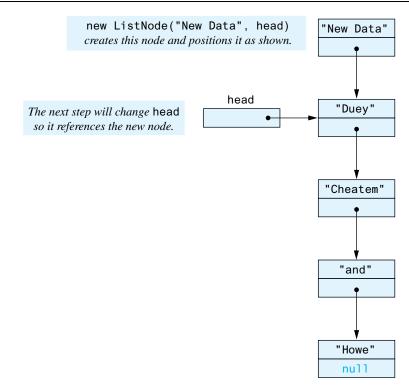
So far, we have added a node only at the start of the linked list. Later, we will discuss adding nodes at other places in a linked list, but the easiest place to add a node is at the start of the list. This is also the easiest place to delete a node.

The method deleteHeadNode removes the first node from the linked list and leaves the head variable referencing the old second node—which is now the first node—in the linked list. We will leave it to you to figure out that the following assignment correctly accomplishes this deletion:

head = head.getLink();

Removing the first node

## FIGURE 12.6 Adding a Node at the Start of a Linked List



Listing 12.6 contains a simple program that demonstrates the behavior of some of the methods we just discussed.

### LISTING 12.6 A Linked-List Demonstration

```
public class StringLinkedListDemo
    public static void main(String[] args)
    {
        StringLinkedList list = new StringLinkedList();
        list.addANodeToStart("One");
        list.addANodeToStart("Two");
        list.addANodeToStart("Three");
        System.out.println("List has " + list.length() +
                           " entries.");
        list.showList();
        if (list.onList("Three"));
            System.out.println("Three is on list.");
        else
            System.out.println("Three is NOT on list.");
        list.deleteHeadNode();
        if (list.onList("Three"));
            System.out.println("Three is on list.");
        else
            System.out.println("Three is NOT on list.");
        list.deleteHeadNode();
        list.deleteHeadNode();
        System.out.println("Start of list:");
        list.showList();
        System.out.println("End of list");
    }
}
```

### Screen Output

```
List has 3 entries.
Three
Two
One
Three is on list.
Three is NOT on list.
Start of list:
End of list.
```

### FAQ What happens to a deleted node?

When your code deletes a node from a linked list, it removes the linked list's reference to that node. So as far as the linked list is concerned, the node is no longer in the linked list. But you gave no command to destroy the node, so it must be some place in the computer's memory. If there is no other reference to the deleted node, the storage that it occupies should be made available for other uses. In many programming languages, you, the programmer, must keep track of deleted nodes and give explicit commands to return their memory for recycling to other uses. This process is called **garbage collecting**. In Java, this task is done for you automatically, or, as it is ordinarily phrased, Java has **automatic garbage collection**.

### GOTCHA NullPointerException

You have undoubtedly received the message NullPointerException at some time when you have run a program. (If you have not received the message, congratulations! You are an exceptionally careful programmer.) The message NullPointerException indicates that your code tried to use a variable of a class type to reference an object, but the variable contains null. That is, the variable does not contain a reference to any object. This message may make more sense to you now. In our nodes, we used null to indicate that a link instance variable contains no reference. So a value of null indicates no object reference, and that is why the exception is called NullPointerException.

A NullPointerException is one of the exceptions that you do not need to catch in a catch block or declare in a throws clause. Instead, it indicates that you need to fix your code.

#### **REMEMBER Most Nodes Have No Name**

The variable head contains a reference to the first node in a linked list. So head can be used as a name for the first node. However, the other nodes in the linked list have no named variable that contains a reference to any of them, so the rest of the nodes in the linked list are nameless. The only way to name one of them is via some indirect reference, like head. getLink(), or by using another variable of type ListNode, such as the local variable position in the method showList (Listing 12.5).



## **SELF-TEST QUESTIONS**

- 18. How do you mark the end of a linked list?
- 19. Assume that the variable head is supposed to contain a reference to the first node in a linked list and that the linked list is empty. What value should head have?
- 20. Write a definition of a method is Empty for the class StringLinkedList that returns true if the list is empty, that is, if it has no nodes.
- 21. What output is produced by the following code?

```
StringLinkedList list = new StringLinkedList();
list.addANodeToStart("A");
list.addANodeToStart("B");
list.addANodeToStart("C");
list.showList();
```

# A Privacy Leak

The point made in this section is important but a bit subtle. It will help you to understand this section if you first review Section 6.5 in Chapter 6. There we said that a privacy problem can arise in any situation in which a method returns a reference to a private instance variable of a class type. The private restriction on the instance variable could be defeated easily if it names an object that has a set method. Getting a reference to such an object could allow a programmer to change the private instance variables of the object.

Consider the method getLink in the class ListNode (Listing 12.4). It returns a value of type ListNode. That is, it returns a reference to a ListNode object, that is, a node. Moreover, ListNode has public set methods that can damage the contents of a node. Thus, getLink can cause a privacy leak.

On the other hand, the method getData in the class ListNode causes no privacy leak, but only because the class String has no set methods. The class String is a special case. If the data were of another class type, getData could produce a privacy leak.

If the class ListNode is used only in the definition of the class StringLinkedList and classes like it, there is no privacy leak. This is the because no public method in the class StringLinkedList returns a reference to a node. Although the return type of the method find is ListNode, it is a private method. If the method find were public, a privacy leak would result. Therefore, note that making find private is not simply a minor stylistic point.

Although there is no problem with the class definition of ListNode when it is used in a class definition like StringLinkedList, we cannot guarantee that the class ListNode will be used only in this way. You can fix this privacy-leak

problem in a number of ways. The most straightforward way is to make the class ListNode a private inner class in the class StringLinkedList, as discussed in the next two sections, "Inner Classes" and "Node Inner Classes." Another, and similar, solution is to place both of the classes ListNode and StringLinkedList into a package; change the private instance variable restriction to the package restriction, as discussed in Appendix 3; and omit the accessor method getLink.

### **Inner Classes**

**Inner classes** are classes defined within other classes. Although a full description of inner classes is beyond the scope of this book, some simple uses of inner classes can be both easy to understand and helpful. In this section, we describe inner classes in general and show how we will use them. In the next section, we give an example of an inner class defined within the linked-list class. That node inner class will be a solution to the privacy leak we just described.

Define an inner class entirely within an outer class

Defining an inner class is straightforward; simply include the definition of the inner class within another class—the **outer class**—as follows:

```
public class OuterClass
{
    Declarations_of_OuterClass_Instance_Variables
    Definitions_of_OuterClass_Methods
    private class InnerClass
    {
         Declarations_of_InnerClass_Instance_Variables
         Definitions_of_InnerClass_Methods
    }
}
```

The definition of the inner class need not be the last item of the outer class, but it is good to place it either last or first so that it is easy to find. The inner class need not be private, but that is the only case we will consider in this book.

An inner-class definition is local to the outer-class definition. So you may reuse the name of the inner class for something else outside the definition of the outer class. If the inner class is private, as ours will always be, the inner class cannot be used outside the definition of the outer class.

The inner-class definition can be used anywhere within the definition of the outer class, and it has a special property that facilitates this use: The methods of the inner and outer classes have access to each other's methods and instance variables, even if they are private. Within the definitions of the inner or outer classes, the modifiers public and private are equivalent. Although some details of inner-class usage can be tricky, we will consider only simple cases similar to the one in the next section.

We will revisit inner classes in Chapter 15, which is on the book's Web site.

### **Node Inner Classes**

ListNode as an inner class

You can make classes like StringLinkedList self-contained by making node classes such as ListNode inner classes, as follows:

Note that we've made the class ListNode a private inner class. If an inner class is not intended to be used elsewhere, it should be made private. Making ListNode a private inner class is also safer, because it hides the method getLink from the world outside the StringLinkedList definition. As we noted earlier, in the section entitled "A Privacy Leak," it can be dangerous for a publicly available method to return a reference to an instance variable of a class type.

If you are going to make the class ListNode a private inner class in the definition of StringLinkedList, you can safely simplify the definition of ListNode by eliminating the accessor and mutator methods (the set and get methods) and just use direct access to the instance variables data and link. In Listing 12.7, we have rewritten the class StringLinkedList in this way. This version, named StringLinkedListSelf-Contained, is equivalent to the class StringLinkedList in Listing 12.5 in that it has the same methods that perform the same actions. In fact, if you run the program StringLinkedListDemo in Listing 12.6, replacing the class StringLinkedListWith StringLinkedListSelfContained, the sample output will not change. (The program StringLinkedListSelfContainedDemo is included with the book's source code and does just that.)

Extra code on the Web



VideoNote
Adding a node anywhere in a linked list

#### **REMEMBER Node Inner Class**

You can make a linked data structure, such as a linked list, self-contained by making the node class an inner class of the linked-list class.

### **Iterators**

An iterator steps through a collection

When you have a collection of objects, such as the nodes of a linked list, you often need to step through all the objects in the collection and perform some action on each object, such as displaying it on the screen or in some way editing its data. An **iterator** is any variable that allows you to step through the list in this way.

# LISTING 12.7 A Linked List with a Node Class as an Inner Class (part 1 of 2)

```
public class StringLinkedListSelfContained
    private ListNode head;
    public StringLinkedListSelfContained()
        head = null;
    }
    Displays the data on the list.
                                       Note that the outer class has direct
    public void showList()
                                       access to the inner-class instance
    {
                                       variables data and link.
        ListNode position = head;
        while (position != null)
            System.out.println(position.data);
            position = position.link;
        }
    }
    Returns the number of nodes on the list.
    public int length()
    {
        int count = 0;
        ListNode position = head;
        while (position != null)
        {
            count++;
            position = position.link;
        return count
    }
    Adds a node containing the data addData at the
    start of the list.
    public void addANodeToStart(String addData)
    {
        head = new ListNode(addData, head);
    Deletes the first node on the list.
    public void deleteHeadNode()
                                                            (continued)
```

# LISTING 12.7 A Linked List with a Node Class as an Inner Class (part 2 of 2)

```
if (head != null)
            head = head.link;
        else
        {
            System.out.println("Deleting from an empty list.");
            System.exit(0);
    }
    Sees whether target is on the list.
    public boolean onList(String target)
        return (find(target) != null);
    //Returns a reference to the first node containing the
    //target data. If target is not on the list, returns null.
    private ListNode find(String target)
        boolean found = false;
        ListNode position = head;
        while ((position != null) && !found)
        {
            String dataAtPosition = position.data;
            if (dataAtPosition.equals(target))
                found = true;
            else
                position = position.link;
        return position;
                                       An inner class
    private class ListNode
        private String data;
        private ListNode link;
        public ListNode()
        {
            link = null;
            data = null;
        }
        public ListNode(String newData, ListNode linkValue)
            data = newData;
            link = linkValue;
                            End of outer-class definition
}
```

We will begin by looking at an iterator for an array, as it is easier to program than an iterator for a linked list. An array is a collection of elements having the same data type. An iterator for an array is an int variable. If the array is named anArray and the int variable is named index, you can step through all the elements in the array as follows:

```
for (index = 0; index < anArray.length; index++)
    Process anArray[index]</pre>
```

The int variable index is the iterator. You can **iterate**—that is, go from element to element—with the action index++.

If you create an array of all the data objects in a linked list, you can iterate through the array. That process is equivalent to iterating through the linked list, provided that you do not want to change the data in the linked list but want only to look at it. For this reason, it is common to have a method in a list class that places all the data in the linked list into an array. Such a method is shown in Listing 12.8. This method, named toArray, can be added to the linked list in Listing 12.7. (The class StringLinkedListSelfContained, included in the source code available on the Web, contains this method.)

Extra code on Web

### LISTING 12.8 Placing the Linked-List Data into an Array

This method can be added to the linked-list class in Listing 12.7.

```
/**
Returns an array of the elements on the list.
*/
public String[] toArray()
{
    String[] anArray = new String[length()];
    ListNode position = head;
    int i = 0;
    while (position != null)
    {
        anArray[i] = position.data;
        i++;
        position = position.link;
    }
    return anArray;
}
```

#### **RECAP Iterators**

Any variable that allows you to step through a collection of data items, such as an array or a linked list, one item at a time in a reasonable way is called an iterator. By "a reasonable way," we mean that each item is visited exactly once in one full cycle of iterations and that each item can have its data read and, if the data items allow it, can have the data changed.

If you want an iterator that will move through a linked list and allow you to perform operations, such as change the data at a node or even insert or delete a node, having an array of the linked-list data will not suffice. However, an iterator for an array hints at how to proceed. Just as an index specifies an array element, a reference for a node specifies a node. Thus, if you add an instance variable, perhaps named current, to the linked-list class StringLinkedListSelfContained given in Listing 12.7, you can use this instance variable as an iterator. We have done so in Listing 12.9 and have renamed the class StringLinkedListWithIterator. As you can see, we have added a number of methods to manipulate the instance variable current. This instance variable is the iterator, but because it is marked private, we need methods to manipulate it. We have also added methods for adding and deleting a node at any place in the linked list. The iterator makes it easier to express these methods for adding and deleting nodes, because it gives us a way to name an arbitrary node. Let's go over the details.

LISTING 12.9 A Linked List with an Iterator (part 1 of 4)

```
Linked list with an iterator. One node is the "current node."
Initially, the current node is the first node. It can be changed
to the next node until the iteration has moved beyond the end
of the list.
public class StringLinkedListWithIterator
{
    private ListNode head;
    private ListNode current;
    private ListNode previous;
    public StringLinkedListWithIterator()
    {
        head = null;
        current = null;
        previous = null;
    }
    public void addANodeToStart(String addData)
    {
        head = new ListNode(addData, head);
        if ((current == head.link) && (current != null))
             //if current is at old start node
             previous = head;
    }
```

(continued)

# LISTING 12.9 A Linked List with an Iterator (part 2 of 4)

```
/ * *
Sets iterator to beginning of list.
public void resetIteration()
    current = head;
    previous = null;
}
/**
Returns true if iteration is not finished.
public boolean moreToIterate()
    return current != null;
Advances iterator to next node.
*/
public void goToNext()
{
    if (current != null)
        previous = current;
        current = current.link;
    else if (head != null)
        System.out.println(
            "Iterated too many times or uninitialized
            iteration.");
        System.exit(0);
    }
    else
    {
        System.out.println("Iterating with an empty list.");
        System.exit(0);
    }
}
Returns the data at the current node.
public String getDataAtCurrent()
{
    String result = null;
    if (current != null)
        result = current.data;
```

# LISTING 12.9 A Linked List with an Iterator (part 3 of 4)

```
else
    {
        System.out.println(
                "Getting data when current is not at any node.");
        System.exit(0);
    }
    return result;
}
Replaces the data at the current node.
public void setDataAtCurrent(String newData)
{
    if (current != null)
    {
        current.data = newData;
    else
    {
        System.out.println(
                "Setting data when current is not at any node.");
        System.exit(0);
    }
}
Inserts a new node containing newData after the current node.
The current node is the same after invocation as it is before.
Precondition: List is not empty; current node is not
beyond the entire list.
public void insertNodeAfterCurrent(String newData)
{
    ListNode newNode = new LisNode();
    newNode.data = newData;
    if (current != null)
    {
        newNode.link = current.link;
        current.link = newNode;
    }
    else if (head != null)
    {
        System.out.println(
                "Inserting when iterator is past all " +
                "nodes or is not initialized.");
        System.exit(0);
    }
                                                          (continued)
```

# LISTING 12.9 A Linked List with an Iterator (part 4 of 4)

```
else
    {
        System.out.println(
                 "Using insertNodeAfterCurrent with empty list.";
        System.exit(0);
    }
    / * *
    Deletes the current node. After the invocation,
    the current node is either the node after the
    deleted node or null if there is no next node.
    */
    public void deleteCurrentNode()
        if ((current != null) && (previous == null))
            previous.link = current.link;
            current = current.link;
        else if ((current != null) && (previous == null))
        {//At head node
            head = current.link;
            current = head;
        }
        else //current==null
             System.out.println(
                "Deleting with uninitialized current or an empty " +
                "list.");
             System.exit(0);
        }
    }
    <The methods length, onList, find, and showList, as well as the private</p>
    inner class ListNode are the same as in Listing 12.7.>
    <The method toArray is the same as in Listing 12.8.>
}
    deleteHeadNode is no longer needed, since
    you have deleteCurrentNode, but if you
    want to retain deleteHeadNode, it must
    be redefined to account for current and
    previous.
```

Instance variables current and previous The method goToNext An internal iterator An external In addition to the instance variables head and current, we have added an instance variable named previous. The idea is that, as the reference current moves down the linked list, the reference previous follows behind by one node. This setup gives us a way to reference the node before the one named by current. Since the links in the linked list all move in one direction, we need the node previous so that we can do something equivalent to backing up one node.

The method resetIteration starts current at the beginning of the linked list by giving it a reference to the first (head) node, as follows:

current = head;

#### **ASIDE Internal and External Iterators**

The class StringLinkedListWithIterator (Listing 12.9) uses the instance variable current of type ListNode as an iterator to step through the nodes of the linked list one after the other. An iterator defined within the linked-list class in this way is known as an internal iterator.

If you copy the values in a linked list to an array via the method toArray, you can use a variable of type int as an iterator on the array. The int variable holds one index of the array and thus specifies one element of the array and one data item of the linked list. If the int variable is named position and the array is named a, the iterator position specifies the element a [position]. To move to the next item, simply increase the value of position by 1. An iterator that is defined outside the linked list, such as the int variable position, is known as an external iterator. Note that the important thing is not that the array is outside the linked list, but that the int variable position, which is the iterator, is outside the linked list. To better understand this point, note that the int variable position is also an external iterator for the array.

You can have several external iterators at one time, each at a different position within the same list. This is not possible with internal iterators, which is a distinct disadvantage.

It is possible to define an external iterator that works directly with the linked list, rather than with an array of the linked-list data. However, that technique is a bit more complicated, and we will not go into it in this text.

Because the instance variable previous has no previous node to reference, it is simply given the value null by the resetIteration method.

The method goToNext moves the iterator to the next node, as follows:

```
previous = current;
current = current.link;
```

This process is illustrated in Figure 12.7. In the goToNext method, the last two clauses of the multibranch if-else statement simply produce an error message when the method goToNext is used in a situation where using it does not make sense.

The method moreToIterate returns true as long as current is not equal to null, that is, as long as current contains a reference to some node. This result makes sense most of the time, but why does the method return true when current contains a reference to the last node? When current references the last node, your program cannot tell that it is at the last node until it invokes goToNext one more time, at which point current is set to null. Study Figure 12.7 or the definition of goToNext to see how this process works. When current is equal to null, moreToIterate returns false, indicating that the entire list has been traversed.

Now that our linked list has an iterator, our code has a way to reference any node in the linked list. The current instance variable can hold a reference to any one node; that one node is known as the **node at the iterator**. The method insertAfterIterator inserts a new node after the node at the iterator (at current). This process is illustrated in Figure 12.8. The method

**Before** After head head "Duey" "Duey" previous "Cheatem" "Cheatem" current previous "and" "and" current.link current "Howe" "Howe" nu11 nu11 current = current.link gives current a reference

FIGURE 12.7 The Effect of goToNext on a Linked List

deleteCurrentNode deletes the node at the iterator. This process is illustrated

to this last node.

in Figure 12.9. The other methods in the class StringLinkedListWithIterator (Listing 12.9) are fairly straightforward, and we will leave it up to you to read The method moreToIterate

Inserting and deleting items within a list

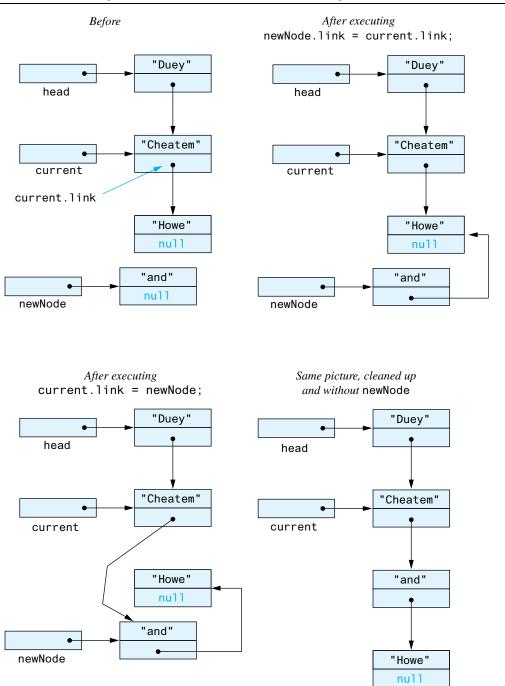


# **SELF-TEST QUESTIONS**

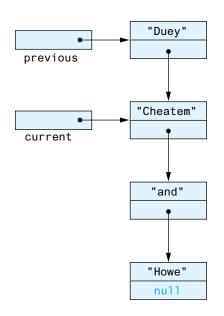
their definitions and see how they work.

- 22. What is an inner class?
- 23. Why does the definition of the inner class ListNode in Listing 12.7 not have the accessor and mutator methods getLink, setLink, getData, and setData, as the class definition ListNode in Listing 12.4 does?
- 24. What is an iterator for a collection of items, such as an array or a linked list?

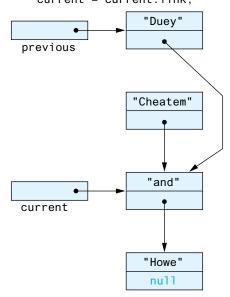
FIGURE 12.8 Adding a Node to a Linked List, Using insertAfterIterator



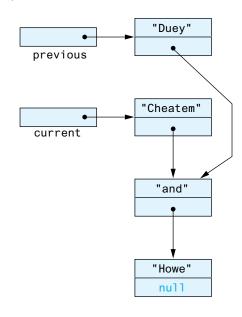
**Before** 



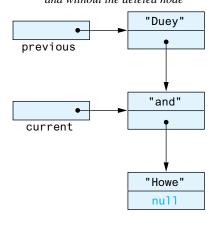
After executing
current = current.link;



After executing
previous.link = current.link;



Same picture, cleaned up and without the deleted node



### The Java Iterator Interface

The standard interface Iterator

Our introduction to iterators defined them as variables that enable you to step through a collection of items. However, Java formally considers an iterator to be an object, not simply a variable. The interface named Iterator in the package java.util stipulates how Java would like an iterator to behave. The interface specifies the following three methods:

- hasNext—returns true if the iteration has another element to return.
- next—returns the next element in the iteration.
- remove—removes from the collection the element returned most recently by the invocation next().

Our iterators do not satisfy this interface, but it is easy to define classes that use our iterators and that do satisfy this interface. The Iterator interface also uses exception handling, but that use is not difficult to understand. Appendix 9, briefly describes the Iterator interface. Exercise 16 at the end of this chapter asks you to define a linked-list class that satisfies this interface.

# **Exception Handling with Linked Lists**

As you may have guessed, you need to have read Chapter 9 on exception handling before reading this section.

Consider the class StringLinkedListWithIterator in Listing 12.9. We defined the methods for that class such that whenever something went wrong, the method sent an error message to the screen and ended the program. However, it may not always be necessary to end the program when something unusual happens. To allow the programmer to provide an action in these unusual situations, it would make more sense to throw an exception and let the programmer decide how to handle the situation. The programmer can still decide to end the program but instead could do something else. For example, you could rewrite the method goToNext as follows:

### LISTING 12.10 The LinkedListException Class

```
public class LinkedListException extends Exception
{
    public LinkedListException()
        {
             super("Linked List Exception");
        }
        public LinkedListException(String message)
        {
             super(message);
        }
}
```

In this version, we have replaced each of the branches that end the program with a branch that throws an exception. The exception class LinkedListException can be a routine exception class, as shown in Listing 12.10.

You can use an exception thrown during an iteration for a number of different purposes. One possibility is to check for the end of a linked list. For example, suppose that the version of StringLinkedListWithIterator that throws exceptions is named StringLinkedListWithIterator2. The following code removes all nodes that contain a given string (badString) from a linked list, throwing an exception if it attempts to read past the end of the list:

```
StringLinkedListWithIterator2 list =
        new StringLinkedListWithIterator2();
String badString:
<Some code to fill the linked list and set the variable badString.>
list.resetIteration();
try
{
    while (list.length() >= 0)
    {
        if (badString.equals(list.getDataAtCurrent()))
            list.deleteCurrentNode();
        else list.goToNext();
    }
}
catch(LinkedListException e)
    if (e.getMessage().equals("Iterating an empty list."))
    {//This should never happen, but
    //the catch block is compulsory.
        System.out.println("Fatal Error.");
        System.exit(0);
    }
System.out.println("List cleaned of bad strings.");
```

This use of an exception to test for the end of a list may seem a bit strange at first, but similar uses of exceptions do occur in Java programming. For example, Java requires something like this when checking for the end of a binary file. Of course, there are many other uses for the LinkedListException class.

The self-test questions that follow ask you to rewrite more of the methods in StringLinkedListWithIterator so that they throw exceptions in unusual or error situations.



### **SELF-TEST QUESTIONS**

- 25. Redefine the method getDataAtCurrent in StringLinkedListWith Iterator (Listing 12.9) so that it throws an exception instead of ending the program when something unusual happens.
- 26. Repeat Question 25 for the method setDataAtCurrent.
- 27. Repeat Question 25 for the method insertNodeAfterCurrent.
- 28. Repeat Question 25 for the method deleteCurrentNode.

### Variations on a Linked List

The study of data structures is a large topic, with many good books on the subject. In this book, we cannot introduce you to all aspects of programming, and therefore we cannot go into the topic of linked data structures in exhaustive detail. Instead, we will give you an informal introduction to a few important linked data structures, beginning with some other kinds of linked lists that link their nodes in different ways.

You can have a linked list of any kind of data. Just replace the type String in the definition of the node class (and other corresponding places) with the data type you want to use. You can even have a linked list of objects of different kinds by replacing the type String in the node definition (and other corresponding places) with the type Object, as shown in the following code:

```
A list node having
Object data
```

```
private class ListNode
{
    private Object data;
    private ListNode link;
    public ListNode()
    {
        link = null;
        data = null;
    }
    public ListNode(Object newData, ListNode linkValue)
```

```
{
    data = newData;
    link = linkValue;
}
```

Because an object of any class type is also of type Object, you can store any kinds of objects in a linked list with nodes of this kind.

Instead of using Object as the data type of the list items, you can use a generic data type. Section 12.3 of this chapter will show you how. By using a generic data type, you restrict the objects in the linked list to having the same data type.

Sometimes it is handy to have a reference to the last node in a linked list. This last node is often called the **tail node** of the list, so the linked-list definition might begin as follows:

The last node in a linked list is its tail node

```
public class StringLinkedListWithTail
{
    private ListNode head;
    private ListNode tail;
```

The constructors and methods must be modified to accommodate the new reference, tail, but the details of doing so are routine.

You have seen that the link portion of the last node in a linked list contains null. In a circular linked list, this link is instead a reference to the first node. Thus, no link in a circular linked list is null. Such a linked list still has a beginning and an end, as well as an external reference to either its first node or its last node. Figure 12.10 illustrates a circular linked list that has an external reference, tail, to its last node. Note that tail.link is then a reference to the list's first node.

A linked list can be circular

An ordinary linked list allows you to follow its links and move down the list in only one direction. A **doubly linked list** has two links in each node: one link is a reference to the next node and one is a reference to the previous node. Figure 12.11 illustrates a doubly linked list.

A linked list can be doubly linked

### FIGURE 12.10 A Circular Linked List

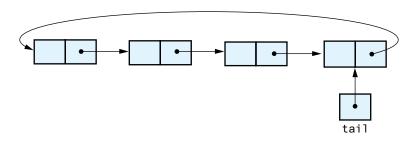
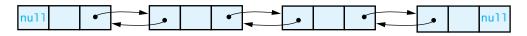


FIGURE 12.11 A Doubly Linked List



The node class for a doubly linked list can begin as follows:

```
private class ListNode
{
    private Object data;
    private ListNode next;
    private ListNode previous;
```

The constructors and some of the methods in the doubly linked list class will have somewhat different definitions than those in the singly linked case in order to accommodate the extra link.

A **circular doubly linked list** is also possible. In this structure, the previous link of the first node references the last node and the next link of the last node references the first node.

### Other Linked Data Structures

We have discussed a few kinds of linked lists as examples of linked data structures. Here are several more linked data structures that you will surely encounter in later studies.

A **stack** is an ADT whose implementation is not necessarily a linked data structure, but it can be implemented as one. A stack organizes its data so that items are removed in the reverse of the order in which they were inserted. So if you insert "one", then "two", and then "three" into a stack and then remove them, they will come out in the order "three", then "two", and finally "one". A linked list that inserts and deletes only at the beginning of the list—such as the one in Listing 12.5—behaves like a stack, and so can be an implementation of a stack.

Another common and powerful data structure is a **tree**. In a tree, each node leads to several other nodes. The most common form of a tree is a **binary tree**, in which each node has links to at most two other nodes. This tree has the same kind of nodes as a doubly linked list, but they are used in a very different way. A binary tree can be represented diagramatically, as shown in Figure 12.12.

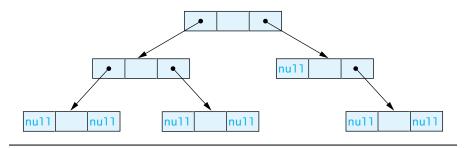
It is not an accident that we have no references leading back up the tree in our diagram of a binary tree. In a tree, the nodes must be arranged without any loops.

The top node in a binary tree is known as the **root node**, and there is normally a reference to this root node, just as there is a reference to the head node of a linked list. Every node can be reached from the root node by following suitable links.

The ADT stack

A binary tree

FIGURE 12.12 A Binary Tree



### 12.4 GENERICS

There are no favorites in my office. I treat them all with the same general inconsideration.

-LYNDON B. JOHNSON, 36th President of the United States.

As we mentioned earlier, beginning with version 5.0, Java allows class definitions to include parameters for data types. These parameters are called **generics**. This section gives a brief introduction to this topic. Programming with generics can be subtle and requires care. To do serious programming with generics, you may want to consult a more advanced text.

### The Basics

Classes and methods can use a **type parameter** instead of a specific data type. When Generics allows you to parameterize a data type using such a class or method, a programmer plugs in any class type for the type parameter to produce a specific class type or method for that particular instance. For example, Listing 12.11 shows a very simple class definition that uses a type parameter T. Notice the angle bracket notation around T in the class heading. You can use any nonkeyword identifier for the type parameter; you need not use T. However, by convention, type parameters start with an uppercase letter, and there seems to be a tradition of using a single letter for these parameters. Starting with an uppercase letter makes sense, since only a class type may be plugged in for the type parameter. The tradition of using a single letter is not as compelling.

When writing a class or method that uses a type parameter, you can use the parameter almost anywhere that you can use a class type. For example, the class Sample in Listing 12.11 uses T as the data type of the instance variable data, the method parameter newValue, and the return type of the method getData. You cannot, however, use a type parameter to create a new object. So even though data is of type T in the class Sample, you cannot write

data = new T(); //Illegal!

Generics allows you to parameterize a data type

# LISTING 12.11 A Class Definition That Uses a Type Parameter

```
public class Sample<T>
{
    private T data;

    public void setData(T newValue)
    {
        data = newValue;
    }
    public T getData()
    {
        return data;
    }
}
```

Moreover, you cannot use a type parameter when allocating memory for an array. Although you can declare an array by writing a statement such as

```
T[] anArray; //Valid declaration of an array
you cannot write
anArray = new T[20]; //Illegal!
```

# **GOTCHA** You Cannot Use a Type Parameter Everywhere You Can Use a Type Name

Within the definition of a parameterized class definition, there are places where a type name is allowed but a type parameter is not. You cannot use a type parameter in simple expressions that use new to create a new object or to allocate memory for an array. For example, the following expressions are illegal within the definition of a parameterized class definition whose type parameter is T:

```
new T(); //Illegal!
new T[20]; //Illegal!
```

A class definition that uses a type parameter is stored in a file and compiled just like any other class. For example, the parameterized class shown in Listing 12.11 would be stored in a file named Sample.java.

Once the parameterized class is compiled, it can be used like any other class, except that when using it in your code, you must specify a class type to replace the type parameter. For example, the class Sample from Listing 12.11 could be used as follows:

```
Sample<String> sample1 = new Sample<String>();
sample1.setData("Hello");
Sample<Species> sample2 = new Sample<Species>();
Species creature = new Species();
. . . <Some code to set the data for the object creature>
sample1.setData(creature);
```

Notice the angle bracket notation for the actual class type that replaces the type parameter. The class Species could be as defined in Chapter 5, but the details do not matter; it could be any class you define.

You should now realize that the class ArrayList, which we discussed at the beginning of this chapter, is a parameterized class. Recall that we created an instance of ArrayList by writing, for example,

```
ArrayList<String> list = new ArrayList<String>(20);
```

Here String replaces the type parameter in the definition of the class.

### **RECAP** Class Definitions Having a Type Parameter

You can define classes that use a parameter instead of an actual class type. You write the type parameter within angle brackets right after the class name in the heading of the class definition. You can use any nonkeyword identifier for the type parameter, but by convention, the type parameter starts with an uppercase letter.

You use the type parameter within the class definition in the same way that you would use an actual class type, except that you cannot use it in conjunction with new.

#### **EXAMPLE**

See Listing 12.11.

### **RECAP** Using a Class Whose Definition Has a Type Parameter

You create an object of a parameterized class in the same way that you create an object of any other class, except that you specify an actual class type, rather than the type parameter, within angle brackets after the class name.

### **EXAMPLE**

```
Sample<String> anObject = new Sample<String>();
anObject.setData("Hello");
```

# **GOTCHA** You Cannot Plug in a Primitive Type for a Type Parameter

When you create an object of a class that has a type parameter, you cannot plug in a primitive type, such as int, double, or char. For example, the following statement will cause a syntax error:

ArrayList<int> aList = new ArrayList<int>(20); //Illegal!

The type plugged in for a type parameter must be a class type.

# PROGRAMMING TIP Compile with the -Xlint Option

There are many pitfalls that you can encounter when using type parameters. If you compile with the -Xlint option, you will receive more informative diagnostics of any problems or potential problems in your code. For example, the class Sample in Listing 12.11 should be compiled as follows:

javac -Xlint Sample.java

If you are using an integrated development environment, or IDE, to compile your programs, check your documentation to see how to set a compiler option.

When compiling with the -X1 int option, you will get more warnings than you would otherwise get. A warning is not an error, and if the compiler gives only warnings and no error message, the class has compiled and can be used. However, in most cases be sure you understand the warning and feel confident that it does not indicate a problem, or else change your code to eliminate the warning.

# PROGRAMMING EXAMPLE

A Generic Linked List

Let's revise the definition of the linked-list class that appears in Listing 12.7 to use a type parameter, E, instead of the type String as the type of data stored on the list. Listing 12.12 shows the result of this revision.

Notice that the constructor heading looks just as it would in a nonparameterized class. It does not include <E>, the type parameter within angle brackets, after the constructor's name. This is counterintuitive to many people. While a constructor—like any other method in the class—can use the type parameter within its body, its heading does not include the type parameter.

Likewise, the inner class ListNode does not have <E> after its name in its heading, but ListNode does uses the type parameter E within its definition. These are correct as shown, however, because ListNode is an inner class and can access the type parameter of its outer class.

#### LISTING 12.12 A Generic Linked-List Class (part 1 of 2)

```
import java.util.ArrayList;
public class LinkedList2<E>
    private ListNode head;
                                      Constructor headings do not
    public LinkedList2( )
                                      include the type parameter.
    {
        head = null;
    public void showList( )
        ListNode position = head;
        while (position != null)
            System.out.println(position.getData( ));
            position = position.getLink( );
        }
    }
    public int length( )
        int count = 0;
        ListNode position = head;
        while (position != null)
            count++;
            position = position.getLink( );
        }
        return count;
    public void addANodeToStart(E addData)
        head = new ListNode(addData, head);
    public void deleteHeadNode( )
        if (head != null)
        {
            head = head.getLink( );
        }
        else
        {
            System.out.println("Deleting from an empty list.");
            System.exit(0);
        }
    public boolean onList(E target)
        return find(target) != null;
    }
                                                                            (continued)
```

}

#### LISTING 12.12 A Generic Linked-List Class (part 2 of 2)

```
private ListNode find(E target)
{
    boolean found = false;
    ListNode position = head;
    while (position != null)
        E dataAtPosition = position.getData();
        if (dataAtPosition.equals(target))
             found = true;
        else
             position = position.getLink();
    return position;
}
private ArrayList<E> toArrayList()
{
    ArrayList<E> list = new ArrayList<E>(length());
    ListNode position = head;
    while (position != null)
        list.add(position.data);
        position = position.link;
    return list;
}
                                       The inner class heading
private class ListNode ←
                                       has no type parameter.
{
    private E data:
    private ListNode link;
    public ListNode()
        link = null;
        data = null;
    public ListNode(E newData, ListNode linkValue)
    {
        data = newData;
                                         However, the type parameter
        link = linkValue;
                                         is used within the definition
                                         of the inner class.
    public E getData()
        return data;
    public ListNode getLink()
        return link;
}
```

The linked-list class in Listing 12.7 can have a method named toArray—shown in Listing 12.8—that returns an array containing the same data as the linked list. However, our generic version of a linked list cannot implement this same method. If we were to translate toArray in Listing 12.8 so that we could include it in our generic linked list in Listing 12.12, it would begin as follows:

```
public E[] toArray()
{
    E[] anArray = new E[length()]; //Illegal
. . .
```

As the comment indicates, the expression new E[length()] is not allowed. You cannot include the type parameter in certain situations, and this, unfortunately, is one of them. Thus, you simply cannot have the method toArray in the generic linked list. Instead, Listing 12.12 defines the method toArrayList, which returns an instance of the class ArrayList. Note that its definition contains a loop like the one in toArray.



Listing 12.13 contains a simple example of using our parameterized linked list.

#### LISTING 12.13 Using the Generic Linked list

#### Screen Output

```
Good-bye
Hello
3
2
1
```

## **GOTCHA** A Constructor Name in a Generic Class Has No Type Parameter

The class name in a parameterized class definition has a type parameter attached—for example, LinkedList<E> in Listing 12.12. This can mislead you into thinking you need to use the type parameter in the heading of the constructor definition, but that is not the case. For example, you use

```
public LinkedList()
```

instead of

```
public LinkedList<E>() //Illegal
```

However, you can use a type parameter, such as E, within the body of the constructor's definition.

## FAQ Can a class definition have more than one type parameter?

Yes, you can define a class with more than one type parameter. To do so, you write the type parameters one after the other, separated by commas, with one pair of angle brackets. For example, the class Pair could begin as follows:

```
public class Pair<S, T>
```

You would use S and T within the definition of Pair as you would actual data types. This class allows you to create pairs of objects that have different data types.

## REMEMBER An Inner Class Has Access to the Type Parameter of Its Outer Class

An inner class can access the type parameter of its outer class. In Listing 12.12, for example, the definition of the inner class ListNode uses the type parameter E, which is the type parameter of its outer class LinkedList, even though ListNode does not have <E> after its name in its heading.

## PROGRAMMING TIP Defining Type Parameters in an Inner Class

An inner class can define its own type parameters, but they must be distinct from any defined in the outer class. For example, we could define the outer and inner classes in Listing 12.12 as follows:

```
public class LinkedList<E>
{
    private ListNode<E> head;
    . . .
    private class ListNode<T>
    {
        private T data;
        private ListNode<T> link;
        . . .
        public ListNode (T newData, ListNode<T> linkValue)
        {. . .
        }
    }
}
```

Notice how the inner class ListNode uses T consistently as its type parameter and the outer class LinkedList has E as its type parameter. When ListNode is used as a data type within this outer class, it is written as ListNode<E>, not ListNode<T>. Also, note that we have no reason to give ListNode its own type parameter in this example, other than to show the syntax you would use if you wanted to do so.

#### **SELF-TEST QUESTIONS**

- 29. Revise the definition of the class ListNode in Listing 12.4 so that it uses a type parameter instead of the type String. Note that the class is, and should remain, public. Rename the class to ListNode2.
- 30. Using the definition of the ListNode2 class from the previous question, how would you create a ListNode2 object named node that stores a value of type Integer?

#### 12.5 GRAPHICS SUPPLEMENT

This section introduces the **Scene Builder**, a graphical program to help you build complex GUI applications.

#### Building JavaFX Applications with the Scene Builder

Building complex interfaces can be tedious and difficult to visualize when directly coding the layout panes. To assist with UI development Oracle has released the JavaFX Scene Builder. If you are using an IDE then the Scene Builder may already be installed on your system. Oracle no longer releases binary executables of the Scene Builder (you have to build it from source code) but free binaries can be downloaded from Gluon Labs at http://gluonhq.com/



labs/scene-builder. Consult your IDE's documentation if configuration is needed to integrate the JavaFX Scene Builder. At the time of this writing, the latest version of the Gluon Scene Builder is 8.2.

The Scene Builder allows the programmer or UI designer to graphically construct the interface and quickly test the layout of UI controls. When using the Scene Builder a JavaFX application will typically be split up into at least three separate files, each handling a different aspect of the program:

 FXML file. This is an eXtensible Markup Language (XML) file created by the Scene Builder that describes the layout of nodes in the scene. A sample FXML file with a text field, button, and label inside a VBox follows. While you could manually create the file, it is normally generated by the Scene Builder.

```
<?xml version="1.0" encoding="UTF-8"?>
<?import javafx.scene.text.*?>
<?import javafx.scene.control.*?>
<?import java.lang.*?>
<?import javafx.scene.layout.*?>
<VBox maxHeight="-Infinity" maxWidth="-Infinity" minHeight="-</pre>
Infinity minWidth="-Infinity" prefHeight="200.0"
prefWidth="350.0" xmlns="http://javafx.com/javafx/8"
xmlns:fx="http://javafx.com/fxml/1">
   <children>
      <TextField fx:id="txt" text="0">
         <font>
            <Font size="20.0" />
         </font>
      </TextField>
      <Button fx:id="btn"
          mnemonicParsing="false"
               text="Click to add one">
         <font>
            <Font size="25.0" />
         </font>
      </Button>
      <Label fx:id="lbl" text="23">
         <font>
            <Font size="20.0" />
         </font>
      </Label>
   </children>
</VBox>
```

2. **Application file**. This is the JavaFX Java source code that contains the start method. When used with an FXML file, the start method merely loads the FXML file using the FXMLLoader class.

3. **Controller file**. This file contains a class that implements javafx. fxml.Initializable and contains event handlers that respond to UI controls.

If you are using an IDE that includes the Scene Builder, then consult your IDE's documentation on how to create a new JavaFX FXML Application project. Otherwise, you can directly launch the Scene Builder application after downloading and installing it. Figure 12.13 shows the Scene Builder after dragging an AnchorPane from the "Containers" section to the middle of the window, followed by dragging a TextField, Button, and Label from the "Controls" section. You can select a control by either clicking it on the form or by selecting it by name under "Hierarchy" within the "Document" section on the bottom left. The latter is useful for "invisible" controls such as a label with no text. Once a control is selected you can edit properties, such as the text or font size, in the "Properties" section in the "Inspector" window on the right.

The AnchorPane allows us to anchor sides of a control to edges of the pane. This is useful if the window is resized. For example, if we want the button to fit the entire width of the window when it is resized then we would anchor the left and right edges. This is illustrated in Figure 12.14. The button has been selected and under the "Layout" section of the "Inspector," anchors have been set on the left and right sides. You can see the test result using the "Preview" command from the main menu.

To load a saved FXML file created by the Scene Builder we use the FXMLLoader class. Listing 12.14 shows how to load an FXML file named FXMLDocument.FXML. Since the layout details are in the FXML file, very little coding is needed in the application class.

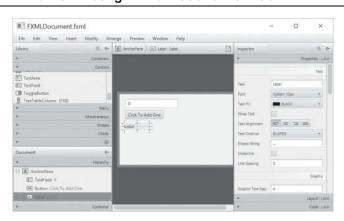
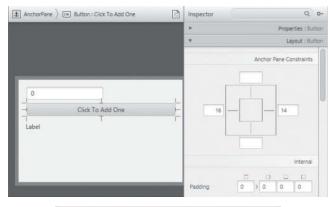


FIGURE 12.13 UI Design with Scene Builder

#### FIGURE 12.14 Anchoring a Button Using Scene Builder 2.0



Preview in Window



### LISTING 12.14 JavaFX Application Class for FXMLDocument.FXML

```
import javafx.application.Application;
import javafx.fxml.FXMLLoader;
import javafx.scene.Parent;
import javafx.scene.Scene;
import javafx.stage.Stage;
public class JavaFXApp extends Application
{
    @Override
    public void start(Stage stage) throws Exception
    {
        Parent root = FXMLLoader.load
           (getClass().getResource
           ("FXMLDocument.fxml"));
        Scene scene = new Scene(root);
        stage.setScene(scene);
        stage.show();
    public static void main(String[] args) {
        launch(args);
    }
}
```

Next we need a Controller class to respond to events. A class named JavaFXAppController.java is shown in Listing 12.15 that implements a button handler to read the number entered in the text field, increment it by one, and output the result in the label. This class implements Initializable and must have an initialize method that can be used to initialize the controller.

To link variables defined in the JavaFXAppController class to UI controls created in the Scene Builder, place the @FXML annotation before the variable definition. This injects the necessary values from the FXML loader.

LISTING 12.15 JavaFX Controller Class for JavaFXApp.FXML

```
import java.net.URL;
import java.util.ResourceBundle;
import javafx.event.ActionEvent;
import javafx.fxml.FXML;
import javafx.fxml.Initializable;
import javafx.scene.control.Button;
import javafx.scene.control.Label;
import javafx.scene.control.TextField;
public class JavaFXAppController implements Initializable
    @FXML
    private Label lblNumber;
    private Button btnClick;
    @FXMI
    private TextField txtNumber;
    private void handleButtonAction(ActionEvent event)
    {
        int val = Integer.parseInt(txtNumber.getText());
        val++:
        lblNumber.setText(Integer.toString(val));
    }
    @Override
    public void initialize(URL url, ResourceBundle rb) {
        // Required by Initializable interface
        // Called to initialize a controller after
        // the root element has been processed
    }
}
```

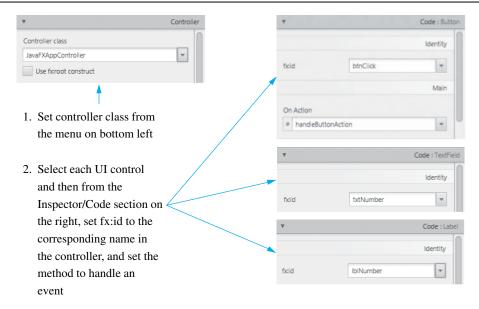
Finally, we need to link the controller to the FXML file. Back in the Scene Builder, select the Java file containing the controller in the "Controller" section

located at the bottom left side of the Scene Builder. In our example, the controller is named JavaFXController.java.

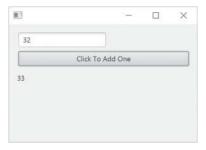
Next, select each UI control that has a corresponding variable defined in the controller. To link the controls, select the variable name from the "Code" section of the "Inspector" on the right. You can also select a method for an event handler. For example, in Listing 12.15, we named the label variable 1b1Number. In the Scene Builder, the same name should be entered in the fx:id field for the label on the form.

Figure 12.15 depicts the process to link the controller of Listing 12.15 to the FXML file constructed by the Scene Builder. Once the linkages are made, the Java programs can be compiled and the main application run to produce output such as that shown in the Program Output of Figure 12.15.

FIGURE 12.15 Linking the Controller in the Scene Builder



Program Output (after compiling and running JavaFXApp)





#### **SELF-TEST QUESTIONS**

- 31. What is the purpose of the FXML file?
- 32. What do you add to the controller to link an instance variable to the corresponding control in the FXML file?

#### Where to Go from Here

In this book, we have presented only a small sip of what JavaFX can do. JavaFX provides a structure and APIs for visual effects, animation, graphics, media, and the construction of graphical user interfaces. In addition, JavaFX supports declarative programming, separates controlling code from display code through FXML, and offers a Scene Builder application to assist with the construction of complex user interfaces. For additional reading about JavaFX, visit the Oracle JavaFX overview page at http://www.oracle.com/technetwork/java/javase/overview/javafx-overview-2158620.html and the JavaFX documentation website at http://docs.oracle.com/javase/8/javase-clienttechnologies.htm.

#### **CHAPTER SUMMARY**

- ArrayList is a class in the Java Class Library. Instances of ArrayList can be thought of as arrays that can grow in length. You create and name such instances in the same way as any other object except that you specify their base type.
- ArrayList has powerful methods that can do many of the things you must do for yourself when using an array.
- The Java Collections Framework is a collection of interfaces and classes that may be used to manipulate collections of objects in a consistent way.
- The HashSet class is part of the Java Collections Framework and may be used to efficiently implement a set.
- The HashMap class is part of the Java Collections Framework and may be used to map from one value to another.
- A linked list is a data structure consisting of objects known as nodes, such that each node contains both data and a reference to one other node. In this way, the nodes link together to form a list.
- You can make a linked data structure, such as a linked list, self-contained by making the node class an inner class of the linked-list class.
- A variable or object that allows you to step through a collection of data items, such as an array or a linked list, one item at a time is called an iterator.

- You can define a class that uses a parameter instead of an actual class type. You write the type parameter within angle brackets right after the class name in the heading of the class definition.
- The code that creates an object of a parameterized class replaces the type parameter with an actual class type, retaining the angle brackets.
- The standard classes ArrayList and LinkedList are parameterized classes.
- The Scene Builder allows you to graphically design complex JavaFX applications.

#### **Exercises**

- 1. Repeat Exercise 2 in Chapter 7, but use an instance of ArrayList instead of an array. Do not read the number of values, but continue to read values until the user enters a negative value.
- 2. Repeat Exercise 3 in Chapter 7, but use an instance of ArrayList instead of an array. Do not read the number of families, but read data for families until the user enters the word done.
- 3. Repeat Exercise 5 in Chapter 7, but use an instance of ArrayList instead of an array.
- 4. Repeat Exercises 6 and 7 in Chapter 7, but use an instance of ArrayList instead of an array. We will no longer need to know the maximum number of books purchased, so the methods will change to reflect this.
- 5. Write a static method removeDuplicates(ArrayList<Character> data) that will remove any duplicates of characters in the object data. Always keep the first copy of a character and remove subsequent ones.
- 6. Write a static method

that returns a new instance of ArrayList containing all of the strings common to both list1 and list2.

7. Write a program that will read sentences from a text file, placing each sentence in its own instance of ArrayList. (You will create a sentence object by adding words to it one at a time as they are read.) When a sentence has been completely read, add the sentence to another instance of ArrayList. Once you have read the entire file, you will have an instance of ArrayList that contains several instances of ArrayList, one for each sentence read. Now ask the user to enter a sentence number and a word number. Display the word that occurs in the given position. If the sentence number or word number is not valid, provide an appropriate error message.

- 8. Repeat Exercise 12 in Chapter 7, but use an instance of ArrayList instead of an array. Make the following slight changes to the methods to reflect that an ArrayList object can grow in size:
  - Change the constructor's parameter from the maximum degree to the desired degree.
  - The method setConstant might need to add zero-valued coefficients before ai. For example, if  $a_0 = 3$ ,  $a_1 = 5$ ,  $a_2 = 0$ ,  $a_3 = 2$ ,  $a_4 = 0$ , and  $a_5 = 0$ , the polynomial would be of degree 3, since the last nonzero constant is  $a_3$ . The invocation setConstant (8, 15) would need to set  $a_6$  and  $a_7$  to 0 and  $a_8$  to 15.
- 9. Write a program that will read a text file that contains an unknown number of movie review scores. Read the scores as Double values and put them in an instance of ArrayList. Compute the average score.
- 10. Revise the class StringLinkedList in Listing 12.5 so that it can add and remove items from the end of the list.
- 11. Suppose we would like to create a data structure for holding numbers that can be accessed either in the order that they were added or in sorted order. We need nodes having two references. If you follow one trail of references, you get the items in the order they were added. If you follow the other trail of references, you get the items in numeric order. Create a class DualNode that would support such a data structure. Do not write the data structure itself.
- 12. Draw a picture of an initially empty data structure, as described in the previous exercise, after adding the numbers 12, 80, 24, and 50, and deleting the node with number 24.
- 13. Write some code that will use an iterator to add an item with value one greater than for every item in an instance of StringLinkedListWithIterator in Listing 12.9. For example, if the list contains "10", "20", and "30", after the code runs, it will contain "10", "11", "20", "21", "30", and "31".
- 14. Write some code that will use an iterator to move the last item in an instance of StringLinkedListWithIterator (Listing 12.9) to the beginning of the list. For example, if the list contains "a", "b", "c", and "d", after the code runs, it will contain "d", "a", "b", and "c".
- 15. Write some code that will use an iterator to interchange the items at the beginning and end in an instance of StringLinkedListWithIterator in Listing 12.9. For example, if the list contains "a", "b", "c", "d", "e", and "f", after the code runs, it will contain "f", "b", "c", "d", "e", and "a".
- 16. The class StringLinkedListWithIterator (Listing 12.9) is its own iterator, but it does not quite implement the Java Iterator interface. Redefine the class StringLinkedListWithIterator so that it implements

the Iterator interface. This interface declares the methods next, remove, and hasNext as follows:

```
/**
Returns the next element on the list.
Throws a NoSuchElementException if there is
no next element to return.
*/
public E next() throws NoSuchElementException
/**
Removes the last element that was returned most recently
by the invocation next().
Throws an IllegalStateException if the method next has
not yet been called or if the method remove has already
been called after the last call to the method next.
*/
public void remove() throws IllegalStateException
/**
Returns true if there is at least one more element for
the method next to return. Otherwise, returns false.
*/
public boolean hasNext()
```

Notice the generic data type E in the specification of the method next.

If you follow the instructions in this question carefully, you do not need to know what an interface is, although knowing what one is may make you feel more comfortable. Interfaces are covered in Chapter 8.

Begin the class definition with

```
import java.util.Iterator;
public class StringLinkedListWithIterator2
    implements Iterator<String>
{
    private ListNode head;
    private ListNode current;
    private ListNode previous; //follows current
    private ListNodetwoBack; //follows previous
    private booleanremoveSinceNext;//true if the method
    //remove has been called since the last call of
    //the method next. Also true if next has not
    //been called at all.
    public StringLinkedListWithIterator2()
    {
        head = null;
        current = null;
        previous = null;
        twoBack = null;
        removeSinceNext = true;
    }
```

The rest of the definition is like the one in Listing 12.9, except that you add the method definitions specified by Iterator, make a small change to the method resetIteration so that the new instance variable twoBack is reset, and omit the methods deleteCurrentNode, goToNext, and moreToIterate, which become redundant.

#### (Hints:

- Despite its pretentious-sounding details, this exercise is fairly easy. The three method definitions you need to add are easy to implement using the methods we have.
- Note that the method hasNext and the method moreToIterate in Listing 12.9 are not exactly the same.
- The exception classes mentioned are all predefined, and you should not define them. These particular exceptions do not need to be caught or declared in a throws clause. The Iterator interface says that the method remove throws an UnsupportedOperationException if the remove method is not supported. However, your method remove has no need ever to throw this exception.)
- 17. Write a program that creates two instances of the generic class LinkedList given in Listing 12.12. The first instance is stadiumNames and will hold items of type String. The second instance is gameRevenue and will hold items of type Double. Within a loop, read data for the ball games played during a season. The data for a game consists of a stadium name and the amount of money made for that game. Add the game data to stadiumNames and gameRevenue. Since more than one game could be played at a particular stadium, stadiumNames might have duplicate entries. After reading the data for all of the games, read a stadium name and display the total amount of money made for all the games at that stadium.

#### **PRACTICE PROGRAMS**

Practice Programs can generally be solved with a short program that directly applies the programming principles presented in this chapter.

- 1. Revise the method selectionSort within the class ArraySorter, as shown in Listing 7.10 of Chapter 7, so that it sorts the strings in an instance of the class ArrayList<String> into lexicographic order instead of sorting the integers in an array into ascending order. For words, lexicographic order reduces to alphabetic order if all the words are in either lowercase or uppercase letters. You can compare two strings to see which is lexicographically first by using the String method compareTo, as described in Figure 2.5 of Chapter 2.
- 2. Implement the sequential search on an instance of LinkedList instead of an array as discussed in Section 7.4 of Chapter 7.

- 3. Write a class Employee with name and salary. Create an ArrayList that sorts the Employees based on salary. Use any sorting technique mentioned in Section 7.4 of Chapter 7.
- 4. Write a program that allows the user to enter an arbitrary number of integer grades from the keyboard. Each grade should be added to an ArrayList. Stop inputting grades when -1 is entered. The program should then iterate through the ArrayList, calculate the average grade, and output it along with the minimum and the maximum grade value.
- 5. Write a program that uses a HashMap to compute a histogram of positive numbers entered by the user. The HashMap's key should be the number that is entered, and the value should be a counter of the number of times the key has been entered so far. Use -1 as a sentinel value to signal the end of user input. For example, if the user inputs:

```
5
12
3
5
5
3
21
-1
```

then the program should output the following (not necessarily in this order):

```
The number 3 occurs 2 times. The number 5 occurs 3 times. The number 12 occurs 1 times. The number 21 occurs 1 times.
```

#### PROGRAMMING PROJECTS

Programming Projects require more problem-solving than Practice Programs and can usually be solved many different ways. Visit www.myprogramminglab.com to complete many of these Programming Projects online and get instant feedback.

- 1. Write a program that creates Pet objects from data read from the keyboard. Store these objects into an instance of ArrayList. Then sort the Pet objects into alphabetic order by pet name, and finally display the data in the sorted Pet objects on the screen. The class Pet is given in Chapter 6, Listing 6.1.
- 2. Repeat the previous programming project, but sort the Pet objects by pet weight instead of by name. After displaying the sorted data on the screen, write the number and percentage of pets that are under 5 pounds, the number and percentage of pets that are 5 to 10 pounds, and the number and percentage of pets that are over 10 pounds.

- 3. Repeat the previous programming project, but read the input data from a file and send the output to another file. If you have covered binary files, use binary files; otherwise, use text files. Read the file names from the user.
- 4. Use the class ClassObjectIODemo shown in Listing 10.10 of Chapter 10 to create a file of Species objects. The class Species is given in Chapter 10, Listing 10.9. Then write a program that reads the Species objects from the file you created into an instance of ArrayList, sorts these instances alphabetically by Species name, and then writes the sorted data to both the screen and a file. Read all file names from the user.
- 5. Define a variation on StringLinkedListSelfContained from Listing 12.7 that stores objects of type Species, rather than of type String. Write a program that uses that linked-list class to create a linked list of Species objects, asks the user to enter a Species name, and then searches the linked list and displays one of the following messages, depending on whether the name is or is not on the list:

```
Species Species_Name is one of the Number_Of_Species_Names_On_List species on the list. The data for Species_Name is as follows:
Data_For_Species_Name
or
```

Species Species\_Name is not a species on the list.

The user can enter more Species names until indicating an end to the program. The class Species is given in Listing 5.19 of Chapter 5. (If you prefer, you can use the serialized version of Species in Listing 10.9 of Chapter 10.)

- 6. Repeat the previous programming project, but read the input data from a file and send the output to another file. If you have covered binary files, use binary files; otherwise, use text files. Read the file names from the user.
- 7. Define a variation on StringLinkedListSelfContained from Listing 12.7 that stores objects of type Employee, rather than objects of type String. Write a program that uses this linked-list class to create a linked list of Employee objects, asks the user to enter an employee's Social Security number, and then searches the linked list and displays the data for the corresponding employee. If no such employee exists, display a message that says so. The user can enter more Social Security numbers until indicating an end to the program. The class Employee is described in Programming Project 6 of Chapter 9. If you have not already done that project, you will need to define the class Employee as described there.
- 8. Repeat the previous programming project, but read the input data from a file and send the output to another file. If you have covered binary files, use binary files; otherwise, use text files. Read the file names from the user.



- 9. Write a parameterized class definition for a doubly linked list that has a parameter for the type of data stored in a node. Make the node class an inner class. Choosing which methods to define is part of this project. Also, write a program to thoroughly test your class definition.
- 10. Create an application that will keep track of several groups of strings. Each string will be a member of exactly one group. We would like to be able to see whether two strings are in the same group as well as perform a union of two groups.

Use a linked structure to represent a group of strings. Each node in the structure contains a string and a reference to another node in the group. For example, the group {"a", "b", "d", "e"} is represented by the following structure:



One string in each group—"d" in our example—is in a node that has a null reference. That is, it does not reference any other node in the structure. This string is the **representative string** of the group.

Create the class GroupHolder to represent all of the groups and to perform operations on them. It should have the private instance variable items to hold the nodes that belong to all of the groups. The nodes within each group are linked together as described previously. Make items an instance of ArrayList whose base type is GroupNode, where GroupNode is a private inner class of GroupHolder. GroupNode has the following private instance variables:

- data—a string
- link—a reference to another node in the group, or null

Define the following methods in the class GroupHolder:

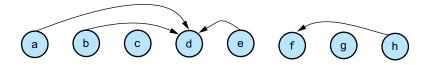
- addItem(s)—adds a string s to an empty group. First search items for s; if you find s, do nothing; if you do not find s, create a new GroupNode object that has s as its string and null as its link and add it to items. The new group will contain only the item s.
- getRepresentative(s)—returns the representative string for the group containing s. To find the representative string, search items for s. If you do not find s, return null. If you find s, follow links until you find a null reference. The string in that node is the representative string for the group.
- getAllRepresentatives—returns an instance of ArrayList that contains the representative strings of all the groups in this instance of GroupHolder. (A representative string is in an instance of GroupNode that contains a null reference.)

- inSameGroup(s1, s2)—returns true if the representative string for s1 and the representative string for s2 are the same and not null, in which case the strings s1 and s2 are in the same group.
- union(s1, s2)—forms the union of the groups to which s1 and s2 belong. (*Hint*: Find the representative strings for s1 and s2. If they are different and neither is null, make the link of the node containing s1's representative string reference the node for s2's representative string.)

For example, suppose that we call addItem with each of the following strings as an argument: "a","b","c","d","e","f","g", and "h". Next, let's form groups by using these union operations:

```
union("a", "d"), union("b", "d"), union("e", "b"), union("h", "f")
```

We will have four groups—{"a", "b", "d", "e"}, {"c"}, {"f", "h"}, and {"g"}—represented by the following structure:



The representative strings for these four groups are "d","c","f", and "g", respectively. Now the operation inSameSet("a", "e") would return true because both getRepresentative("a") and getRepresentative("e") return d. Also, inSameSet("a", "f") would return false because getRepresentative("a") returns d and getRepresentative("f") returns f. The operation union("a", "f") would make the node containing the representative string of the group to which "a" belongs—which is "d"—reference the node containing the representative string of the group to which "f" belongs, which is "f". This reference would be represented by an arrow from "d" to "f" in the previous diagram.

Your application should create an instance of GroupHolder and allow the user to add an arbitrary number of strings, each to its own group. It should then perform an arbitrary number of union operations to form several groups. Finally, it should demonstrate the other operations.

- 11. For this project, we will create a data structure known as a **queue**. A queue can be thought of as a line. Items are added at the end of the line and are taken from the front of the line. You will create a class LinkedQueue based on one of the linked-list classes given in this chapter. It should have private attributes for
  - front—a reference to the first node in the linked list of queue items
  - count—the number of items in the queue

and the following operations:

- addToQueue(item)—adds item to the end of the queue. (Add it at the end of the linked list.)
- removeFromQueue()—removes the first item from the queue and returns it. If the queue is empty, returns null.
- is Empty—returns true if the queue contains no items; otherwise, returns false.

Create a program that demonstrates the methods of the LinkedQueue class.

- 12. Repeat the previous programming project, but use a circular linked list to implement the queue. Recall from Figure 12.10 that a circular linked list has one external reference, which is to the list's last node.
- 13. Suppose that we would like to perform a bird survey to count the number of birds of each species in an area. Create a class BirdSurvey that is like one of the linked-list classes given in this chapter. (The linked list you use will affect what your new class can do, so give some thought to your choice.) Modify the inner node class to add room for a count.

BirdSurvey should have the following operations:

- add(bird)—adds the bird species bird to the end of the list, if it is not already there, and sets its count to 1; otherwise, adds 1 to the count for bird.
- getCount(bird)—returns the count associated with the species bird. If bird is not on the list, returns zero.
- getReport—displays the name and count for each bird species on the list.

Write a program that uses BirdSurvey to record the data from a recent bird survey. Use a loop to read bird names until done is entered. Display a report when finished.

14. Consider a text file of names, with one name per line, that has been compiled from several different sources. A sample is shown below:

Brooke Trout Dinah Soars Jed Dye Brooke Trout Jed Dye Paige Turner

There are duplicate names in the file. We would like to generate an invitation list but don't want to send multiple invitations to the same person. Write a program that eliminates the duplicate names by using a HashSet. Read each name from the file, add it to the HashSet, and then output all names in the HashSet to generate the invitation list without duplicates.



- 15. You have a list of student ID's followed by the course number (separated by a space) that the student is enrolled in. The listing is in no particular order. For example, if student 1 is in CS100 and CS200 while student 2 is in CS105 and MATH210 then the list might look like this:
  - 1 CS100
  - 2 MATH210
  - 2 CS105
  - 1 CS200

Write a program that reads data in this format from the console. If the ID is -1 then stop inputting data. Use the HashMap class to map from an Integer (the student ID) to an ArrayList of type String that holds each class that the student is enrolled in. The declaration should look like this:

After all data is input, iterate through the map and output the student ID and all classes stored in the vector for that student. The result should be a list of classes organized by student ID.

#### **Answers to Self-Test Questions**

- aList.add("Hello");
- aList.set(5, "Go");
- 3. No. The index for set must be greater than or equal to 0 and less than the size of the list. Thus, you can replace any existing element, but you cannot place a new element at any higher index. That is, you cannot add an element beyond the last-used index. This situation is unlike that of an array. If an array is partially filled to index 10, you can add an element at index 20, as long as the array is that large.
- 4. No. The index for add must be greater than or equal to 0 and less than or equal to the size of the list. Thus, you can insert an element at any index that is currently holding an element, and you can insert an element immediately after the last element, but you cannot insert an element at any higher index.
- 5. Yes. The method add can add an element right after the last element on the list, that is, at index size(). However, the index position for set must be less than size().
- 6. The seven elements of aList are at indices 0 through 6. A new element added at index 7 is the eighth element and is at the end of the list.
- 7. "red", "blue", "orange", "green", "yellow"

- 8. Yes. The list can contain more than 20 elements. The argument to the constructor merely gives the initial memory allocation for the list. More memory is automatically allocated when it is needed.
- 10. No, you cannot have an instance of ArrayList that has the base type int. However, you can have one that has the base type Integer, and thanks to automatic boxing and unboxing, it can be used as if it were a list of ints.
- 11. The method invocation list.size() returns the number of elements currently in list. The capacity of list, however, is the number of elements for which memory has been allocated.
- 12. The new elements at indices 10 through 19 will have null for their values.
- 13. HashSet<String> colors = new HashSet<String>();

```
14. colors.add("red");colors.add("blue");System.out.
    println(colors.contains("blue"));colors.remove("blue");
```

```
15. HashMap<Integer, String> studentids =
    new HashMap<Integer, String>();
```

```
16. studentIDs.put(5531, "George");
    studentIDs.put(9102, "John");
    System.out.println(studentIDs.get(9102));
```

- 17. Replace ArrayList with LinkedList in the import statement and twice in the statement that invokes the constructor.
- 18. You indicate the end of a linked list by setting the link instance variable of the last node to null.
- 19. head should have the value null.

```
20. public boolean isEmpty()
    {
        return length() == 0;
    }
    or
    public boolean isEmpty()
    {
        return head == null;
    }
}
```

Since the first version invokes another method and the second one does not, the second method will execute faster.

```
21. C
B
A
```

- 22. An inner class is a class defined within the definition of another class.
- 23. They are not needed, because the methods in the linked-list class have access to the instance variables data and link of the nodes.
- 24. Any variable that allows you to step through the collection one item at a time, such that each item is visited exactly once in one full iteration cycle. Each item can have its data read and, if the data items allow it, can have the data changed. For example, an int variable that holds an index value can serve as an iterator for an array. To go to the next item in the array, your code needs only to increase the value of the int variable by 1.

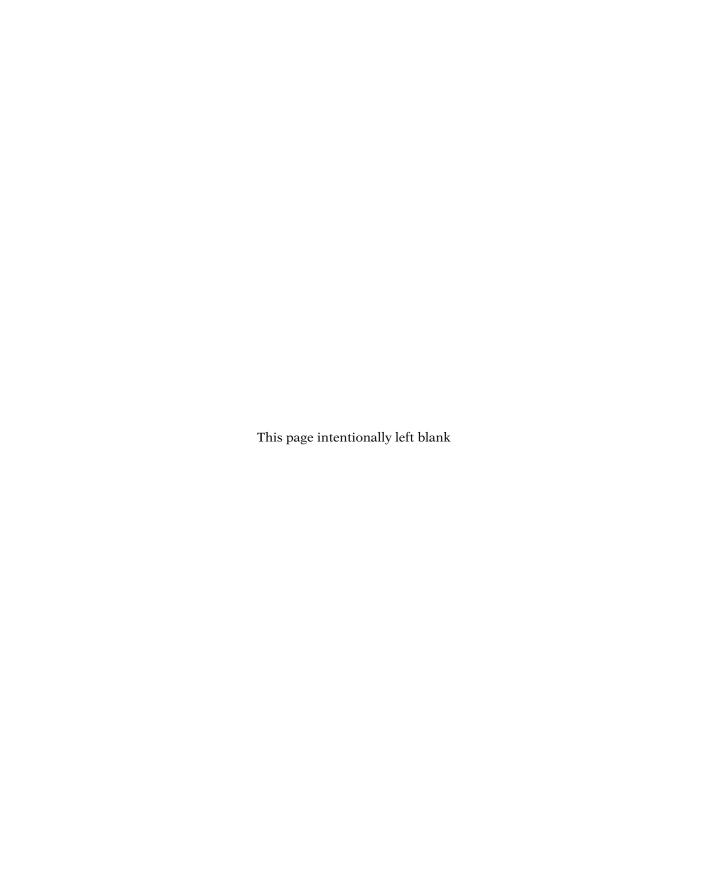
```
25. public String getDataAtCurrent() throws LinkedListException
   {
       if (current != null)
            return current.data;
       else
            throw new LinkedListException("Attempted data " +
            "access when current is not at any node.");
   }
26. public void setDataAtCurrent(String newData)
       throws LinkedListException
       if (current != null)
            current.data = newData;
       else
            throw new LinkedListException("Attempted data " +
                "change when current is not at any node.");
   }
27. public void insertNodeAfterCurrent(String newData)
       throws LinkedListException
       ListNode newNode = new ListNode();
       newNode.data = newData;
       if (current != null)
            newNode.link = current.link;
           current.link = newNode;
       else if (head != null)
            throw new LinkedListException("Inserting when " +
                "iterator is past all nodes or " +
                "is not initialized.");
       }
       else
            throw new LinkedListException("Attempted insertion " +
                                          "into an empty list.");
       }
   }
```

29. The complete definition is given as the class ListNode2 in the source code available on the Web.

```
public class ListNode2<E>
{
    private E data;
    private ListNode2<E> link;
    public ListNode2()
        link = null;
        data = null;
    }
    public ListNode2(E newData, ListNode2<E>linkValue)
        data = newData;
        link = linkValue;
    public void setData(E newData)
        data = newData;
    public E getData()
        return data;
    public void setLink(ListNode2<E>newLink)
        link = newLink;
```

```
public ListNode2<E> getLink()
{
    return link;
}
```

- 30. ListNode2<Integer> node = new ListNode2<Integer>();
- 31. The FXML file describes the layout and design of a GUI application, but does not contain the code to implement event handlers. It separates presentation from implementation.
- 32. Use the @FXML annotation before the variable name.



## Getting Java



A number of Java compilers and integrated development environments (IDEs) are available free of charge for various operating systems. The following list provides links to a selection of these resources.

#### ■ The Java SE Development Kit (JDK)

Available from Oracle, the JDK for Linux, Solaris, and Windows includes the Java Runtime Environment (JRE) and command-line tools that you can use to write applications.

http://www.oracle.com/technetwork/java/index.html

#### BlueI

BlueJ is an IDE developed at a university. It was created specifically for beginning Java students and is available for MacOS, Windows, and other systems at www.bluej.org.

BlueJ requires that you already have Java installed. Windows users should download and install the JDK from Oracle, as described previously. MacOS users will already have Java installed by default.

#### Eclipse

Eclipse is an open-source IDE for Linux, MacOS, and Windows that is available at www.eclipse.org.

Eclipse requires that you already have Java installed. Linux and Windows users should download and install the appropriate JDK from Oracle, as described previously. MacOS users will already have Java installed by default.

#### DrIava

DrJava is a lightweight development environment created for students. It is available freely under the BSD license at

www.drjava.org.

DrJava requires that you already have Java installed.

#### NetBeans

NetBeans is an open-source IDE for Linux, MacOS, Solaris, and Windows that is available at

www.netbeans.org.

The website has a link to download the IDE by itself, in which case you must already have Java installed. Alternately, there is a link to download the IDE bundled with the JDK. MacOS users will already have Java installed by default.

Installation instructions for each of these resources are available at the given URLs.

## Running Applets



As you know, applets are Java programs that are run from a Web page. The document that defines any Web page is written in HTML, which is a language designed for this purpose. Chapter 14, which is available on the book's Web site, provides some details about writing an HTML document. However, we can also use the Java tool appletviewer to run our applet. This tool requires a simple HTML document that we can write without looking at the details given in Chapter 14. Note that if you are using an IDE, you likely can run an applet without any reference to HTML.

After you have written an applet, you should compile it. If your applet code is in the file MyApplet.java, for example, compiling this file produces another file—MyApplet.class—that contains the bytecode for the applet.

Next, to run the applet using appletviewer, you need to create another file for a simple HTML document. Its contents have the following form:

```
<applet code = "Applet_Name.class"
width = Applet_Width height = Applet_Height>
</applet>
So for our MyApplet example, our HTML file could contain
<applet code = "MyApplet.class" width = 400 height = 400>
</applet>
```

The number of lines we use for the HTML is irrelevant. The name of the HTML file should be *Applet\_Name*.html, in this case, MyApplet.html.

Now we are ready to run the applet using the command appletviewer MyApplet.html

#### **RECAP Using appletviewer to Run an Applet**

To run an applet that is in the file <code>Applet\_Name.java</code>, you take the following steps:

- Create a file named Applet\_Name.html that contains the following code: applet code = "Applet\_Name.class" width = Applet\_Width height = Applet\_Height> </applet>
- Give the following commands at your computer's command line: javac Applet\_Name.java appletviewer Applet\_Name.html

# **APPENDIX**

## Protected and Package Modifiers

In this text, we always use the modifiers public and private before instance variables and method definitions. Normally, these are the only modifiers you need, but there are two other possibilities that fall between the two extremes of public and private. In this appendix, we discuss the modifier protected as well as the restriction that applies when you use no modifier at all.

If a method or instance variable is modified by protected rather than public or private, it can be accessed directly by name within

- Its own class definition
- Any descendant class
- Any method definition for any class in the same package

That is the extent of the access; the protected method or instance variable cannot be accessed by name within any other classes. Thus, if a method is marked protected in class A, and class B is derived from class A, the method can be called inside any method definition in class B. However, in a class that is not in the same package as class A and is not derived from class A, the protected method behaves as if it were private.

The modifier protected imposes a peculiar sort of restriction, since it allows direct access to any programmer who is willing to go through the bother of defining a suitable derived class. Thus, it is like saying, "I'll make it difficult for you to use this item, but I will not forbid you to use it." In practice, instance variables should never be marked protected; they should be private. However, you can have protected accessor and mutator methods for such instance variables.

If you want an access level that is not public but not as restrictive as private access, an alternative is possible and often preferable. You may have noticed that if you forget to place one of the modifiers public or private before an instance variable or method definition, your class definition will still compile. In such cases, the instance variable or method can be accessed by name within the definition of any class that is in the same package. It cannot, however, be accessed by name outside of the package. This type of access is called package access, or default access. You use package access when you have a package of cooperating classes that act as a single encapsulated unit. Note that package access is more restricted than protected access and that it gives more control to the programmer defining the classes. If you control the package directory, you control who is allowed package access.

### The DecimalFormat Class



The class DecimalFormat is in the Java Class Library within the package java. text. Thus, you make it available to a Java program by including the following import statement at the beginning of a program:

```
import java.text.DecimalFormat;
```

You can use this class to convert decimal numbers to formatted strings that can be displayed on the screen or written to a text file. Although the class defines a number of different methods, this appendix describes only one of them, namely, the method format. Complete documentation for the class DecimalFormat is available on the Oracle Web site.

The general approach to using the method format requires you to create a String pattern that describes the desired format for decimal numbers. For example, the pattern "00.000" means that there will be two digits before the decimal point and three digits after the decimal point. If the value of the number is not consistent with the specified format pattern, the format will be violated so that no digits are lost on the left of the decimal point. For example, the pattern "00.000" asks for only two digits before the decimal point, but the value 123.456 will be formatted as 123.456. Note, however, that the fractional portion is rounded when the pattern specifies fewer digits than are available in the actual number. So, using the same pattern, the value 12.3456 will be formatted as 12.346.

Once you have a pattern, you then create an object of the class Decimal-Format by writing a statement of the following form:

#### **SYNTAX:**

DecimalFormat Decimal\_Format\_Object\_Name=
DecimalFormat(Pattern);

#### **EXAMPLE:**

DecimalFormat formattingObject = new DecimalFormat("00.000");

You then can use the method format to convert a value of type double to a corresponding numeral String, as follows:

#### SYNTAX:

```
Decimal_Format_Object_Name.format(Double_Expression)
```

The method returns a string that corresponds to *Double\_Expression*.

#### **EXAMPLE:**

```
System.out.println(formattingObject.format(12.3456));
```

If the object formattingObject is created with the pattern "00.000", as in our previous example, the output produced by the foregoing println statement is 12.346.

Note that the method format returns a string that is an object of the class StringBuffer, not String. StringBuffer is similar to String but has methods that can modify the value of its instances.

#### Other Pattern Symbols

You can also create patterns such as "#0.##0", in which the character '0' stands for a compulsory digit and the character '#' stands for an optional digit. If '#' corresponds to a leading or trailing zero, the zero is omitted from the resulting string. For example, the statements

```
DecimalFormat formattingObject = new DecimalFormat("#0.0#");
   System.out.println(formattingObject.format(3.5));

display 3.5, whereas
   DecimalFormat formattingObject = new DecimalFormat("00.00");
   System.out.println(formattingObject.format(3.5));

display 03.50.
```

The character '%' placed at the end of a pattern indicates that the number is to be expressed as a percentage. The '%' causes the number to be multiplied by 100 and have a percent sign (%) appended to it. For example, the statements

```
DecimalFormat formattingObject = new DecimalFormat("##0.0%");
System.out.println(formattingObject.format(0.1234));
```

You can place a dollar sign and/or commas into a pattern to format currency or large values. These two characters appear unchanged in the locations specified by the pattern. Figure A4.1 includes some examples of such patterns.

ETCHDE	A / 1	Somo	Poculte	٥f	Formatting	Docimal	Numbore
LIGUKE	A4.1	Some	Results	ОТ	Formatting	Decimai	numbers

display 12.3%.

Value	3.5	3.5	1234.5678	123.45	12345.670	12345.678
Pattern	#0.0#	00.00	##.##	00000.000	###,###.###	\$###,###.00
Result	3.5	03.50	1234.57	00123.450	12,345.67	\$12,345.68

FIGURE A4.2 Some Results of Formatting Decimal Numbers Using the Same E-Notation Pattern

Value	0.12345	12345	123456	1234.567
Pattern	##0.##E0	##0.##E0	##0.##E0	##0.##E0
Result	123.45E-3	12.345E3	123.46E3	1.2346E3

You can specify that a value be displayed using E-notation by including an 'E' in the pattern string. For example, the pattern "00.###E0" approximates the specification of two digits before the decimal point, three or fewer digits after the decimal point, and at least one digit after the E, as in 12.346E1. The exact details of what string is produced are a bit more involved. When the number of digits before and after the decimal point satisfies certain constraints, the exponent is a multiple of 3, a notation used by engineers. To see how E-notation patterns work, you should play with a few cases. In any event, do not count on a very precisely specified number of significant digits. Figure A4.2 shows the results of formatting some values using E-notation.

Listing A4.1 contains a program that demonstrates some patterns and their effect.

#### LISTING A4.1 A Demonstration of the DecimalFormat Class (part 1 of 2)

```
import java.text.DecimalFormat;
public class DecimalFormatDemo
    public static void main(String[] args)
        DecimalFormat twoDigitsPastPoint = new DecimalFormat("0.00");
        DecimalFormat threeDigitsPastPoint =
                new DecimalFormat("00.000");
        double d = 12.3456789;
        System.out.println(twoDigitsPastPoint.format(d));
        System.out.println(threeDigitsPastPoint.format(d));
        double money = 12.8;
        System.out.println("$" + twoDigitsPastPoint.format(money));
        String numberString = twoDigitsPastPoint.format(money);
        System.out.println(numberString);
        DecimalFormat percent = new DecimalFormat("0.00%");
        double fraction = 0.734;
        System.out.println(percent.format(fraction));
```

(continued)

#### LISTING A4.1 A Demonstration of the DecimalFormat Class (part 2 of 2)

```
//1 or 2 digits before decimal point:
DecimalFormat eNotation1 = new DecimalFormat("#0.###E0");
//2 digits before decimal point:
DecimalFormat eNotation2 = new DecimalFormat("00.###E0");
double number = 123.456;
System.out.println(eNotation1.format(number));
System.out.println(eNotation2.format(number));
double small = 0.0000123456;
System.out.println(eNotation1.format(small));
System.out.println(eNotation2.format(small));
}
```

#### Screen Output

```
12.35
12.346
$12.80
12.80
73.40%
1.2346E2
12.346E1
12.346E 6
```

## Javadoc 5

The Java language comes with a program named javadoc that will automatically generate HTML documents that describe your classes. This documentation tells somebody who uses your program or class what she or he needs to know in order to use it but omits all the implementation details, such as the bodies of all method definitions (both public and private), all information about private methods, and all private instance variables.

Javadoc is normally used on packages, although it can also be used on single classes. Packages are discussed in Chapter 6. You need to have access to an HTML browser (a Web browser) so that you can view the documents produced by javadoc. However, you do not need to know very much HTML in order to use javadoc.

In this appendix, we will first discuss how you should comment your classes so that you can get the most value out of javadoc. We will then discuss the details of how you run the javadoc program.

#### Commenting Classes for Use with javadoc

To get a useful javadoc document, you must write your comments in a particular way. javadoc extracts these comments, along with the heading for your class and the headings for all public methods and public instance variables. No method bodies and no private items are extracted.

For javadoc to extract a comment, the comment must

- Immediately precede a public class definition, public method definition, or other public item
- Begin with /\*\* and end with \*/

We will call such comments javadoc comments. Note that both comments beginning with // and comments preceding any private items will not be extracted.

Within a javadoc comment, you can use tags to identify and describe such things as the method's parameters and return values. The following shows the syntax of some of the tags allowed:

@param Parameter\_Name Parameter\_Description
@return Description\_Of\_Value\_Returned
@throws Exception\_Type Explanation

Each tag begins with the symbol @ and begins a new line within the comment. When used, these three tags must appear in the order given here. You can omit any tag that is not relevant, and you can also use a tag more than once if needed.

For example, the following method has a valid javadoc comment:

```
/**
Computes the total cost of multiple identical items.
@param number number of items purchased
@param price cost of one item
@return total cost of all items at given price per item
*/
public static double computeCost(int number, double price)
{
    return number * price;
}
```

The documentation that javadoc prepares from this comment appears as follows:

#### ComputeCost

You can also insert HTML commands in your comments so that you gain more control over javadoc, but that is not necessary and may not even be desirable. HTML commands can clutter the comments, making them harder to read when you look at the source code. Chapter 14, which is on the Web, contains more about HTML than you need to know for this purpose.

To save space, the javadoc comments given in this book do not include tags or HTML commands.

#### Running javadoc

You run javadoc on an entire package. However, if you want to run it on a single class, you can make the class into a package simply by inserting the following at the start of the file for the class:

```
package Package_Name;
```

Remember that the package name should describe a relative path name for the directory or folder containing the files in the package.

To run javadoc, you must be in the folder (directory) that contains the package folder for which you want to generate documentation, not in the package folder itself. Then all you need to do is give the following command:

```
javadoc -d Document_Folder Package_Name
```

*Document\_Folder* is the name of the folder in which you want javadoc to place the HTML documents it produces.

The code on the book's Web site contains a package named javadocsample, which contains the two classes Person and Student from Chapter 8. It also contains the result of running the following command:

```
javadoc -d javadocsampledocs javadocsample
```

You can include an option on the command line that tells javadoc to include live links to standard classes and methods within the documentation. The syntax is as follows:

```
javadoc -link Link_To -d Document_Directory Package_Name
```

*Link\_To* is either a path to your local version of the Java documentation or the URL of the standard Java documentation on the Oracle Web site.

## Differences Between C++ and Java



This appendix is for readers who have had significant programming experience with either C or C++. Other readers can ignore this appendix.

Java and C++ appear to be very similar, but they have more differences than a casual examination of the two languages might lead you to believe. We will not describe all of the differences in this appendix, but we will go over a few similarities and differences in order to help you make the transition from C++ (or C) to Java.

## **Primitive Types**

Java has most of the same basic primitive types as C and C++ (int, short, long, float, double, and char), but Java adds the types byte and boolean. The Java type boolean corresponds to the C++ type bool. Java has no type named long double. Unless using the primitive data types introduced in C++11, in Java the size, in bytes, of a value for some specific primitive type is fully specified and is not implementation dependent. See Chapter 2 for details.

## **Strings**

Unlike some versions of C and C++, in Java strings are not special kinds of arrays of characters. Java has a class String that serves as a predefined type. String is somewhat similar to the class string in recent versions of C++. (Coverage of the String class starts in Chapter 2.)

#### **Flow of Control**

Control structures (if-else, switch, while, do-while, and for) are the same in Java as in C and C++. However, there are some differences in Java that can affect your use of control structures. Specifically, Java has no comma operator; the type boolean in Java is not a numeric type, nor can its values be type cast to a numeric type; and the assignment operator is better behaved in Java than in C and C++. We discuss each of these differences briefly below.

Java does not have the comma operator. However, the for statement in Java has been defined so as to allow the use of the comma, as in the following code:

```
for (int n = 1, product = 1; n < = 10; n++)
    product = product * n;</pre>
```

This "comma operator" can be used only in a for statement.

In Java, the type boolean has the two values, true and false, which cannot be interpreted as numeric values, even with a type cast.

A classic error in C and C++ is to use = in place of ==, as in the following code:

```
if (n = 42)
```

In C and C++, the expression n = 42 returns the value 42, which either is or will be converted to a boolean value, depending on what version of C or C++ you are using. In Java, n = 42 also returns the value 42, but in Java, 42 is not of type boolean, nor will it convert to type boolean. So in Java, this mistake will produce a compiler error message.

## **Testing for Equality**

Testing objects of a class type for equality can be troublesome in Java. With values of a primitive type, the == operator tests for equality, as you might expect. However, when you use == to compare two objects of a class type, the addresses of the objects are compared instead of their data. Java classes often define a method called equals to test objects for our intuitive idea of equality. You cannot overload the == operator (or any operator) in Java.

## main Method (Function) and Other Methods

Functions are called methods in Java. The main method serves the same purpose in Java as the main function in C and C++. In Java, the main method heading is always as follows:

```
public static void main(String[] Parameter_Name)
```

In Java, all methods are defined inside of a class, as is code of any kind.

## Files and Including Files

Java does not have an #include directive, but it does have an import statement that allows you to import either a class or an entire package (library) for use in a class.

The general layout of a Java program consists of a number of classes, each in a file by itself. If all the classes are in the same folder (directory), Java will automatically find the class (file) it needs when it needs it. The import statement also makes it possible to combine classes (files) from different folders. See Section 6.7 in Chapter 6 for more details.

In Java, a class must be in a file that has the same name as the class, but with the suffix .java. For example, a class named MyClass must be in a file named MyClass.java. The compiled version of the class will be placed in a file named MyClass.class.

## Class and Method (Function) Definitions

In Java, all methods must be defined in some class. Additionally, a class definition can be fully defined in one file. Java has no required header, or .h, file, as do C and C++. In particular, all method definitions are given in their entirety in their class definition. See Chapter 5 for more details. Java does provide for an interface, which is similar in form to a header file in C and C++ but serves a different purpose. Chapter 8 introduces Java interfaces.

## No Pointer Types in Java

There are no pointer types in Java. Java does have pointers; in fact, all objects are named by means of pointers. However, the pointers are called *references*, and they are handled automatically. For example, a variable of type String will contain a reference (pointer) to a string, but there is no type for a pointer to a String. See Section 5.3 in Chapter 5 for more details.

## Method (Function) Parameters

Strictly speaking, Java has only one mechanism for parameter passing, namely, call-by-value. In practice, however, Java's parameter-passing mechanism behaves one way for primitive types—such as int, double, and char—and another way for class types.

For primitive types, the call-by-value parameter-passing mechanism behaves as C and C++ programmers would expect. That is, the parameter contains the value of its corresponding argument. But Java parameters of a class type contain a reference to the class object that is passed. This allows a method (function) to change the data in the object, and so some people consider this mechanism to be a call-by-reference mechanism. It does not satisfy the most common definition of *call-by-reference*, but when doing most simple tasks, it behaves very much like call-by-reference. See Chapter 5 for more details.

## **Arrays**

Java arrays are very much like C or C++ arrays, but there are some differences, and Java arrays are better behaved. An array in Java "knows" its range. If a is an array, the instance variable a.length contains an integer equal to the number of elements that the array can hold. Java ensures that the values of array indices (subscripts) are valid, and an exception is thrown if your code attempts to use an array index that is out of range. See Chapter 7 for more details.

## **Garbage Collection**

Memory management and garbage collection are automatic in Java. Java uses the new operator to create and allocate memory for a new object of a class type. This is the only way to explicitly allocate memory. Additionally, Java provides automatic garbage collection, relieving the programmer from this responsibility. Memory leaks, which can be a problem in C and C++, are not an issue in Java.

#### Other Comparisons

- Comments in Java and C++ are essentially the same.
- There are no global variables in Java.
- Java has no typedef.
- Java has no structures or unions.
- You can overload method (function) names in Java, as you can in C++, but you cannot overload operators in Java.
- Java has no multiple inheritance, but interfaces provide much of the functionality of multiple inheritance. See Chapter 8 for more details on interfaces.
- Java has no templates, but it does have generics in their place. See Chapter 12 for an introduction to generics.
- In Java, a class can have a constructor with a parameter of the same type as the class, but this constructor has no special status, unlike a copy constructor in C++.
- Java has no destructors.
- The assignment operator in C++ will perform a shallow copy of instance variables when used to copy one object to another. In Java only a reference to the object is copied.

## APPENDIX

## Unicode Character Codes

The printable characters shown are a subset of the Unicode character set known as the ASCII character set. The numbering is the same whether the characters are considered to be members of the Unicode character set or members of the ASCII character set. (Character number 32 is the blank.)

32		56	8	80	Р	104	h
33	!	57	9	81	Q	105	i
34	"	58	:	82	R	106	j
35	#	59	;	83	S	107	k
36	\$	60	<	84	Т	108	1
37	%	61	=	85	U	109	m
38	&	62	>	86	V	110	n
39	•	63	?	87	W	111	0
40	(	64	6	88	Χ	112	р
41	)	65	Α	89	Υ	113	q
42	*	66	В	90	Z	114	r
43	+	67	С	91	[	115	s
44	,	68	D	92	\	116	t
45	-	69	Е	93	]	117	u
46		70	F	94	۸	118	V
47	1	71	G	95	_	119	W
48	0	72	Н	96	•	120	x
49	1	73	I	97	а	121	У
50	2	74	J	98	b	122	Z
51	3	75	K	99	С	123	{
52	4	76	L	100	d	124	1
53	5	77	M	101	е	125	}
54	6	78	N	102	f	126	~
55	7	79	0	103	g		

# APPENDIX

## Introduction to Java 8 Functional Programming

Functional programming was introduced in Java 8. The core addition is functional programming with lambda expressions. In this appendix we describe the benefits of functional programming and give a few examples of the programming style. Most of the Java 8 features are more appropriate for an advanced Java text but the concepts apply to material we have discussed, particularly in the context of the Collections framework covered in Chapter 12 or to event handlers for JavaFX applications.

A lambda expression is a nameless function. In functional programming, a function is the same thing as a method. Related concepts you may hear about include closures, anonymous functions, and function literals. As a nameless function, a lambda expression is essentially a little snippet of code that you can pass around as data but have it treated like a function with parameters. Lambda expressions provide a neat way of implementing classes that normally have only one function and make it easy to modify methods on the spot rather than go through the work of defining a method to perform a specialized task. Additionally, lambda expressions help Java parallelize itself to run more efficiently on multi-core or multi-processor machines. For example, normally we will process elements in an ArrayList by creating a for loop that accesses each element one by one. This is considered external access to the loop. In contrast, with lambda expressions we can internally iterate through the ArrayList by providing a function that tells Java how to process each element. The JVM can then parallelize the operating by farming the function and elements to different processors.

The format to define a lambda expression looks like this:

```
parameters-> body
```

The arrow separates the parameters from the body. In many cases the body is short and just a single line of code. If it were longer, than a traditional method may make more sense. Here is a lambda expression that returns the sum of two integers x and y:

```
(int x, int y) -> { return (x+y); }
```

In many cases Java can determine the type of the parameters, in which case we can leave the data type off. We can also just provide an expression on the right side and it automatically becomes the return value:

$$(x, y) \rightarrow x+y$$

Java's lambda expressions are particularly useful when applied to collections. Three common operations that we typically perform are to *filter*, *map*, or *reduce* the collection. In this appendix we give a short example of each.

Let's start with the concept of a filter. Consider the following code, which creates a list of doubles:

```
ArrayList<Double> nums = new ArrayList<>();
nums.add(3.5);
nums.add(56.3);
nums.add(81.1);
nums.add(4.8);
```

If we only want to output the values in the array that are over 50 then in traditional Java-style (external processing) we would make a loop with an if statement:

```
for (int i = 0; i < nums.size(); i++)
  if (nums.get(i) > 50)
    System.out.println(nums.get(i));
```

Using Java 8's lambda expressions we can do the same thing by creating a stream of the elements in the ArrayList and then filtering them. This is accomplished through a sequence of function calls:

```
nums.stream().filter((Double val) -> val > 50).forEach((Double
val) -> System.out.println(val));
```

For readability purposes it is common to put each function call on a separate line:

```
nums.stream()
    .filter((Double val) -> val > 50)
    .forEach((Double val) -> System.out.println(val));
```

The stream() method creates a stream that generates a list which we can iterate once. Not to be confused with data streams, this new type of stream can be accessed in parallel or sequentially. In our case we are only using sequential streams. Once the stream is generated then we invoke filter and the forEach. Inside filter we specify a lambda expression. Each element in the ArrayList is filtered according to the lambda expression. In this case, the variable val is an element in the ArrayList that is being processed and the function says to filter only those elements whose value is greater than 50. Next, the forEach iterates through the filtered elements and outputs each one via println. In our example, this would output 56.3 and 81.1.

We can simplify the code a little bit more by leaving out the data type because Java is able to deduce it from the context. The resulting code becomes:

```
nums.stream()
    .filter(val -> val > 50)
    .forEach(val -> System.out.println(val));
```

The new format is quite different than the traditional method but the style is more concise, can be more easily parallelized, and in general will require less code than the old technique.

Next, consider the concept of a map. A map takes elements in the collection and transforms them in some way. Consider a simple mapping where we would like to add 100 to every element in the ArrayList. We can do so as follows:

```
nums.stream()
    .map(val -> (val + 100))
    .forEach(val -> System.out.println(val));
```

This will output 100 added to each value (i.e., 103.5, 156.3, 181.1, 104.8). Note that each function is invoked in sequence. If we add our previous filter before the map then we would only get 156.3 and 181.1:

```
nums.stream()
    .filter(val -> val > 50)
    .map(val -> (val + 100))
    .forEach(val -> System.out.println(val));
```

Finally, consider the concept of collecting. Collecting means that we process all of our elements in some way and collect final results. The final result is often a single value. Examples include summing, averaging, finding the minimum, or finding the maximum of a set of data. The following code shows how we can compute the sum of all elements in our ArrayList:

```
double d = nums.stream()
    .mapToDouble(v -> v)
    .sum();
System.out.println("The sum is " + d);
```

The mapToDouble function takes each element and maps it as a double (a bit redundant here since we are starting with doubles) and then accumulates them into a sum. As you might surmise, there are also the methods mapToInt(), mapToLong(), etc. and methods to compute min(), max(), average(), and other values.

More customization is possible using the reduce function. In our case we'll use the version that takes as input a seed value and a binary function. Consider a collection with values v1, v2, and v3. If we start with a seed value s, then reduce will first apply the binary function to s and v1, producing r1. The binary function is then applied with r1 and v2, producing r2. Then the binary function applies r2 and v3, producing r3 which is returned as the final value. The following code computes the sum of all values using reduce:

```
d = nums.stream()
   .reduce(0.0, (v1, v2) -> v1 + v2);
System.out.println("The sum is " + d);
```

In this case, 0.0 is the seed value and the second parameter is the function that specifies how to accumulate the sum of the value. For the first step, v1

corresponds to 0.0 and v2 corresponds to 3.5. This produces the intermediate sum of 3.5. In the second step, v1 corresponds to 3.5 and v2 corresponds to 56.3 to produce 59.8. In the third step, v1 corresponds to 59.8 and v2 to 81.1, and so on until the sum is produced.

For an additional example, consider the following list of names:

```
ArrayList<String> names = new ArrayList<>();
names.add("Paco");
names.add("Enrique");
names.add("Bob");
```

If we want to compute the average length of all names then we could map the length to an integer:

```
d = names.stream()
    .mapToInt(name -> name.length())
    .average()
    .getAsDouble();
System.out.println("The average is " + d)
```

In this case we map each name to an int using the length() method, compute the average, and get the value as a double.

For the final example, say that we want to get the largest name. We can use the reduction technique:

System.out.println("longest Name: " + s);

We use a block in this case where the function compares the length of the strings and returns the largest one. This is one case where we would commonly use the? operator to shorten the code:

These examples should give you an idea of what Java lambda expressions look like and what they can do. While there is definitely a learning curve, lambda expressions allow you to write concise code that can run in parallel. Java 8's new syntax supports functional programming and object-oriented programming in a way that reaps the benefits of both styles.

## The Iterator Interface



The Iterator interface is designed to be implemented in conjunction with classes whose objects are collections of elements. In a good implementation, repeated execution of the method next would visit all elements in the collection. The Iterator interface might be implemented by the collection class itself or by another class whose objects are iterators for the collection class. The Iterator interface specifies three methods and appears as follows:

```
public interface Iterator<E>
{
     /**
    Returns the next element. Throws a
    NoSuchElementException if there is no next element.
     **/
    public E next();
    Returns true if an element is left for next to return.
    public boolean hasNext();
     / * *
    Removes the last element that was returned by next.
    Throws an UnsupportedOperationException if the remove
    method is not supported by this Iterator. Throws an
    IllegalStateException if the next method has not yet
    been called or if the remove method has already been
    called after the last call to the next method.
     */
    public void remove();
}
```

Interfaces can specify a generic data type, much as a class can. Chapter 12 discusses how to use or write a class that has a generic data type. Interfaces use the same notation. For example, the interface Iterator has the generic data type E. Note that Iterator has <E> in its heading and uses E as the return type of the

method next. Thus, E represents the data type of the elements in the collection to be iterated.

We could revise the class LinkedList, as given in Listing 12.10 of Chapter 12, so that it implements the interface Iterator by adding an implements clause to the class's heading, as follows:

```
public class LinkedList<E> implements Iterator<E>
```

We would then implement the methods of LinkedList as well as those in the interface Iterator.

The Iterator interface is in the package java.util. So when denning a class that implements the Iterator interface, the file should contain the following import statement:

```
import java.util.Iterator;
```

Finally, note that all the exception classes mentioned in the description of Iterator's methods are derived classes of RunTimeException. Thus, none of these exceptions need to be caught or declared in a throws clause.

## Cloning APPENDIX

A clone of an object is an exact copy of the object. The emphasis here is on both *exact* and *copy*. A clone should have exactly the same data values as the original object, and it should be a distinct object and not simply another name for the original one.

A clone is made by invoking the method named clone. Recall from Chapter 8 that this method is defined in the class Object but needs to be overridden—that is, redefined before it will behave correctly for a specific class.

The standard class ArrayList is a class that defines its own clone method, as Chapter 12 mentioned. Suppose we define a list of strings using ArrayList, as follows:

```
ArrayList<String> aList = new ArrayList<String>();
<Some code to fill aList>
```

We then can make an identical copy of aList, so that we have two separate copies, by invoking ArrayList's method clone:

Although the method clone returns a copy of aList, it always returns it as an object of type Object. So we normally need a type cast.

For lists of objects other than strings, using the method clone can be more complicated and can lead to a few pitfalls. Let's examine this problem by first seeing how we can add a clone method to our own classes. For example, consider the class Pet in Listing 6.1 of Chapter 6. After we make suitable revisions to the class definition, we will be able to make a copy of an object of type Pet as follows:

```
Pet originalData = new Pet("Fido", 2, 5.6);
Pet duplicateData = (Pet)originalData.clone();
```

Be sure to notice the type cast of the clone from Object to Pet. Now let's make the necessary revisions to Pet.

First, the class must implement the standard interface Cloneable. We do that by beginning the class definition for Pet as follows:

```
public class Pet implements Cloneable
```

This interface is actually empty, but it requires that you add a definition of the method clone to the class definition. The heading for the method clone in the class Object is

```
protected Object clone()
```

Pet will override this method with the following public version:

```
public Object clone()
```

If a class's instance variables have either primitive types or class types whose objects cannot be changed by their methods, such as the type String, the definition of clone need only invoke the inherited version of clone. Since Pet is such a class—it has one instance variable of type String and two that have primitive types—the method clone shown in Listing A10.1¹ will work fine. In that definition, the method clone invokes the version of clone in the class Object,² which simply makes a bit-by-bit copy of the memory used to store the calling object's instance variables. The try-catch blocks are required because the method clone can throw the exception CloneNot-SupportedException if the class does not implement the Cloneable interface. Of course, in these classes, we are implementing the Cloneable interface, so the exception will never be thrown, but the compiler will still insist on the try-catch blocks.

## LISTING A10.1 A Simple Implementation of the Method clone

```
public Object clone()
{

Works correctly for a class like Pet, in which each
instance variable has either a primitive type or
the type String. Will not work correctly in most
other cases.

return super.clone();//Invocation of Object's clone
}
catch(CloneNotSupportedException e)
{//This should not happen.
return null; //To keep the compiler happy.
}
}
```

<sup>1</sup> The source code on the book's Website contains a version of the class Pet that includes this definition of the method clone.

<sup>2</sup> If your class is a derived class of some class (other than Object), we are assuming that the base class has a well-defined clone method, since super.clone will then refer to the base class.

Note that the Cloneable interface and clone method behave in more complicated ways than most interfaces and inherited methods. Although the class Object has a method named clone, it is not inherited automatically. You must include implements Cloneable in the definition of the class, and you must include a definition of clone, even if it is simply defined as in Listing A10.1. This version of clone behaves as clone would if it were inherited from Object in the normal way.

If your class has instance variables of a class type whose objects can be changed by their methods, the definition of clone in Listing A10.1—although legal—probably will not do what you want a clone method to do. This version produces a clone that has a copy of each instance variable's memory address, rather than a copy of the instance variable's data. For a class like String, whose objects cannot be changed—that is, has no set methods—this condition is not a problem. Such was the case when we cloned a Pet object or the list of strings earlier in this appendix.

For most other classes, this condition would allow access to private data in the way we described in Section 6.5, entitled "Information Hiding Revisited," of Chapter 6. For these classes, your definition of clone should make a clone of each instance variable of a changeable class type. Of course, this task requires that those class types for the instance variables have a suitable clone method themselves. The way to define such a clone method is illustrated in Listing A10.2. Let's go over some of the details in that listing.

#### LISTING A10.2 A Class and Its clone Method

```
public class Neighbor implements Cloneable
    private String name;
    private int numberOfChildren;
    private Pet familyPet;
    public Object clone()
        try
        {
           Neighbor copy = (Neighbor)super.clone();
           copy.familyPet = (Pet)familyPet.clone();
           return copy;
        }
        catch(CloneNotSupportedException e)
        {//This should not happen.
             return null; //To keep the compiler happy.
        }
    }
```

```
public Pet getPet()
{
    return (Pet)familyPet.clone();
}
<There are presumably other methods that are not shown.>
}
```

The class Neighbor has three instance variables. Two—name and numberOfChildren—are not a concern when we define a clone method, since their data types are String and int, respectively. But familyPet's data type is Pet, which is a class that has set methods. Let's see how this affects Neighbor's clone method.

The following statement in clone makes a bit-by-bit copy of the memory used to store the receiving object's instance variables:

```
Neighbor copy = (Neighbor)super.clone();
```

This sort of copy works fine for the instance variables name of type String and numberOfChildren of type int. However, the value it gives to copy's instance variable familyPet—that is, copy.familyPet—is the *address* of the instance variable familyPet in the receiving object. We want a *copy* of that instance variable, not its address. To get a copy, we call Pet's clone method as follows:

```
copy.familyPet = (Pet)familyPet.clone();
```

Neighbor's clone method then returns copy as the clone.

We have included Neighbor's accessor method getPet in Listing A10.2. To avoid the privacy leak described in Section 6.5 of Chapter 6, getPet returns a clone of the instance variable familyPet instead of familyPet itself.

Let's return briefly to our opening example, where we cloned an object of ArrayList. This class's clone method does not clone the objects in the list. So while aList and duplicateList are two distinct objects, they share the same strings as their elements. For example, the first string in aList is also the first string in duplicateList. We do not have two separate but equal first strings. The good news is that the strings on the lists cannot be modified, so it is perfectly safe for the two lists to share the same collection of strings.

# APPENDIX

## Java Reserved Keywords

The following keywords are reserved in the Java programming language. You cannot use them as identifiers. Additionally, true, false, and null are literals that also cannot be used as identifiers.

abstract	continue	for	new
switch	assert	default	goto
package	synchronized	boolean	do
if	private	this	break
double	implements	protected	throw
byte	else	import	public
throws	case	enum	instanceof
return	transient	catch	extends
int	short	try	char
final	interface	static	void
class	finally	long	strictfp
volatile	const	float	native
super	while		

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Chapter 7, pg. 595: Combined Layout Demo: Program Output, Oracle Corporation, NA.

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**Chapter 10**, pg. 849: A File Organizer GUI: Screen Output After Entering the Remove Line Button, Oracle Corporation, NA.

**Chapter 10**, pg. 849: A File Organizer GUI: Screen Output After Entering the File Name and Clicking the Show First Line Button, Oracle Corporation, NA.

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Chapter 13, pg. 64: Labeling a Text Field: Screen Output, Oracle Corporation, NA.

Chapter 13, pg. 70: An Addition GUI: Screen Output, Oracle Corporation, NA.

Chapter 13, pg. 74: A GUI with Exception Handling: Screen Output, Oracle Corporation, NA.

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**Chapter 15**, pg. 164: A Demonstration of the CardLayout Manager: Screen Output: Initially or After the Reset Button is Clicked, Oracle Corporation, NA.

**Chapter 15**, pg. 164: A Demonstration of the CardLayout Manager: Screen Output: After the Red Button is Clicked, Oracle Corporation, NA.

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## Index

Note: Page numbers followed by f or l represent figures or listings, respectively.

% (arithmetic operator), 106 * (asterisk), 91 writing, 676 \$ (dollar sign), 91 == (equality operator), 184f, 185 string usage, 191 usage, 184–185, 370–371 arrays, combination, 546 problem, 372f && (logical operator), 185 effect, 189f summary, 186 usage, 262 ! (not operator) avoidance, 188 effect, 189f    (or logical operator), 186 expression, 186 summary, 186–187 usage, 262 {} (braces), 88 '' (single quotes), 91 (decrement operator), 117 < (operator), 209 = (assignment operator), 93, 94 usage, 184 arrays, combination, 546 > (operator), 209 (>=) greater than or equal to, 177	\' (single quote), 127f \ (backslash), 127f \n (new line), 127f \r (carriage return), 127f \t (tab), 127f  A  abstract (keyword), 682 Abstract (method), 682 overriding, 682–683 Abstract base class, 683 Abstract classes, 682–683 interfaces, relationship, 657 type, 684 Abstract data type (ADT), 363, 920 Abstract Window Toolkit (AWT), 66 Access modifiers, 341 presence, 487 Accessor methods (get methods), 346–347 defining, 346, 484 self-test questions, 349–350 summary, 349 types, 451 usage, 347l ActionEvent (class), 685 Actual parameters, 332 add (method), definitions, 479 addInterest, 440 Address (byte number), 39–40 adjustment (variable), 107	age (name), 317 age (instance variable), reference, 319 Algorithms, 61–62 directions set, 62 mistakes, 63 requirement, 112 results, storage, 62 Alphabetic order (programming), 193 Alphabetic ordering, checking, 192 amount (name), 94 amount (variable), 107 amountString (string), character return, 478 Ancestor class, 627 object, 645 and, && (logical operator) usage, 186 Angle bracket notation, 969 answer (), 357 invocation, 358 answer (method), 359 invocation, 356 answer (variable), 215 Append, term (usage), 796 Appending, text file (opening), 797 appleCount, 152–153 appleString (variable), 152 Applets, 49–50. See also Multiface applet
	adjustment (variable), 107 ADT. <i>See</i> Abstract data type	Multiface applet graphics display, 66–67

Applets (continued) polygons, usage, 597l–598l programming example. See Question-and-answer applet running, 998–999	example, 106 ArithmeticException, occurrence, 737 Array-based data structures, 921–922 Array-processing loop,	details, 519–522 elements, 516 initialization, 528–529 presence, test, 544 search, 564 usage, 528
appletviewer (Java tool), 998, 999	iteration (problems), 525	entries, number, 559 equality operator (==) test,
Application Programming	ArrayList (class), 922	544
Interface (API), 65.	arrays, objects (differences),	example, 517l-518l
See also Java 2D API	926	indexed variable, value,
class interface,	early versions, 930	540
relationship, 363	implementation, 932	indices, 525-526
Application programs, 116	methods, 927f	initiation, 516
Applications, 49–50	self-test question, 926, 928	out of bounds property,
programs, graphics display,	usage, 922, 928l-929l	526
66–67	ArrayList (instance)	validity, 525
ArcAngle, 73	creation, 922-923	initial section, importance,
Arcs	elements (access), for-each	559
drawing, 73–75	loop (usage), 930	initialization, 528–529
specification, 74f	naming, 923	length, 559
ArcType, 73	ArrayList (methods), usage,	nonspecification, 542
ArcType.CHORD, 75	924–926	linked-list data, placement,
ArcType.OPEN, 75	Arrays. See Multidimensional	953l
Arguments, 52	arrays; Partially filled	for (loop), usage, 524
change, method (timing), 540	arrays; Ragged arrays; Two-dimensional	objects, 836–837 differences, 926
formal parameters,		file I/O, 8371–8381
correspondence, 336	arrays access, 516–518, 1010	relationship, 546
indexed variable	arguments, 541	parameters
change, method	characteristics, 542	alternative syntax, 541
(timing), 540	assignment, equality	summary, 541–542
relationship, 538	(relationship),	privacy leaks, 549
objects (passing), method	543-544	regions, consideration, 562
(impact), 385	base type, 519	return, methods
term, usage, 335	basics, 515	example, 547l
value, copying, 387	creation, 516-518	usage, 546
Arithmetic expressions, 106	summary, 519–520	return, summary, 548
Java arithmetic expressions,	data type, name	screen output, sample, 518
111f	(summary), 548	searching, 560, 565
operands, usage, 107	declaration	self-help questions, 529,
spaces, importance, 109	alternative syntax, 519	549-550
writing, 208	summary, 519-520	singular names, usage,
Arithmetic operators (%), 94,	defining, named constant	521–520
106–109	(usage), 520	sorting, 560, 679l

Arrays.sort (method), 681 ASCII characters set, 127, 1012 storage, 818 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 Assertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operators, 110–111 usage, 383 Assignment statements, operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  Auxiliary memory (secondary memory), 39 AVT. See Abstract Window Toolkit Sals Species (class), serialization, 835 primitive values, writing, 815–814 reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 891–895 demonstration, 895l–896l example, 93f screen output, sample, 896–897 self-help questions, 897 Binary search, 892 Server output, sample, 896–897 self-help questions, 897 Binary search, 896 Binary search, 896 Example, 30 Signal demonstration, 826 Signal demons	square brackets, usage	Automatic documentation,	implementation, impact,
types, 519 reference types, relationship, 546 usage, 530, 550 value, rearrangement, 560 visualization, 517f Automobile (class), actions, wrapping, 5551–5571 ArraySearcher, 893–894 Arrays.sort (method), 681 ArraySearcher, 893–894 Arrays.sort (method), 681 ASCII characters set, 127, 1012 storage, 818 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 ASSertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment operator, 93, 94 specialized assignment operator, 110–111 usage, 383 Assignment statements,	(process), 520	javadoc (usage),	345
types, 519 reference types, relationship, 546 usage, 530, 550 value, rearrangement, 560 visualization, 517f Vary (class), 565 ArraySearcher, 893–894 Arrays.sort (method), 681 ArraySearcher, 893–894 Automobile class, 3c09 Automobile class, 3c9 Autom	terminology, 521f	363-364	Binary data file, processing,
relationship, 546 usage, 530, 550 value, rearrangement, 560 visualization, 517f wrapping, 5551–557l Arrays (class), 565 Arrays (ass), 565 Arraysearcher, 893–894 Arrays.sort (method), 681 ASCII characters set, 127, 1012 sset, 127, 1012 sset (astement), usage, 381 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 Assertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  Rutomobile class), actions, 469–471 Automobile (class), actions, 31 Binary digit (bit), 40 holding, 41 Binary digit (bit), 40 holding, 41 Binary files, 788–789 array objects, 836–837 self-test questions, 839 creation, 811, 812 summary, 814 end of data, detection, 826 l/O, 811 Species (class), serialization, 8321 object, writing, 835 primitive values, writing, 1 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, 92 summary, 814 end of data, detection, 826 l/O, 811 objects/arrays, usage, 813 Species (class), serialization, 8321 object, writing, 835 primitive values, writing, 813–814 reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 8941–8951 demonstration, 895 example, 94 execution, 481 primitive types, interpretation, 803 usage, 126 Backslash (\), 127f interpretation, 803 usage, 126	types, 519	Automatic type conversion,	
relationship, 546 usage, 530, 550 value, rearrangement, 560 visualization, 517f wrapping, 5551–557l Arrays (class), 565 Arrays (ass), 565 Arraysearcher, 893–894 Arrays.sort (method), 681 ASCII characters set, 127, 1012 sset, 127, 1012 sset (astement), usage, 381 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 Assertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  Rutomobile class), actions, 469–471 Automobile (class), actions, 31 Binary digit (bit), 40 holding, 41 Binary digit (bit), 40 holding, 41 Binary files, 788–789 array objects, 836–837 self-test questions, 839 creation, 811, 812 summary, 814 end of data, detection, 826 l/O, 811 Species (class), serialization, 8321 object, writing, 835 primitive values, writing, 1 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, 92 summary, 814 end of data, detection, 826 l/O, 811 objects/arrays, usage, 813 Species (class), serialization, 8321 object, writing, 835 primitive values, writing, 813–814 reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 8941–8951 demonstration, 895 example, 94 execution, 481 primitive types, interpretation, 803 usage, 126 Backslash (\), 127f interpretation, 803 usage, 126	reference types,	overloading	example, 827l–829l
usage, 530, 550 value, rearrangement, 560 value, rearrangement, 560 visualization, 517f visualization, 520f visualization, 821f visualization, 821		(relationship),	Binary digit (bit), 40
value, rearrangement, 560 visualization, 517f varapping, 5551–557l Arrays (class), 565 Arrays (class), 565 Arrays(class), 565 Arraysearcher, 893–894 Arrays.sort (method), 681 ASCII characters set, 127, 1012 storage, 818 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 Assertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  Automobile (class), actions, self-test questions, 839 creations, 819 array objects, 836–837 self-test questions, 839 creations, 819 creation, 811, 812 summary, 814 end of data, detection, 826 l/O, 811 Species (class), serialization, 832 l/O, 813 Species (class), 87			
visualization, 517f wrapping, 5551–557l Arrays (class), 565 ArraySearcher, 893–894 Arrays.sort (method), 681 ASCII characters set, 127, 1012 storage, 818 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 Assertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 execution, 481 primitive types, involvement, 95  Automobile (class), actions, 308 solus age, 309 Automobile class, 626 flooklat constructions, 811 byectection, 826 l/O, 811 objects/arrays, usage, 831 species (class), serialization, 835 primitive values, writing, 813–814 reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 class, 894l–895l demonstration, 895l–896l example, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894		Automatic unboxing, 451	
wrapping, 555l–557l 308 self-test questions, 839 Arrays (class), 565 Automobile.class, 309 creation, 811, 812 Arraysearcher, 893–894 Automobile.java, 309 summary, 814 Arrays.sort (method), 681 Auxiliary memory (secondary memory), 39 ASCII characters memory), 39 ASCII numbering system, 105 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 ASSertion BadStringOperationException, relating at the following action, 831 Assertion Assertion Assertion Assertion Assertion Assertion BadStringOperationException, relating at the following action, 839 Assignment compatibilities, parallel, 196 Assignment compatibilities, 101–102, 646 Value, assignment, 102 Assignment operator, 93, 94 Assignment operator, 93, 94 Assignment statements, p3–94, 109 Assignment statements, p3–			array objects, 836–837
Arrays (class), 565 Arraysearcher, 893–894 Arrays.sort (method), 681 ASCII characters set, 127, 1012 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381  Assertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  Automobile.class, 309 Automobile.java, 309 Automobile.class, 309 Automobile.class, 309 Automobile.class, 309 Automobile.java, 100, 81 AVI. See Abstract Window Toolkit Sall ASCII objects/arrays, usage, 831 Aspecies (class), perialization, 831 Aspecies (class), erialization, 831 Aspecies (class), perialization, 821 Abjectes, 281–282 value, 194 variable, 196 Base case, 869, 877, 892 summary, 822 strings, writing, 816–817 usage, decision, 789 usage, 26 inary search, 892 class study, 80–892 class stu	wrapping, 555l–557l		
ArraySearcher, 893–894 Arrays.sort (method), 681 ASCII characters set, 127, 1012 storage, 818 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 ASSertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  AWIT. See Abstract Window Toolkit  B AWIT. See Abstract Window Objects/arrays, usage, 1/0, 811 Species (class), serialization, 8321 object, writing, 835 primitive values, writing, 813–814 reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 894l–8951 demonstration, 895 Binary tree, 966 flowchart, 967f binarySearch, 894		Automobile.class, 309	
Arrays.sort (method), 681 ASCII characters set, 127, 1012 storage, 818 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 Assertion checking, 282 on/off status, 282 checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operators, 110–111 usage, 383 Assignment statements, operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  Auxiliary memory (secondary memory), 39 AVT. See Abstract Window soll, 10, 811 objects/arrays, usage, 81 Species (class), serialization, 832l object, writing, 835 primitive values, writing, 815–814 reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 894l–895l default constructor demonstration, 895l–896l example, 93f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894	ArraySearcher, 893–894	Automobile.java, 309	summary, 814
ASCII characters set, 127, 1012 storage, 818 ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 Assertion checking, 282 on/off status, 282 on/off status, 282 true/false value, 281 Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  AWT. See Abstract Window Toolkit  Species (class), serialization, 8321 object, writing, 835 primitive values, writing, 813–814 reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 8941–8951 demonstration, 8951–8961 example, 493 for Binary tree, 966 flowchart, 967f binary Search, 894	Arrays.sort (method), 681		
storage, 818  ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage,	ASCII characters		
storage, 818  ASCII numbering system, 105 Assembly language, 43 assert (operator), 738 assert (statement), usage,	set, 127, 1012	AWT. See Abstract Window	objects/arrays, usage,
Assembly language, 43 assert (operator), 738 assert (statement), usage,	storage, 818	Toolkit	
Assembly language, 43 assert (operator), 738 assert (statement), usage, 381 Assertion Checking, 282 On/off status, 282 Checks, 281–282 true/false value, 281 Assignment compatibilities, 101–102, 646 Value, assignment, 102 Assignment operator, 93, 94 specialized assignment Operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  Base case kslash (\), 127f object, writing, 835 primitive values, 835 primitive values, writing, 813–814 reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 894l–895l demonstration, 895l–896l example, 893f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894	ASCII numbering system, 105	_	Species (class), serializa-
assert (statement), usage, 381 usage, 126 813–814  Assertion BadStringOperationException, checking, 282 722 summary, 822 on/off status, 282 balance strings, writing, 816–817 checks, 281–282 value, 194 usage, decision, 789 true/false value, 281 Variable, 196 Values, 789  Assignment compatibilities, 101–102, 646 value, assignment, 102 Base-case constructor, calling, 459 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383  Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  assignment interpretation, 803 primitive values, writing, 813–814  reading, 818 summary, 822 strings, writing, 816–817 usage, 869, 877, 892 Binary operator, operands (usage), 67  Binary search, 892 class, 894l–895l demonstration, 895l–896l example, 893f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894	Assembly language, 43	В	
assert (statement), usage, 381 usage, 126 813–814  Assertion BadStringOperationException, checking, 282 722 summary, 822 on/off status, 282 balance strings, writing, 816–817 checks, 281–282 value, 194 usage, decision, 789 true/false value, 281 Variable, 196 Values, 789  Assignment compatibilities, 101–102, 646 value, assignment, 102 Base-case constructor, calling, 459 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383  Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  assignment interpretation, 803 primitive values, writing, 813–814  reading, 818 summary, 822 strings, writing, 816–817 usage, 869, 877, 892 Binary operator, operands (usage), 67  Binary search, 892 case study, 890–892 class, 894l–895l demonstration, 895l–896l example, 893f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894	assert (operator), 738	Backslash (\), 127f	object, writing, 835
Assertion BadStringOperationException, checking, 282 722 summary, 822 strings, writing, 816–817 checks, 281–282 value, 194 usage, decision, 789 true/false value, 281 Assignment compatibilities, 101–102, 646 summary, 879 value, assignment, 102 Base-case constructor, calling, assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95 involvement, 95  abadStringOperationException, reading, 818 summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789  balance summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789  binary operator, operands (usage), 67  Binary search, 892 case study, 890–892 class, 8941–8951 demonstration, 8951–8961 example, 893f screen output, sample, 893–894, 109 default constructor, 636 example, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894	assert (statement), usage,	interpretation, 803	primitive values, writing,
checking, 282 722 summary, 822 on/off status, 282 balance strings, writing, 816–817 checks, 281–282 value, 194 usage, decision, 789 true/false value, 281 variable, 196 values, 789  Assignment compatibilities, 101–102, 646 summary, 879 (usage), 67 value, assignment, 102 Base-case constructor, calling, 816–817 assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 calling, 636 example, 893f Assignment statements, 109–94, 109 default constructor, 636 examples, 94 definition, overriding, 100 execution, 481 primitive types, 100 involvement, 95 private instance variables/  summary, 822 strings, writing, 816–817 usage, decision, 789 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 894l–895l demonstration, 895l–896l example, 893f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894		usage, 126	813-814
on/off status, 282 checks, 281–282 true/false value, 281  Assignment compatibilities, 101–102, 646 value, assignment, 102 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383  Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  balance value, 194 variable, 196 value, 194 variable, 196 values, 789 Binary operator, operands (usage), 67 Binary search, 892 case study, 890–892 class, 894l–895l demonstration, 895l–896l example, 893f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894	Assertion	BadStringOperationException,	reading, 818
checks, 281–282 value, 194 usage, decision, 789 true/false value, 281 variable, 196 values, 789  Assignment compatibilities, 101–102, 646 summary, 879 (usage), 67  Value, assignment, 102 Base-case constructor, calling, 25 case study, 890–892 case study, 890–892 case study, 890–892 case, 869, 877, 892 ginary search, 892 case study, 890–892 case study, 890–892 case study, 890–892 class, 8941–8951 demonstration, 8951–8961 example, 893f screen output, sample, 2628 ginary search, 897  Examples, 94 definition, overriding, 2628 ginary search, 897 definitive types, 2628 final class, differences, 630 flowchart, 967f binarySearch, 894		722	
true/false value, 281 variable, 196 values, 789  Assignment compatibilities, 101–102, 646 summary, 879 (usage), 67  value, assignment, 102 Base-case constructor, calling, 23 specialized assignment operator, 93, 94 specialized assignment 24 operators, 110–111 constructor 25 demonstration, 8951–8961 examples, 94 definition, overriding, 293–94, 109 default constructor, 636 examples, 94 definition, overriding, 294 execution, 481 primitive types, involvement, 95 final class, differences, 630 private instance variables/  has e case, 869, 877, 892 binary operator, operands (usage), 67  Binary search, 892  case study, 890–892  class, 8941–8951  demonstration, 8951–8961  example, 893f  screen output, sample, 896–897  self-help questions, 897  Binary tree, 966  flowchart, 967f  binarySearch, 894	on/off status, 282	balance	strings, writing, 816-817
Assignment compatibilities, 101–102, 646 summary, 879 summary, 879 (usage), 67  value, assignment, 102 Base-case constructor, calling, specialized assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 calling, 636 calling, 636 example, 893f Assignment statements, 93–94, 109 default constructor, 636 examples, 94 execution, 481 primitive types, involvement, 95 final class, differences, 630 private instance variables/  Base case, 869, 877, 892 (usage), 67  Binary search, 892  case study, 890–892  class, 8941–895l  demonstration, 8951–896l  example, 893f  screen output, sample, 896–897  self-help questions, 897  Binary tree, 966  flowchart, 967f  binarySearch, 894	checks, 281-282	value, 194	usage, decision, 789
101–102, 646 summary, 879 (usage), 67 value, assignment, 102 Base-case constructor, calling, Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 calling, 636 example, 893f Assignment statements, invocation, 635 screen output, sample, 93–94, 109 default constructor, 636 examples, 94 definition, overriding, execution, 481 primitive types, involvement, 95 final class, differences, 630 private instance variables/  101–102, 646 summary, 879 (usage), 67  Binary search, 892 case study, 890–892 class, 8941–895l demonstration, 8951–896l example, 893f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894		variable, 196	values, 789
value, assignment, 102 Assignment operator, 93, 94 specialized assignment operators, 110–111 usage, 383 Assignment statements, 93–94, 109 examples, 94 execution, 481 primitive types, involvement, 95  Base-case constructor, calling, 723 Base class, 625 class, 8941–895l demonstration, 8951–896l example, 893f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894			Binary operator, operands
Assignment operator, 93, 94 specialized assignment operators, 110–111 constructor demonstration, 8951–896l example, 833  Assignment statements, 93–94, 109 default constructor, 636 examples, 94 definition, overriding, execution, 481 primitive types, involvement, 95 final class, differences, 630 involvement, 95 case study, 890–892 class, 8941–895l demonstration, 8951–896l example, 636 example, 893f screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894		summary, 879	
specialized assignment operators, 110–111 constructor demonstration, 8951–896l defoult constructor, 636 default constructor, 636 definition, overriding, execution, 481 definition, overriding, self-help questions, 897 definitive types, final class, differences, 630 flowchart, 967f binarySearch, 894		Base-case constructor, calling,	
operators, 110–111 constructor demonstration, 8951–896l usage, 383 calling, 636 example, 893f Assignment statements, invocation, 635 screen output, sample, 93–94, 109 default constructor, 636 896–897 examples, 94 definition, overriding, execution, 481 628 Binary tree, 966 primitive types, final class, differences, 630 flowchart, 967f binarySearch, 894		723	
usage, 383  calling, 636  example, 893f  Assignment statements,		Base class, 625	
Assignment statements, 93–94, 109 default constructor, 636 896–897 definition, overriding, execution, 481 628 Binary tree, 966 primitive types, involvement, 95 private instance variables/ screen output, sample, 896–897 screen output, sample, 896–897 self-help questions, 897 Binary tree, 966 flowchart, 967f binarySearch, 894			
93–94, 109 default constructor, 636 896–897 examples, 94 definition, overriding, self-help questions, 897 execution, 481 628 Binary tree, 966 primitive types, final class, differences, 630 flowchart, 967f involvement, 95 private instance variables/ binarySearch, 894			•
examples, 94 definition, overriding, self-help questions, 897 execution, 481 628 Binary tree, 966 primitive types, final class, differences, 630 flowchart, 967f binarySearch, 894			
execution, 481 628 Binary tree, 966 primitive types, final class, differences, 630 flowchart, 967f involvement, 95 private instance variables/ binarySearch, 894			
primitive types, final class, differences, 630 flowchart, 967f involvement, 95 private instance variables/ binarySearch, 894		definition, overriding,	
involvement, 95 private instance variables/ binarySearch, 894			
· ,	- · · · · · · · · · · · · · · · · · · ·		
usage, 930-931 private methods 630 Rlank lines appearance 488		-	
	usage, 930-931	private methods, 630	Blank lines, appearance, 488
variable declaration, Base type, requirement, 924 Blocks, 330–331		,	
combination, 96 Base_Type summary, 331			
	Asterisk (*), 91		
writing, 676 parameters, 926 330–331	Attributes (characteristics), 58	Behaviors, 58	BlueJ (IDE), 56, 997
writing, 676 parameters, 926 330–331	e		
	(1 11 00), 00	,	, ( ),, ·

Body, 316	self-test questions,	Callable, implementation,
Body (loop), 238	276–277	664
Body (method), 52	usage, 274-275	Calling methods, 430-431
Body (statement), 243, 256	example, 275l	Capacity (array), 519
Body mass index (BMI)	breed (name), 317	Capsule, detail, 59
calculation program,	Buffer, 791	Carnegie, Dale, 116
2021–2031	Bug (program mistake), 63	Carriage return (r), 127f
case study, 201	retesting, 279	Case label, 212
	Bug infestation (roaches)	
computation, algorithm, 201–202	,	ordering, 214
Boolean (data type), 91	algorithms, 248, 249	Case sensitivity, 91
` '- '	example, 250l–251l	catch (block), 715–716 addition, avoidance, 737
Boolean expressions, 184 control, 239	programming example, 247–248	exception, 722
example, 177	screen output, sample, 251	catch-block parameter, 715
joining, 186	self-test questions,	ceil (method), 447
negation, 187	252–253	Central processing unit (CPU)
semicolon, usage, 243	Built-in utility, usage, 279	(processor), 39
true value, 239	Buttons	Change-making program,
Boolean-valued methods,	addition, 493	windowing I/O
378–379	in BorderPane layout,	(usage), 160–161
naming, programming,	589l-590l	char (primitive type), 450
379–380	creation, 493	character (wrapper class),
Boolean values	and event handler, 685,	452
input/output, 210–211	686f	char (type), arguments, 467
return, method (usage), 373	byte (integer type), 90	Character (class), static
Boolean variables, 206–207	Bytecode, 9	methods, 453f
usage, 269-270	language, Java compiler	Character graphics, case study,
value, 207	translation, 46	665–666
Boolean_Expression, 274	Bytes, 39–40	Characteristics (attributes), 58
BorderPane layout	number, address, 41	Characters
adding buttons to,		averaging, 470
589l-590l	C	equality (checking), equals
regions, 589f	C++, vs. Java, 1008-1011	method (usage), 452
Bottom-up testing, 464	Call (invoke)	set, 127
box, reference, 662	action, 52	type casting, 105
Boxing, 450. See also	method, 54	wrapper class, 452
Automatic unboxing	usage, 122	charValue (accessor method),
Braces { }, 178	Call by reference, 385	451
compound statement,	Call-by-reference parameter,	chat (method), 357
enclosure, 239	385	CheckBox control, 759
requirement, 195	Call-by-value mechanism, 332	Checked exception, 736–737
usage, 145	Call-by-value parameter	Child class, 627
Branching, usage, 284l–287l	mechanism,	ChoiceBox control, 763
break (statement), 212	argument value	Circle (object), reference, 662
omission, 216	сору, 387	Circle (type), object, 663

CircleCalculation (class), 145	parameters, 382–385	mutator methods, usage,
Circles, drawing, 71-72	primitive type	347l
Circular doubly linked list,	parameters,	objects, methods, 122
966	differences, 388l	outline, 308f
Circular linked list, 965, 965l	reference types,	private instance variables,
Class (string), 119-128	relationship, 366	3421
self-test question, 128	variables declaration, 91	private object, change,
Class (name), usage, 153–154	Class variables	4831–4841
Class definitions, 307, 336	behavior, 368f-369f	sales report, case study, 530
comments, 362	static variables,	serialization, ability, 831
main (method), placement,	relationship, 436	static members,
4461	summary, 436	non-static members
parameter, presence, 974	Class(es), 47, 1010. See also	(interaction), 438
type parameter, 969	Abstract classes;	static set, 440
usage, 968l	Derived classes; Inner	static variables, 435
Class diagram. See Universal	classes; Outer classes	types, angle bracket
Modeling Language	accessor methods, usage,	notation, 969
class diagram	3471	usage, 59, 550
constructors	action, 660	type parameter, 969
absence, 422	arrays	ClassNotFoundException, 722
inclusion, reason, 430	usage, 530	Client/server network
example, 422f	wrapping, 555–557l	communication, 840f
usage, 378f, 532f	blueprint, 307f	clone (method), 649, 1019
Class loader, 47	compiling, 56	heading for, 1020
Class objects, file I/O,	data (corruption), public	implementation of, 1020l
8331-8351	instance variables	Cloning, 1019–1022
Class path	(impact), 344	close, calls, 792
base directories, 489–490	defining, encapsulation	Closing parentheses,
current directory, exclu-	(usage), 362–363	semicolon (usage),
sion, 492	equals (method), defining,	243
variable, value, 489	371	Code, 44
Class scanner, documentation,	files, 309	embedding, 112
65f	get methods, 440	Collection (interface),
Class species, class diagram	hierarchy, 624f	931-932
(usage), 378f	impact, 58	methods, 932f
Class-type parameters,	implementation, 361	Colon, usage, 212
primitive-type	instance variables,	Color
parameters	presence, 481	addition, 220l-221l
(differences), 386,	reasons, 312	defining, 222
3881, 389	interface, relationship, 363	specification. See Drawing
Class type variables, 366–369	interfaces, 657-658	color
Class types, 89, 370	is-a relationship (defining),	color (instance variable), 487
== (equality operator),	inheritance (usage),	Comma
usage, 370-371	626	operator, 262
action, 218	Java class, compiling, 56	usage, 262

Comma-separated values	Compound statements,	Java definition, 426, 429
(CSV) file, processing	178–180	method, usage, 428l
case study, 808-809	alternatives, 183	multiple definitions, 422
sales transactions, presence,	usage, 180	name (generic class), type
809l-810l	computeDayHours (method),	parameter (absence),
screen output, sample, 810	582	974
Comments, 142–144. See	Computers	private method, 430
also Postcondition	basics, 38-47	calling, 4311–4331
comment; Precondi-	language implementers, 99	screen output, sample, 428
tion comment	program, algorithm, 272	summary, 429
appearance, 488	self-test questions, 47-48	super
highlight, text editors	systems, components, 39	call, omission, 636
(usage), 142–143	computeStats (method), 532,	usage, 637
indentation, relationship,	536	this, usage, 637
144l	computeWeekHours	three-parameter
notes, 142	(method), 582	constructor,
self-test questions, 147	Concatenation, 120–121	invocation, 433
usage, 149l	operator, 120	usage, 425, 430, 630, 635
writing, 143	Conditional operator (ternary	example, 427f
compact discs (CDs), auxiliary	operator), 204	writing. See Interdependent
memory, 39	expression, 204	constructors
Comparable (interface), 680	Constants (literals), 98-99	continue (statement)
case study, 678	difference, 99	self-test questions, 276-277
implementation, Fruit	name, defining, 101	usage, 274-275
(class) usage,	named constants, 100-101	Control
680l-681l	naming, 146l	flow, 176, 1008-1009
compareTo (method), 191,	Constructors, 421. See also	exception, throwing
486, 678	Default constructor	(absence), 716l–717l
calling, 681	absence, 422, 470	structures, 176
invocation, 680	action, 421	Control Panel, usage, 491
usage, 192–193	calling, 433	Controlling Boolean
Comparison operators. See	example, 434l	expression, 278
Java	methods, 430-431	problem, 279
Compilation, 309	objects, usage (relation-	Controlling expression, 212
Compilers, 43–9	ship), 426–427	answer (variable), 215
complaints, 95	summary, 434-435	complication, 214–215
considerations, 462–463	declaration, absence, 658	Coordinate system, 70
correctness, 463	defining, 421–422	screen coordinate system,
language translation, 44	definitions, grouping, 427	example, 71f
usage, 9, 485–486	headings, 468	count (variables declaration),
Compiling	inclusion, reasons, 430	328
-Xlint (option), usage, 970	integer argument, usage,	Count-controlled loops, 267
Compiling, javac command	551	countDown (method), 869,
(usage), 56	invocation, 426	870
Complete evaluation, 210	super, usage, 635	recursive calls, 871f

countOfEntries, 554	Default constructor	case study, 872-874
countOfEntries (instance	absence, 454	recursion program, 874l
variable), usage, 558	omission, 429-430	DimensionConverter (class),
Coworkers, maliciousness,	parameters, absence, 426	437
631-632	summary, 429	Directories (folders), 41
CSV. See Comma-separated	Defining methods, usage,	disc, usage, 662
values	317-319	displayAsWords, 872, 876-877
current (instance variables),	Deleted node, 947	definition, 882
958	deleteHeadNode (method),	iterative version, 883l
Current directory, 491	945	method, 873
exclusion, 492	delimiter, separation, 809	recursive call, 874
_	Delimiters, change, 137, 138l	recursive method,
D	delphi.answer(), 358	execution, 874
Data, 39	Demonstration class,	displayAsWords(number),
auxiliary memory storage, 39	386l-387l	algorithm, 873
encoding, 40	DemoSpecies (class type), 387	displayResults (method), 532
file, processing. See Binary	Derived classes, 624-627	DivideByZeroException (class),
data file	class extension, 625	723–724, 729, 734
members, 436	constructors, usage,	catch (block), 741
program reading, 53	635-636	definition, 751
storage, variables (usage),	derived class, 638	exceptions, catching, 734
52	example, 639l	throwing, 751
structure, 920	example, 625l–626l	Division operator, 107–108
tree, 966	object, 646	do-while loop, 242
types, 52, 88, 89-91	base class function, 644	action, 245f
DEBUG flag, usage, 280	private instance variables,	body, execution, 244
Debugging, 63–64	direct access	example, 244l
self-test questions, 63-64	(absence), 631	execution, 243
DecimalFormat class,	private methods, indirect	screen output, sample, 244
1001-1004	access, 631	do-while statement, 242–244
demonstration of,	subclass, relationship, 628	avoidance, 264–265
1003l-1004l	summary, 627-628	semantics, 246f
importing, 1001	Descendant, 627	summary, 246-247
object of, 1001-1002	Descriptive names, usage, 471	doCalculation (method)
pattern symbols, 1002–1003	Designers, interfaces (usage),	definition, 748–749
Declaration, 88	660	heading, 751
assignment, combination,	Dialog box. See Yes-or-no	loop, coding, 749
95	questions	Documentation, 141–147
syntax, 89	Dialog windows (dialog	Dog (class)
Decomposition, 461–462	boxes) (dialogs), 152	definition, 310l
Decrement operators (-),	multiline output, 160	implementation,
117–118	presence, 160f	programming
self-test question, 119	Digital video discs (DVDs),	(example), 309–310
default case, 212	auxiliary memory, 39	screen output, sample, 311
omission, 216	Digits to words	usage, 311l

Dog (objects), variables (relationship), 312 Dollar sign (\$), 91 DollarFormat (corrected class), 460l–461l DollarFormatFirstTry (class), 458l testing, driver (usage), 459l screen output, sample,	Dummy variable, 75 Dynamic binding, 653 application, 664 inheritance, relationship, 652–654 Java assumption, 655 polymorphism, relationship, 656 self-test questions, 656	End-of-line character, elimination, 137 English-language keyboard, usage, 127 Enhanced enumeration suit, 486l entries, usage, 521 entry (array), usage, 554 entry.length, 554
459	toString, usage, 655–656	Enumerated data type, 218
Dot, 52	type checking, interaction,	Enumerations, 218–219
double (base type), 541	663	access modifier, presence,
double (type), 88, 102	Dynamic structure, 920	487
value	T.	class, 485-486
assignment, 103	E	class type action, 218, 219
return, 447	e notation, 99	enhanced enumeration
variable, 516	Eclipse (IDE), 56, 997	suit, 486l
double (amount) display,	Efficiency, implementation	usage, 577
algorithm (usage), 456	(impact), 346	value, behavior, 219
Double quotes ("), 127	e.getMessage(), 715, 728	EOFException (class), 824
spaces, appearance, 109	Elements, 516	self-test questions,
usage, 130	meanings, 521	830-831
Double.parse	usage, 528	summary, 825
Double(theString),	e.length (array), 522	usage, 8241-8251
451–452	else. See if-else statement	Equality
doubleValue (accessor	if, matching, 196	array assignment,
method), 451	omission, 181	relationship, 543–544
doubleVariable, 101–102	pairing, 195	kinds, 5451–546l
Doubly linked list, 965, 966l	else-if parts, addition, 197	test, 184
drawAt (method), 665	Employee time records	testing, strings
examination, 670	(programming	(relationship), 190l
drawFaceSansMouth, 397	example), 577	Equality operator (==), 184f,
drawHere ( ), 682	empty (statement), 260	185
drawHere (method), 665, 669	Empty list, null (usage),	testing, 544, 1009
definition, 671	941	usage, 546
invocation, 684	Empty string, 120, 137	problem, 372f
drawHorizontalLine,	Encapsulation, 59, 337–338,	equals (definition), 374
algorithm, 671	360–363	overriding, 651
Drawing color, specification,	grouping, 360	equals (method), 191, 486
drawsides (method) 671 672	principle, usage, 361	consideration, 384
drawSides (method), 671–672	summary, 363	defining, 371, 373l, 643 demonstration, 374l–375l
drawString (method), 597 drawTop (method), 675, 676	techniques, 361	impact, 650–651
Driver programs (drivers), 457	usage, 360 End of data, detection, 826	improvement, 650–651
DrJava, 997	End of file, checking, 826	example, 652l
$D_{1}$ $\alpha v \alpha_{i} J J i$	Life of fife, checking, 020	CAUTIPIC, 0321

parameter-passing mechanism, 385	programmer-defined exception class, 724l,	Expr_A    Expr_B, 210 Expressions, 86. <i>See also</i>
parameter types,	729-730	Boolean expressions
differences, 650	self-test questions,	connection, 185
usage, 452	730–733	usage, 53
equals (identifier), usage, 375	Exception (objects), 718	value, 93
equalsIgnoreCase (method),	characteristics, 728	External iterators, 958
191	throwing, 715	Г
Error (class), objects, 738	Exception (base class),	F
Error message, production,	constructor (calling),	FEET_PER_YARD, copy, 435
471	723-724	Fibonacci numbers, 884
Errors, 738	Exception handling, 710–711	Fields, 436
Escape characters, 126–127	Exceptions, 711, 829–830	Figures, size/position, 70-71
problems, avoidance, 804	catching, 715, 734, 741	File (class), 801
types, 127f	programming, 741	methods, 804-805, 806f
Escape sequences, 126	checked exception,	summary, 805
evaluate (method)	736–737	File (method), 801
consideration, 750	declaration, 733-735	File I/O, overview, 787
exception, catching, 755	description, documenta-	File organizer GUI, 845l–849l
Evaluation. See Complete	tion, 755	FileInputStream, 818
evaluation; Lazy	getMessage (method), 715	summary, 822-823
evaluation;	handling, 711, 719–720	fileNameField, 850
Short-circuit	example, 713l-714l	fileNameField.setText, 849
evaluation	Java code, usage, 711	FileNotFoundException, 791
Event-driven programming,	programming, 742	PrintWriter constructor,
493, 685	self-test questions,	throwing, 791
EventHandler (interface), 685	720–721	throwing, 799
Event handlers, 685, 686f	handling, linked lists	FileOutputStream (class), 796
lambda functions and,	(usage), 962	constructor, impact,
902–904, 9041–9051	importing, 722–723	811–812
Event handling	kinds, 736-737	summary, 822–823
in anonymous inner class,	summary, 738	Files, 41, 1009–1010
691–692, 6921–6941	multiple exceptions,	deletion, 849
in main GUI application	catching, 739l–740l	file object, differences, 806
class, 689, 690l-691l	rethrowing, 746	input/output (I/O),
mouse, 765, 765l–768l	throwing, 711, 714, 719	8331–8351
in separate class, 686,	absence, 716l–717l	manipulation
6861–6871	code, impact, 744	JavaFX GUI, 845
Exception (classes), 733.	location, 744–745	names, 794
See also Predefined	method cessation, 734	reading, 801–802,
exception classes	unchecked exception	8021
defining, 723–724	(run-time exception),	naming rules, 794
timing, 729	737	opening, 790
getMessage, preservation,	exit (method), 204–205	overwriting, 796
727–728	summary, 205	readability, 804

Files (continued) reading, 8021	comparison, 184–185 computation, 185	linking controller to, 979–980, 980f
ObjectInputStream,	floor (method), 447	loading, 978l
usage, 820l-821l	FlowPane layout pane, 586,	-
types, 788–789	586l-587l	G
writing, ObjectOutput-	HBox and, embedding into	Garbage values, 553-554
Stream (usage),	BorderPane, 5931–5951	Garbage collection, 1011
812l-813l	Folders (directories), 41	gc (graphics context), 75
fillOval (method)	for (loop), 255	gc.strokeArc (method)
syntax, 72	action, 258f	example, 74f
fillPolygon (graphics	description, 256-257	syntax, 73
method), 597	initialization, 262	gc.StrokeOval (method),
summary, 598–599	mechanism, impact, 267	example, 72, 72f
fillText (method), 288-289,	usage, 524	general.utilities (package),
398, 399	for (statement), 255–256	488–489
Filter, concept of, 1013–1015	body, execution, 260	Generic data types, 931
final (modifier), 629–630	comma, usage, 262	Generic linked list, 970
Final class, base class	equivalence, 257	class, 9711–972l
(differences), 630	example, 257l	usage, 973l
finally (block), 745–746	screen output, 257	Generic types, 127, 920
Firing, event, 685, 685f	semantics, 259f	Generics, 967
First-draft algorithm, 890	summary, 258–259	basics, 967–968
firstHalf (array), 899	variables (declaration),	Get methods (accessor
firstInitial, 98	261–262	methods), 346–347,
firstLineField, 850	for-each (statement), 264	925
FirstProgram, class	For-each loop, usage, 930	getAgeInHumanYears,
defining, 50	Formal parameters, 331	309–310, 317–319
file location, 55	arguments,	getAgeOfFirst (method),
FirstProgram.java, compiling,	correspondence, 336	484
56	data type, 334	getArea (definitions), usage,
Flash drives, auxiliary	format (method), 1001	663
memory, 39	Format specifiers, 139	getAverage (static method),
float (primitive type), 450	selection, 140f	466
Floating-point constant	Formatted output, 139	getAverage (method),
number, 98	Fruit (class)	definition, 538
Floating-point notation, 99 Floating-point number, 90, 279	defining, 679l	getCircumference, invocation,
accuracy, loss, 100	example, 680l–681l impact, 680	663 getData (method), 532, 533,
floating, meaning, 99	Fruit (objects), array (sorting),	948
percent (%) operator, be-	679l	getIndexOfSmallest,
havior, 108	Full path name, 803	564
Floating-point numbers	Functional programming	getInterestRate, 440
imprecision, 100	(Java 8), 1013–1016	getMessage (method), 715,
Floating-point types, 107	Functions, 320	720, 722
Floating-point values	FXML file, Scene Builder, 976	preservation, 727–728
rioating-point values	17MVIL IIIC, OCCINE DUHUCI, 970	preservation, 121-120

getNameOfFirst (method), 484 getNumberOfZeros (recursive method), 884–887 getPerimeter (statement), 660 getPerimeter (definitions), usage, 663 getPopulationIn10 body, statements, 325 method, usage, 323 getTotalCost (method), 350 getWeightOfFirst (method), 484 getWordFromDigit, 872 giveNewValues, 347 giveSecondChance, 727 Global variables, 330 Gosling, James, 48–49 goToNext (method), 958 effect, 945f Grammar, 53 Graphical User Interface (GUI), 66 components, instance variable definition, 850 Graphics application named constants, usage, 150 display, 66–67 happy face, drawing, 68l supplement, 66–67, 147 GraphicsContext (class), 390–393 methods, 391 GraphicsContext (method), 597 Greater than or equal to (>=), 177 GridPane layout pane, 587, 5871–5881 growthRate (instance variables), 795 GUI. See Graphical User	H handleDivideByZeroException, 755 handleUnknownOpException, 755 Happy face, drawing, 671 Hard disk drives, auxiliary memory, 39 Hardware, 39–41 Has-a relationship, programming, 646–647 hashCode (), 933 HashMap (class), 934 demonstration, 9351–9361 screen output, sample, 936 HashSet (class), 932–933 demonstration, 9331–9341 HashSet <t> (class), 933, 936 hasNext (method), 962 hasSameName (method), 645 haveMoney, Boolean variable (occurrence), 274–275 HBox layout pane, 583, 5841 and FlowPane, embedding into BorderPane, 5931–5951 head (instance variables), 958 Head node, 941 Head reference, 941 Heading, 316 Helping (method), 394 usage, 4451 Hidden errors, 64 High-level languages, 43 Higher precedence, 110 highest, initialization, 537 Highest precedence, 110 HPos (class), usage, 587  I Icons addition, 494</t>	Identifier, 91 names, 92 if (b == true), 207 if, else (matching), 196 if (b), writing, 207 if-else statement, 176, 645.  See also Multibranch if-else statements; Nested if-else statements action, 178f, 194 basics, 177 description simplification, compound statements (usage), 180 execution, 194 screen shot, sample, 179 semantics, 180f–181f summary, 183 usage, 1791 Illegal identifiers, 92 Image (class), usage, 495 Implementation See Class(es) details (hiding), encapsulation (usage), 360 Implementers, 99 implementsSerializable, addition, 831 import (statement), 489 requirement, 205 Import, necessity, 54 Importing, packages (relationship), 488–489 INCHES_PER_FOOT (constant), 438 Increment operators, 117–118 self-test question, 119 incrementArrayBy2, 541 Indentation, 145, 178 comments, relationship, 1441 Index (indices), 516 avoidance, 577
GUI. See Graphical User Interface	addition, 494 picture, usage, 495l–496l	expression, 517

. 1 ( )	11 1 1111	
Index (continued)	linked list, 951l–952l	Instructions (statements), 52
initiation. See Arrays	type parameters, defining,	int (integer type), 90, 101, 196
out of bounds index	974-975	value, assignment, 103
(invalid index), 525	innermost (loop), 275	int (primitive type), 450
zero values, 528	Input	int (variable)
Indexed variables, 516	binary file, opening, 818	position marker, 554
•	delimiters, 137–138	usage, 551
arguments		e
example, 539l	import, requirement, 54	int (type), value (return),
screen output, sample,	problem, 154	462
539	program, example, 97l	int [][], 571, 574
summary, 540	prompt, 99	(int)distance, 103
method arguments, 538	stream, 787	Integer (int), 88, 153
value, 540	syntax, 157–158	character, type casting, 105
IndexOutOfBoundsException,	terminology, 789	storage, 99
925	validation, 182	types, 90, 107
Infinite loops, 251–252,	Input (string), 153	Integer argument, usage, 551
277–278	Input/output (I/O)	Integer.parseInt, 153
data, impact, 278	change-making program,	Integrated development envi-
Infinite recursion, 880–881	162l	ronment (IDE), 56
self-test questions,	files, usage (reason), 788	interchange (method), 564
881–882	JOptionPane, usage,	Interchange sorting algorithm,
Information hiding, 59,	150l-151l	561
337–338, 481	Species (class), serializa-	Interdependent constructors,
programming, 742	tion, 832l	writing, 435
what/how, separation, 338	windowing, 147–148	Interfaces
Information overload,		
•	JOptionPane, usage,	abstract classes,
avoidance, 338	157–158	relationship, 657
Inheritance, 59, 60	Input streams, 787f	acceptance, 748
basics, 622-623	inputStream, 92	class implementation,
demonstration, Student	Insecure class, 482l	661
(usage), 627l	insertAfterIterator (method),	dynamic binding,
diagrams. See Universal	958-959	application, 664
Modeling Language	usage, 960f	extension, 664–665
dynamic binding, relation-	Instance, 308	implementation, 651,
ship, 652-654	Instance variables, 310-311,	659-660
hierarchy, 61f	436	class, action, 660
mechanism, usage, 623	encapsulation grouping,	list, 938
multiple inheritance, 651	360	polymorphism,
usage, 626, 635	initialization, 426	application, 664
Initial capacity, 923	absence, 422	technical meaning, 361
Initializing statements,	presence	types
266–267	reasons, 312	relationship, 661
Inner classes, 949	primitive type, usage, 484	self-test questions,
access, 974	usage, 522	664
definition, 949	Instantiation (action), 308	Internal iterators, 958
deminion, Jaj	motantiation (action), 500	internal iterators, 750

Internet applications, Java	arithmetic expressions, 111f	Java 8, functional program-
(advantage), 9	array, object type, 516 assertion check, 281	ming in, 1013–1016
Interpreters, 43–9	•	Java Application Programming
language translation, 44	base type, requirement,	Interface (API), 65
usage, 46	924	Java Class Library, 65
intValue (accessor method),	bytecode, 9–47	availability, 205
451	impact, 9	Java code
Invalid index (out of bounds	C++ vs. Java, 1008–1011	pseudocode
index), 525	case sensitivity, 93	algorithm, translation,
Invoke (call)	class, compiling, 56	893-894
action, 52	collections framework,	usage, 457
method, 54	931	translation, 114
IOException, 722, 818	programming, 937	usage, 270, 898
catching, 811	command, usage, 56	Java Development Kit (JDK),
Is-a relationship, 626	comments, 144	version 7, 214–215
modeling, inheritance	comparison operators,	Java language
(usage), 627	184f	case sensitivity, 91
programming, 646–647	compiler, Java program	grammar, 53
isExtinct (Boolean-valued	translation, 46	history, 48–49
method), 379–380	data types, 89, 90	name, reason, 49
isOnList (method), definition,	dynamic binding, 655	self-test questions, 55
554	exceptions, 711	syntax, 53
isPopulationLargerThan	functions, 320	Java program
(method), 379	identifiers, 88, 91–93	cessation, 205
isSelected (method), 759,762	integer, positive number,	classes, 47
Iteration, 238, 883	182	compiling, 55–57
Iterative methods, recursive	interfaces, 658	example, 46f
methods (differences),	example, 659l	data, reading, 38
882-883	summary, 659	I/O, windowing, 147–148
Iterator interface, 1017	Iterator (interface), 962	running, 9, 55-57
generic data type,	keywords, lowercase	example, 46f
1017-1018	identification, 92	sample, 51l, 87l
methods, 1017	logical operators, 189f	self-test questions, 57
Iterators, 950	loop statements, 238	software accommodation,
external iterators, 958	multidimensional array	49
inclusion, 954l-957l	representation,	storage, 788
interface, 962	574-575	translation, 46
internal iterators, 958	primitive data type,	variable, declaration, 88
self-test questions, 959	811	writing, 55–57
summary, 953	system, 363-364	Java statement, 117
·	distribution, 56	braces, usage, 145
J	type checking, dynamic	spaces, importance, 109
Java	binding (interaction),	Java Virtual Machine
application, programs,	663	(JVM), 9
50-54	utility, 50	javac command, usage, 56
	· ·	, , , , , , , , , , , , , , , , , , , ,

javadoc, 1005 comments, writing, 755,	file name, reading, 801-802 input, 132-137	Letter grades, assignation, 198 multibranch if-else state-
1005-1006	demonstration,	ment, usage, 200l
running, 1006–1007	1331-1341	Lexicographic order, determi-
usage, 143, 363-364	program, example, 971	nation, 191–192
JavaEx Application	Scanner (class), usage,	Line-oriented calculator
branching, usage, 284l-287l	134-99	case study, 747-751
looping, usage, 2841-2871	input/output (I/O),	example, 756l–758l
JavaFX, 66	129–140	screen output, sample, 758
application	self-test questions,	Linked data
adding labels to, 398,	140-141	structures, 937, 966
3981-3991	keyboard (object name),	Linked lists, 938–939
with icon picture, 495,	313-314	circular linked list, 965,
495l-496l	keyboard.next( ), 749	965l
sample, 67–70	keyboard.nextInt(), 96, 132	class, example, 9421-9431
style rules applied to,	Keywords (reserved words),	data, placement, 9531
148-149	92, 1023	demonstration, 946l
controls, 759, 760l-762l,	*	doubly linked list, 965,
762–763	L	966l
event handling in. See	Labels	flowchart, 939f
Event handling	icon, addition, 495,	generic linked list, 970
Scene Builder. See Scene	495l–496l	goToNext, effect, 959f
Builder	in JavaFX application, 398,	iterator
Java SE Development Kit	3981–3991	inclusion, example,
(JDK), 997	Lambda expression, 1013	9541–9571
java.io (package), 790	Lambda functions	movement, 954
javautil (package), 938	and event handlers,	movement, 944f
java.util.Scanner, 132	902–904, 9041–9051	node, addition, 945f
javax.swing.JOptionPane, 157	lastHalf (array), 899	insertAfterIterator,
import statement, 162	Late binding, 653	usage, 960f
JOptionPane (class), 148	Layout panes, 591	node class/inner class,
introducing, 150	BorderPane, 589, 589f,	9511-9521
self-test questions,	5891–5901	operations, implementa-
158–159	combining, 593, 5931–5951	tion, 941, 943
usage, 151l–152l, 224	FlowPane, 586, 586l–587l	tail node, 965
JOptionPane.showMessage-	GridPane, 587, 587l–588l	traversal, 944
Dialog, 155	HBox, 583, 584l	usage, 962
JOptionPane.YES_NO_	StackPane, 584, 585l	variations, 964–965
OPTION, 225	Lazy evaluation (short-circuit	LinkedList (class), 937–938,
Just-in-Time (JIT) compiler,	evaluation), 209	1018
usage, 9	Legal identifiers, 92	usage, 938
K	Length (array), 519	LinkedListException (class),
	length (instance variable),	963l Links holding 929
Keyboard	522, 574	Links, holding, 938
characters, usage, 666l	value, assignation, 522	List, 922

class, 550–551 copying, assignment	break statement, usage, 274–275	main (static method), 443 main (void method), 317
statement (usage),	bugs, 277-279	Main memory, 39
930-931	cessation, Boolean variable	bytes, presence, 40
end (detection), One-	(usage), 269–270	current program/data,
WayNoRepeatsList	example, 271l	holding, 41
(usage), 557	screen output, sample,	example, 40f
initial capacity, 923	271	Map, concept of, 1015
maintenance, ArrayList	continue statement, usage,	Map (interface), 934
(usage), 928l-929l	274–275	methods, 935f
representation, class (array	design, 265	Math (class), 446–449
wrapping), 555l-557l	pseudocode, usage,	math (class), static methods
Listener objects, event, 685, 685f	269–270	(usage), 448f
ListNode (class), 948, 950	ending, break statement	Math E (constant), usage, 447
E parameter, 970	(usage), 275l	Math.floor(start), 447–448
ListNode (type), 940	errors, types, 277	Math.PI (constant), usage, 447
Literals (constants), 98–99	initialization, 270	Mathround (method), 478
Local variables, 316, 328, 436	iteration, 238	Measurable (interface), 660
example, 329l	number, control,	implementation, 661l
screen output, sample, 329	267-268	example, 662l
summary, 330	next (variable), usage, 266	Measurable.java (file), 658
Localhost, usage, 842	programming, 264–265	Megapixel, 70
Logic error, 63	usage, decision, 248	Members, 310
Logical operator (&&), 185	Low-level languages, 43	Memory
effect, 189f	programs, instructions, 47	data, presence, 39
Logical operators. See Java	Lowercase letters, usage, 92	locations, 40, 41
long (integer type), 90	Lowest precedence, 110	saving, trimToSize (usage),
long (primitive type), 450	_	930
long (value), conversion, 456	M	Memory addresses
Loop (body)	Machine language, 43	copy, 367, 383
lines, example, 287	instructions, translation, 46	inclusion, 370
loop (body), 265	programs, production, 9	numbers, 369, 370
execution, 243, 256	main (method), 145, 1009	Merge sort
instruction, execution, 266	addition, 445	algorithm, 898
iteration, 239	arguments, 542-543	efficiency, 902
pseudocode expression,	helping methods, 443	programming, example, 898
265	usage, 445l	self-test questions, 902
loop (statement)	invocation, 542	MergeSort (class), 8991–9011
selection, 263-264	reason, 316	demonstration, 901
semicolon, usage, 260-261	placement, 446l	Merging process, Java code
Looping, usage, 284l–287l	repetitive code, 444l	(usage), 898–899
Loops, 238. See also Count-	subtasks, 443	Message, display, 219
controlled loops;	variables, declaration, 328	Method call (method invoca-
Nested loops; Unin-	main (predefined meaning),	tion), 52, 358
tended infinite loops	92	object name, writing, 123

Method(s), 51-52, 313-314,	example, 475l-477l	self-test questions,
1010	implementation, 474	742-743
arrays	screen output, sample, 480	Multiple types, reading, 818
arguments, 541	usage, 479l–480l	Mutator methods (set
usage, 530	Mouse event handling, 765,	methods), 346-347
calling, 315, 354	765l-768l	defining, 346
constructors, usage, 630	MOUTH_HEIGHTO, 288	screen output, sample, 348
quantity, return, 315	Multibranch if-else state-	self-test questions, 349–350
defining, 484, 806-807	ments, 196-197	summary, 349
definitions, 307, 321-322	equivalence, 197	usage, 347l-349l
location, arrows (usage),	execution, 197	Mutually exclusive possibili-
633	meaning, 198	ties, 197
overriding, 628–629	mutually exclusive possi-	MyClass, compiling, 56
design, 338	bilities, 197	MyClass.java, 56
specifications, precondi-	screen output, sample,	myNumber (identifier), 93
tions/postconditions	200	
(usage), 339	self-test questions, 203	N
heading, 318, 336-337	semantics, 199f	n-dimensional array, 568
invocations, 153, 313, 315,	summary, 197-198	name (instance variables),
471	usage, 200l	795
invoking (calling), 54	Multidimensional arrays,	name (name), 317
kinds, 313	567-568	Name clashes, 492
name	basics, 568	Named constants, 100-101
definitions, parameters	declaration/creation, 571	behavior, 219
(differences), 472	indexed variables, 570	defining, 101
overloading, 466	Java representation,	JOptionPane (class),
overloading, application,	574-575	usage, 225
468-469	parameters, 571-573	syntax, 101
parameters, 333l, 1010	example, 572l–573l	usage, 145–148, 520
inclusion, 340l	summary, 573	revision, 148l–149l
private methods, 359	values, table, 567f	Names
problems, 99	Multiface JavaFx Application,	instance variables, 317
sales report, case study, 530	programming	selection, 88
separate tests, 464	(example), 283	usage. See Path names
signature, 468	Multiline output (dialog	variable names, 141-142
testing, 464	window), 160, 160f	Naming conventions, 93
Methods calling methods, 354	Multiple catches, 739–740	Naming methods, 319
Methods calling other	self-test questions,	Naughton, Patrick, 49
methods, 355l	742-743	Negation operator, avoidance,
Minus sign, 98	Multiple exceptions, catching,	187f
Modifiers. See Access modifi-	7391–7401	Negative balance, display, 197
ers; private; public	Multiple faces, programming	Negative number, usage, 182
Modulus operator (remainder	(example), 394	Negative test, 381
operator), 108	Multiple inheritance, 651	NegativeNumberException
Money (class), 474	Multiple throws, 739-740	(class), 741l

NetBeans, 997 Nested if-else statements, 194 Nested loops example, 254l–255l programming example,	Non-static addInterest, usage, 440 Non-static members, non- static members, 438 mixing, 4391–440l	numberOfStudents (integer variable), 267 numbers.dat (file), 813 Numeric wrapper classes, 452
253 Nested statements (clarity), braces (addition), 194	Non-static methods invocation, 442 usage, example, 441l Nonkeyword identifier, 967	Oak, Java original name, 49 Object (class), 648–649 self-test questions,
Nested structure, 145	NO_OPTION, 225	649–650
Nested try-catch (blocks), 745	NoSuchMethodException,	Object (name)
NetBeans, 56	722	usages, 153–154
Netscape Communications	not operator (!)	writing, 123
Corporation, Java (usage), 49	effect, 189f usage, 188	Object (type), parameters, 926 Object box, size/indentation
Network client program,	Note-taking, programming,	(revision), 668
8421–8431	249	Object-oriented languages,
Network communication client/server network com- munication, 840f	null (instance variable), 941 null (place holder), 154 usage, 463	capabilities, 59 Object-oriented programming (OOP), 57–60
self-test questions, 844	null (statement), 260	classes, usage, 59
streams, usage, 839–840	null, usage, 941	design principles, 59
Network programming,	Null pointer	languages, knowledge, 59
implementation,	error message, 533	methodology, 60
840	exception, 463	objects, usage, 59
Network server program,	NullPointerException, 947	terminology, 58
8411–8421	num (integer variable), 869	Object program (object code),
new (unary operator), 312 new (operator), usage, 421 New line (n), 127f	Number adding, programming example, 694–695,	44 ObjectInputStream (class) methods, 819f–820f
newListNode, 945	6951–697l	usage, 820l–821l, 823
next (method), 962	conversion method, 159f	ObjectOutputStream (class),
next (variable), usage, 266	display, 154	811
nextInt (method), 313	numberOfAccounts (static	constructor, 811–812
nextLine(), 844	variable), 438	methods, 815f–816f
Node at the iterator, 958–959	incrementation, 440	usage, 812l–813l, 818
Node (class), 390	numberOfBabies (variable),	objectParam (parameter), 650
Nodes, 938	212	Object(s), 365–366
addition, 960f	numberOfBaskets, 92	action, knowledge, 655
class, example, 940l	numberOfCards	arrays
deletion, 961f	name, 94	creation, 537–538
inner classes, 950	variable, 94	differences, 926
linked list, 9511–952l	numberOfInvocations, 436	relationship, 546
names, absence, 947	numberOfItems, customer	base class function, 644
tail node, 965	entry, 921–922	behaviors, 58

Object(s) (continued)	est enscification 00	width/height 72
Object(s) (continued)	set, specification, 89	width/height, 73 Overflow, 182
characteristics/attributes, 58	Operator (=), usage, 546 Operators	Overloading, 466
	function, 118	
class definition, 58		application, 468–469
compareTo, invocation, 680	precedence, 208	automatic type conver-
instances, creation	list, 208f	sion, relationship,
(absence), 537–538	or (logical operator) (  ), 186	469–471
list, initial capacity, 923	expression, 186	avoidance, descriptive
members, 310	summary, 186–187	names (usage), 471
naming, 653	Oracle (class), 354	basics, 466–469
private instance variable,	demonstration program,	example, 467l
usage, 485	3561–3571	overriding, differences, 629
program reconstruction, 58	OrderItem[], 921	recursion, confusion
representation, 307	otherObject (variable),	(avoidance), 887
serialization, 831	384–385	return type, relationship,
software objects, actions,	Out of bounds array index,	472
52	526	screen output, sample, 467
state (change), set method	Out of bounds index (invalid	self-test questions,
(usage), 427	index), 525	473–474
string arrays, 551	Outer classes, 949	summary, 469, 471
types, 644	type parameter, 974	usage, 468
usage, 59	Output	Overridden method, calling,
writing, 835	display, algorithm, 456	637-638
Off-by-one errors, 278	formatting, case study,	summary, 638
Off-by-one loops, 277	455–457	Overriding, 628–629
One (computer state), 41	import requirement,	overloading, differences,
One-byte opcode, 47	absence, 54	629
One-dimensional array, 568	streams, 787f	P
indexed variables, 571	terminology, 789	
One return (statement), usage,	writing, 7921–7931	package (statement), 488
319	Output (string), 153	Package(s), 50, 487
OneWayNoRepeatsList (class),	OutputInputStream (class),	classes, usage, 488
550–551	811	importing, 488–489
methods, 554	outputStream (variable),	names
object, string arrays, 551	declaration, 795	example, 490f
screen output, sample, 553l	outputStream.println,	summary, 491
usage, example, 552l	795–796	self-test questions, 492
openFile (method), 807	outputStream.writeChar, 814	Paint (method)
OpenFileDemo.java, 807	outputStream.writeUTF, 816	body, statements, 71
Operands, 106	outStream, declaration, 791	Parameter-passing mecha-
comparison, results, 107	out.txt (text file), opening,	nism, 385
usage, usage, 109	790–791	Parameterized classes, 931
Operating system (OS), 43	Ovals	Parameters. See Actual
Operations	drawing, 71–72, 72f	parameters; Formal
order, determination, 110	StrokeArc method, 73	parameters

call-by-reference parameter,	set (methods), example,	comments, usage, 339
385	423l–425l	testing, consideration, 381
class type, 385	Picture element (pixel), 70	Prefix form, 118
generic types, 920	megapixel, 70	Prepare Input Process Output
lists, differences, 629	Picture file (conversion), 495	(PIPO), 116
local names, 334	Plus sign, 98	Primitive data type, 811
methods, 1010	Plus (+) symbol, usage, 121	Primitive-type parameters,
primitive type, 331–332,	pointLocation, 479	class-type parameters
383	Polygons	(differences), 386,
self-test questions, 337	closed figure, 596	3881, 389
summary, 334–335	drawing, 596–599	Primitive types, 89–91, 1008
substitution, 332–333	example, 596f	conversion, 450
term, usage, 335	usage, 597l	involvement, 95
Parent class, 627	Polyline, 596	list, 90f
Parentheses	example, 596f	names, lowercase letter,
omission, 109	usage, 597l	91
requirement, absence, 207	Polymorphism, 59–60, 652	Primitive values, writing,
usage, 109–110	application, 664	813-814
parseDouble (method), 452	demonstration, 654l-655l	print (method name),
parseInt, 153	dynamic binding, relation-	overloading, 468
Partially filled arrays, 558–559	ship, 656	printf, formatted output, 139
example, 558f	population (instance	println
self-help questions, 559–560	variables), 795	calls, 792
Path names	populationAmount, 328	predefined meaning, 92
full path name, 803	Portability, advantages, 9	print, contrast, 131
relative path name, 803	position (name), 944	statements, addition, 280
UNIX path name, 803	position (variable), reference	syntax, 131
usage, 803-804	(presence), 943	println (method)
Payne, Jonathan, 49	positiongetLink, 944	invocation, 130, 649
Percent (%) operator	Positive balance, display, 197	name, overloading, 468
applications, 108	possibleAverage, 538	usage, 130
behavior, 108	Postcondition comment,	PrintStream (class), 468
Person (class), 6231	338-339	method names,
default constructor,	Postfix form, 118	overloading, 468
revision, 637	Precedence rules, 109-110,	PrintWriter (constructor),
private instance variables,	207–208	790
631	example, 110f	throwing, 791
public methods, 626	Precondition comment,	PrintWriter (object),
Person (type), 645	338–339	795
Person [ ], 652–653	Predefined colors, usage, 222f	Privacy leaks, 481–485,
Pet (class)	Predefined exception classes,	948-949
class diagram, example,	721–722	arrays, impact, 549
422f	hierarchy, 737f	summary, 485
constructors, example,	predictPopulation (method),	private (modifiers), 340,
4231–4251	331, 334	342–343, 1000

Private instance variables, 343,	running, 42	Q
630	example, 42f	Quetelet, Adolphe, 201
demonstration, 343	self-documenting pro-	Queteres, ridorprie, 201
direct access, absence, 631	grams, 142	<b>.</b>
presence, 342l	silence, avoidance, 794	R
usage, 485	software, comparison, 43	RadioButton control, 759, 762
Private methods, 342, 359,	structure, 116	Ragged arrays, 575-577
630	System.exit, necessity,	Random access memory
calling, 4311–4331	156–157	(RAM), 39
direct access, absence, 631	text input/output, usage,	rating (value), 219
Private object, change,	157	readDouble (method), usage,
4831-4841	translation, disadvantages,	818
Private static variable, 435	44-9	Reading, 53
Problem	protected (modifiers), 1000	readInput (method), 323, 353
generalization, 897	Pseudocode, 61	usage, 466
situation, 712l	conversion, 270	readLong (method), usage,
problemMethod, definition	English/Java, mixture, 62	818
(overloading), 471	example, 113–114	readObject (method), 831
product (value), 260, 261	expression, 255	usage, 836
initializing value, 267	instruction, translation, 457	readUTF, 817
zero value, 266	usage, 269-270, 373	Receiving object, omission,
Programmer-defined	public (keyword), 318	358-359
exception class, 724l,	public (modifiers), 340,	Recompiling, necessity
729-730	342–343, 1000	(absence), 9
usage, 724l-726l	public, term (usage), 310-311	Rectangle (method), demon-
Programmers, 50	Public instance variables	stration, 676l-677l
interfaces, usage, 660	impact, 344	RectangleInterface, 670
Programming. See Event-	inheritance, 626	Rectangles (class), 3431-3441
driven programming	Public method (calling), con-	constructors, requirement,
advice, 95, 105	structor (usage), 430	670
arrays, usage, 550	public static final, 100–101,	examples, 345l, 672l-673l
basics, 57	145, 147	implementation, program-
classes, usage, 550	Public static variable, 435	ming (example),
inheritance, usage, 635	Public static void, 56, 88, 114	344-345
languages, 43-9	Purchase class	Rectangles (sample), 671f
knowledge, 59	example, 351l-353l	Rectangles, drawing
syntax, 63	programming, example,	algorithm, 670
recursion, usage, 888	350	interfaces, 667l
Programs, 39, 42–43	screen output, sample, 354	Rectangles (object),
control structures, 176	UML class diagram, usage,	referencing, 662
executing, 42	364f	Recurrent subtask, method
file, names, 794	usage, 353l-354l	(usage), 395l-397l
low-level languages, 47	Purchasing cost (determina-	Recursion, 868, 869
output, 494, 598	tion), code (usage),	demonstration, 875l
reading, 53	268	infinite recursion, 880-881

overloading, confusion (avoidance), 887 process, 876–878 screen output, sample, 875	overloaded name, 641 parameters, number (differences), 641–642	methods, 800f usage, 65, 96, 134–99 Scanner_Object_Name, 132 Scene Builder, 975–976
self-test questions, 887–888	Reset (button), clicking, 850 resetIteration (method), 958	application file, 976 controller file, 977
starting over, 888l–889l success, factors, 879	retrievalValue, 347 return (statement), 318	FXML file, 976 UI design with, 977f
usage, 872	Boolean expression, usage,	Scene graph, 390
Recursive algorithm, 869	378	Scientific notation, 98
Recursive call, 869, 874	presence, 463	s1.compareTo(s2), 192
completion, 877	possibility, 320-321	score (integer variable),
execution, 876	usage, 319	207–208
example, 878f	Return type	score (name), 94
Recursive countdown method, 870l	overloading, relationship, 472	Scores (computation), code (usage), 268–269
Recursive invocation, 869	summary, 573	Screen coordinate system,
Recursive method, 869	Returned values, 571–573	example, 71f
definition, 880-881	Roaches. See Bug infestation	Screen input/output, 129–140
iterative method, differ-	round (method), 447	self-test questions,
ences, 882–883	Run command, 47	140–141
storage space, usage, 884	Run-time error, 63	Screen output, 129–131
summary, 872 Recursive sorting method,	Run-time exception (unchecked	simple screen output, 98
programming exam-	exception), 737	Search. See Sequential search
ple, 898	exception), 131	Secondary memory (auxiliary
Reference(s), 365–366	S	memory), 39
returning, constructor	Sales associate class, example,	Secure programming, 182
(usage), 427f	530l-531l	seekAdvice (method), 354,
types, 366, 370	Sales report	359
array types, relationship,	case study, 530	Selection sort, 560–564
546 self-test questions, 380	program, example, 534l–536l	example, 561f implementation,
Regression testing, 380–381	screen output, sample, 536	563l–564l
Relative path name, 803	Sales reporter (class), class	selectionSort (method),
Remainder operator (modulus	diagram (usage), 532f	demonstration, 565l
operator), 108	SalesAssociate (class), objects	Self-documenting code,
remove (method), 962	(input method), 533	writing, 143
Repeated supers, avoidance, 643	SalesAssociate (objects), storage, 537–538	Self-documenting programs, 142
Reserved words (keywords),	Scanner	Semicolon
92	constructor, 799	absence, 212, 218
reset, 347	keyboard, 132	usage, 243, 260–261
reset (method), 626 definitions, 748–749	object, 181 Scanner (class), 55	Sentinel value, 270 usage, 268
delilitions, (40-74)	ocamiei (class), 33	usage, 200

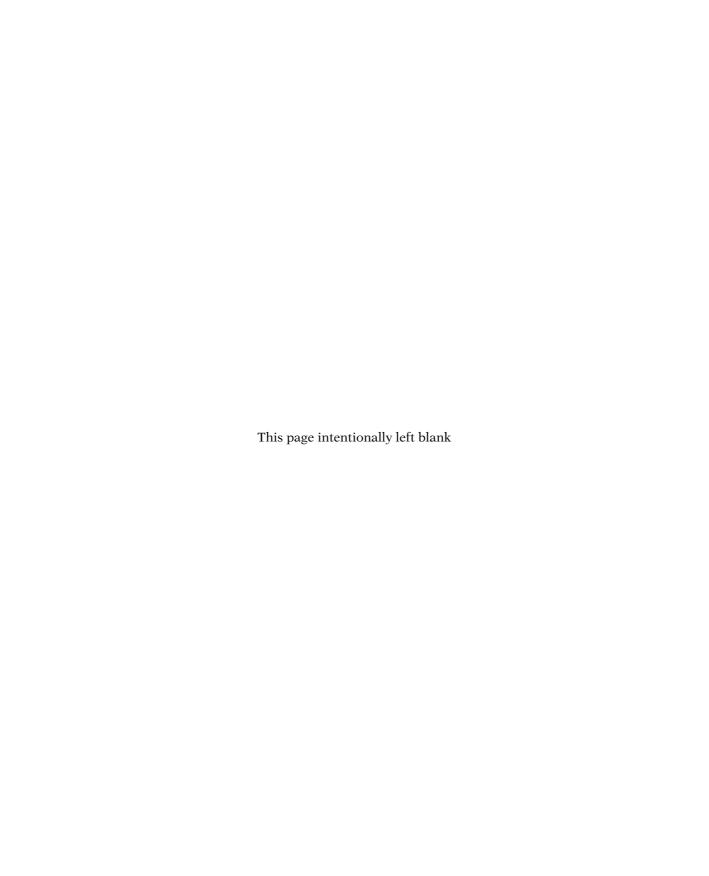
Sequential search, 566	example, 668l–669l	Spaces, importance, 109
Serial number, 836	ShapeBasics (class), 673	Special assignment operators,
Serializability, 836	Shapes (drawing interface),	usage, 111
Serializable (interface), 831	keyboard characters	Special-purpose assignment
Serializable class, properties,	(usage), 666l	operator, production,
836	short (integer type), 90	110
Serialization, 831	Short-circuit evaluation (lazy	Specialized assignment opera-
details, 835-836	evaluation), 209	tors, 110–111
serverSock.accept(), 844	showBalance, 440	self-test questions, 111–112
ServerSocket (class), 841	showConfirmDialog (meth-	Species (class)
set (method), 670, 925	od), arguments, 224	definition, 322l-323l
definitions, 478	showFirstLine (method), 850	example, 376l-377l
overloading, 478	showInputDialogue, 152	implementation, program-
Set methods (mutator	showNewBalance, 330	ming (example), 322
methods), 346-347	showOutput (method), 60	methods, usage, 3231-3241
private method, 430	showTable (method),	programming, example,
usage, 425	574-576	375
example, 428l	Silent program, 794	sample tests, 382l
setFill (method), 220	Simple input, 96	screen output, sample,
predefined colors, usage,	Simple screen output, 98	324
222f	Single character, single quote	Species (type), 835
self-test questions,	enclosure, 91	Species [ ], 837
223-224	Single quotes (' '), 91	SpeciesFirstTry, 324–325
usage, 222	spaces, appearance, 109	class, 326
setFont (method), 288-289	Size (array), 519	speciesOfTheMonth
setGraphic (method), 495,	skipSpaces, 675	instance variables,
496	Socket (class), 841	324-325
setHours (method), 582-583	Sockets	object, 341
completion, 578	objects, throwing, 844	speciesOfTheMonth.name,
setHgap (method), 586	usage, 840	341
setNumberBought (method),	Software, 39	SpeciesOfTheMonth.writeOut-
353	objects, 52	put(), 326
setOnMousePressed	action/interaction, 57–58	SpeciesSecondTry
(method), 765	programs, comparison, 43	class, instance variables,
setPet (method), 431	reuse, 64–65	341
setPrice (method), 353	Sort. See Selection sort	defining, 331
setResult (method),	Sorted array, 890	speed (variable), 88
definition, 748-749	search, algorithm,	Spelling rules, 88
setSelected (method), 759,	890-893	Spending spree
762	Sorting, 560	program, 273l–274l
setVgap (method), 586	algorithm, 564–566. See	programming example,
ShapeBase (abstract class),	also Interchange sorting	271–272
683l	algorithm	screen output, sample, 274
ShapeBasics (base class),	Source program (source	Spinner, 762–763
669-670	code), 44	Square brackets, usage, 520

Stack, 966	String (object)	lexicographic ordering,
overflow, 881	concatenation, 120–121	comparison, 192
StackPane layout pane, 584,	value, change, 125	methods, 121-123
585l	String (parameter), 806–807	name, 125
Stage (class), 390	String (type), 311	number conversion, 452
StartAngle, 73	String (value), 939	plus (+) symbol, usage, 121
Starting over, recursion,	String (variable), 121–122	processing, 123–126
8881–8891	String[ ], 542	sentence, 142
Statements (instructions),	String (instance variable),	substrings, 479
52	value, 728	testing, compareTo (usage),
Static members, non-static	String (type), base type, 923	191
members	String line, 463	writing, 816–817
interaction, 438	String next, 551	String_To_Convert, 159
mixing, 439l-440l	String_Expression, display,	strokeArc (method), 73
Static methods, 435	157–158	example, 74f
class, 437	StringLinkedList, definition,	syntax, 73
defining, 437	950	strokeOval ()method
example, 437l	StringLinkedListSelfCon-	syntax, 72
non-static methods, invo-	tained, 954	strokePolygon (method), 597
cation, 442	StringLinkedListWithIterator,	summary, 598-599
summary, 442	954, 963	strokePolyline (method), 597
types, 466	Strings, 1008	summary, 598–599
usage, 438l, 448f	display, 877	strokeRect (graphics method),
example, 441l	String(s)	596
Static variables, 435–442	==, usage, 191	Stubs, 464
class variables, relationship,	arrays, 551	Student (class), 626, 641–642
436	command, 122	equals (method), improve-
initialization, 436	comparison, 189–190	ment (example), 652l
summary, 436	self-test questions,	parameter, 642
Stopping case, 869, 877	193–194	usage, 627l
summary, 879	concatenation, 120-121	writeOutput, 638
Streams	constants/variables,	Student (derived class), 626
closing, 791–792	119–120	Student (type), 644
concept, 787–788	conversion	studentParam (parameter),
objects, throwing, 844	methods, 159f	650
opening, 806–807	static methods, usage,	Style, 141–147
overview, 787	451	rules, application, 148
summary, 788	empty string, 120	Subclass, 625
usage, 839-840	equality, testing, 190l	derived class, relationship,
variable, 790	screen output, sample,	628
String (class), 484	190	Subexpression, java evalua-
Java supply, 119	greeting, 122	tion, 209, 210
methods, 124f	index, 126	Subscript, 516
type, 89	indices, 123f	Subscripted variable, 516
usage, 125l	letters, conversion, 192–193	Substring, 122–123, 479

Subtasks	getCircumference, invoca-	summary, 793–794
program, impact, 532	tion, 663	data, reading, 798l
solving, 461	method, 314	I/O, 790–792
Subtraction operator, prece-	statement, 637	opening, 797
dence, 209	writing, 447	output, writing, 7921–7931
Suit (class), compiler creation,	systemsAreOK (boolean	reading, 798
485–486	variable), 206	ObjectInputStream,
sum, initialization, 537		usage, 823
Sun Microsystems, 48	T	summary, 799–800
super	Tab (t), 125f	self-test questions, 797,
calling, 728	table (array), 574	800
invocation, 635	table (array named), row/	usage, decision, 789
repetition, avoidance, 643	column indices, 568f	values, 789
usage, 635–636	Tail node, 965	TextArea (class), 591
Superclass, 625	target (element), 890-891	controls, demonstration of,
super(initialName), omission,	Tasks	592l–593l
640switch (state-	decomposition, 461	TextField (class), 591
ment), 212	specification, 455	controls, demonstration of,
controlling expression,	TCP/IP. See Transmission	5921–5931
complication,	Control Protocol and	theNextInteger, 312
214–215	Internet Protocol	this (keyword), 326–327
example, 213l-214	temperature.length, 522, 525	omission, 357
screen output, sample, 213	Temperatures, arrays,	self-test questions,
self-test questions,	5171–5181	327–328
216–218	example, 523l-524l	this (method), 637
summary, 215-216	screen output, sample, 518,	Thread-based solution,
usage, 275	524	844
Swing, 66	Ternary operator (conditional	Three-parameter constructor,
Syntactic variables, 89	operator), 204	invocation, 433
Syntax, 63	Test suite, 380	throw (statement), 714-718
error, 63	Testing, 63-64. See also	Throws (clause), 733-734
System class, 55	Bottom-up testing	throws (clause)
Java Class Library, 205	self-test questions, 64	summary, 736
usage, 65	TestProgram, one-line	usage, 735l
Systemexit	command (usage),	TimeBook (class), 578
necessity, 156–157	543	arrays, usage, 582f
return, 205	Text, drawing, 288-289	Timekeeping program,
Systemexit(0), 156	Text editors, comment high-	5781–5811
problem, 156	lighting, 142–143	Timeline class, 769,
Systemout (static object), 436	Text files, 788–789	7691–7711, 770
Systemout.print, 791	advantage, 789	times (method), definition,
System.out.printf (format	appending, 796-797	479
specifiers), 140f	character, representation,	To-do list, programming
System.out.println, 98, 119,	789	(example), 928
129, 711, 795	creation, 790-792	toArray (method), 953
		* * /

toDoList.START_POSITION	inference, 924	summary, 634
(named constant),	interfaces, relationship, 661	notation, class hierarchy,
553	name, 88	632f
toFile.writeObject, 836	usage, 968-969	Universal Modeling Language
Top-down design, 670	TYPE boolean, 205	(UML) class diagram,
toString (definition), 648-649	Type casting, 103-104	308, 364–365
toString (inherited method),	characters, 105	class outline, 308f
648	self-test questions, 105-106	usage, 364f
toString (method), 486, 648	syntax, 104	UNIX conventions, 804
defining, 796	Type parameter, 967	UNIX path name, 803
programming, 649	absence, 974	UNIX system, usage,
usage, 655-656	defining, 974-975	490–491
Transactions.txt (CSV file),	usage, 968l	UnknownOpException
808	u	(class), 751, 7511
Transmission Control Pro-		throwing, 751
tocol and Internet	Unary operator, 108	UnknownOpException
Protocol (TCP/IP),	new, usage (reasons), 312	(exception),
839-840	Unboxing, 450–451	declaration, 755
Tree, 966	Unchecked exception (run-	update (), 358
Triangle (class)	time exception), 737	update (method), 354, 359
definition, 673	Undergraduate (class),	Uppercase letters, usages, 92
demonstration, 676l–677l	641-642	Users, 50
example, 674l–675l	equals (method), defining, 643	errors, code (impact), 278
Triangles drawing, interfaces, 667l	type compatibility, 643	input, 742
sample, 667f	Undergraduate (type), 644	correctness, 888 interface, defining,
trimToSize, usage, 930	Underscore character, 92	747–748
try (block), 714, 733, 795	Unexceptional cases, 7521–754l	UTF. See Unicode Text Format
execution, cessation, 718	screen output, sample, 754	arr. see amedae reactormae
try-catch (blocks). See Nested	Unicode character set, 127, 1012	V
try-catch	self-test questions, 128	Value, 87. See also Returned
usage, 799	Unicode Text Format (UTF),	values
try-catch-finally (blocks), 746	817	assignation (instance vari-
tryToChange (method), 387	Uninitialized variable, 95	able), 522
Two-dimensional arrays, 567	Unintended infinite loops,	assignment, 102
length (instance variable),	277	garbage values, 553-554
574	Unit testing, case study,	increase, 118
usage, 569l-570l	380-381	return
Туре	Unit tests, 380	defining methods,
cast, change, 103	Universal Modeling Language	usage, 317-319
checking, dynamic binding	(UML)	recursive methods,
(interaction), 663	class hierarchy, details,	usage, 884, 884l-885l
compatibility, 643–646	633f, 640f	set, 94
self-test questions,	inheritance diagrams,	specification, 89
647-648	632-634	storage, 447

valueOf (method), 486 Variable names, 141–142 Variables, 52, 86–89, 119–120.  See also Boolean variables; Global variables; Local variables; Static variables bypassing, 645–646 class type, 366–369 behavior, 366 initialization, null method (usage), 463	Virtual machine, 9 void (keyword), 316 void (methods), 313, 316–317 calling, 315 defining, 316–317 return (statement), presence (possibility), 320–321 writing, 807 Volatile memory, 39 VPos (class), usage, 587	Wrapper (classes), 449–452.  See also Numeric wrapper classes default constructor, absence, 454 int (primitive type), 450 static methods, usage, 451 summary, 453–454 usage, 451 write (method), pseudocode (usage), 456 writeDouble (method), usage,
memory addresses, inclusion, 370	W	818 writeInt (method), 818
declaration, 88, 91	Web browser	writeLong (method), 818
assignment, combina-	development, Java (usage),	writeObject (method), 831
tion, 96	49	invocation, 836
for (statement), usage,	Well-encapsulated class, 361	writeOutput (methods),
261–262	definition, 362f	309-310
syntax, 89	example, 551	calling, 314
dummy variable, 75	while (loop), 239. See also	data, 314
initialization, 95, 266	do-while loop	definition, 642
names	action, 241f	inheritance, 628
selection, 88	cessation, 899	usage, 323
writing, 91	example, 240l	writePositive (method), 462
primitive types, 89	screen output, sample,	writeUTF
behavior, 366	240	details, 817–818
scope, 261–262	semantics/meaning, 242	method, 817
syntactic variables, 89	semicolon, usage, 261	Writing methods, 455
tracing, 279–280	for (statement), equiva-	X
DEBUG flag, usage, 280	lence, 257	
errors, presence, 279	zero iterations, 242	X-coordinate, 70, 71
println statements,	while (statement), 239.	Xlint (option), usage, 970
addition, 280	See also do-while	Y
self-test questions,	statement	
282–283	semantics, 243f	Y-coordinate, 70, 71
types, 436	summary, 241–242	Yes-or-no dialog box, 224f
uninitialized variable, 95	usage, 264 Whitespace, 123	Yes-or-no questions asking, 220
Vending machine change case study, 112–116	optional usage, 747–748	dialog box, usage, 224
change-making program,	usage, 137	dialog box, usage, 224
115l	Windowing input/output,	YES_OPTION, 225
coin numbers (computa-	change-making pro-	120_01 11014, 223
tion), algorithms	gram, 160, 161l	Z
(usage), 113	Windowing interfaces, 157	zero (computer state), 41
(40486), 113		zero (compater state), 11





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