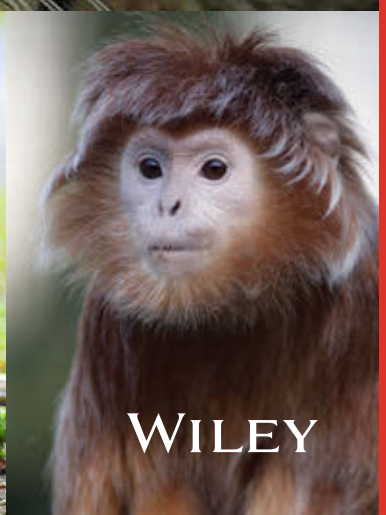
Cay Horstmann

Big Java

6/e

Early Objects

Includes Java 8 coverage



WILEY

Class Declaration

```
public class CashRegister
{
   private int itemCount;
   private double totalPrice;

   public void addItem(double price)
   {
      itemCount++;
      totalPrice = totalPrice + price;
   }
   . . .
}
```

Instance variables

Method

Selected Operators and Their Precedence

(See Appendix B for the complete list.)

`[]`	Array element access
`++ -- !`	Increment, decrement, Boolean *not*
`* / %`	Multiplication, division, remainder
`+ -`	Addition, subtraction
`< <= > >=`	Comparisons
`== !=`	Equal, not equal
`&&`	Boolean *and*
`||`	Boolean *or*
`=`	Assignment

Conditional Statement

```
if (floor >= 13)
{
   actualFloor = floor - 1;
}
else if (floor >= 0)
{
   actualFloor = floor;
}
else
{
   System.out.println("Floor negative");
}
```

Condition

Executed when condition is true

Second condition (optional)

Executed when all conditions are false (optional)

Variable and Constant Declarations

```
int cansPerPack = 6;

final double CAN_VOLUME = 0.335;
```

Type

Name

Initial value

Method Declaration

```
public static double cubeVolume(double sideLength)
{
   double volume = sideLength * sideLength * sideLength;
   return volume;
}
```

Modifiers

Return type

Parameter type and name

Exits method and returns result.

Mathematical Operations

`Math.pow(x, y)`	Raising to a power x^y
`Math.sqrt(x)`	Square root $\sqrt{x}$
`Math.log10(x)`	Decimal log $\log_{10}(x)$
`Math.abs(x)`	Absolute value $\lvert x \rvert$

`Math.sin(x)`
`Math.cos(x)`
`Math.tan(x)`
	Sine, cosine, tangent of x (x in radians)

String Operations

```
String s = "Hello";
int n = s.length(); // 5
char ch = s.charAt(1); // 'e'
String t = s.substring(1, 4); // "ell"
String u = s.toUpperCase(); // "HELLO"
if (u.equals("HELLO")) ... // Use equals, not ==
for (int i = 0; i < s.length(); i++)
{
   char ch = s.charAt(i);
   Process ch
}
```

Loop Statements

```
while (balance < TARGET)
{
   year++;
   balance = balance * (1 + rate / 100);
}
```

Condition

Executed while condition is true

```
for (int i = 0; i < 10; i++)
{
   System.out.println(i);
}
```

Initialization

Condition

Update

```
do
{
   System.out.print("Enter a positive integer: ");
   input = in.nextInt();
}
while (input <= 0);
```

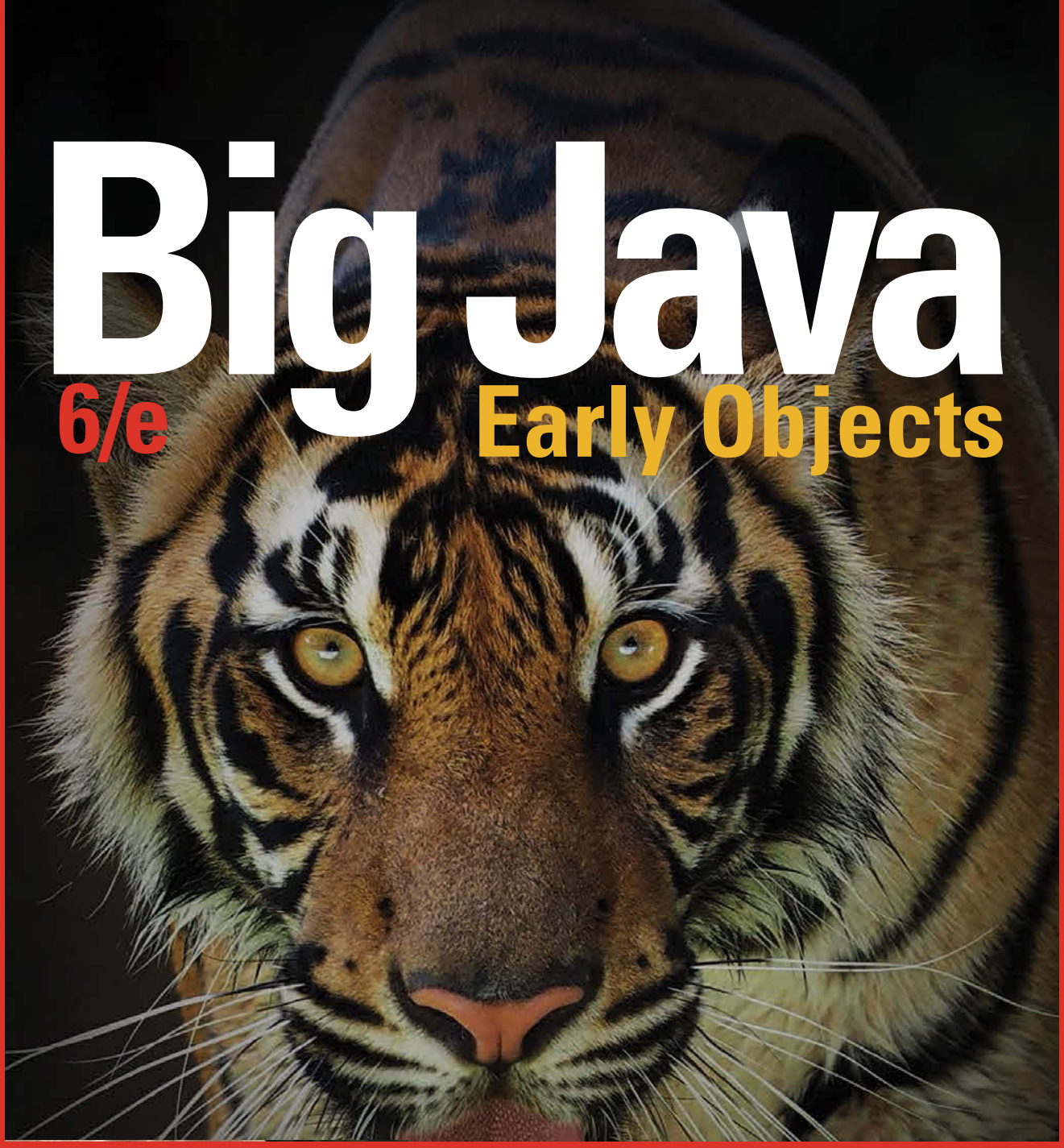
Loop body executed at least once

```
for (double value : values)
{
   sum = sum + value;
}
```

Set to a new element in each iteration

An array or collection

Executed for each element



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San Jose State University

WILEY

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This book was set in 10.5/12 Stempel Garamond LT Std by Publishing Services, and printed and bound by Quad Graphics/Versailles. The cover was printed by Quad Graphics/Versailles.

This book is printed on acid-free paper. ∞

ISBN 978-1-119-05628-7

ISBN-BRV 978-1-119-05644-7

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

PREFACE

This book is an introduction to Java and computer programming that focuses on the essentials—and on effective learning. The book is designed to serve a wide range of student interests and abilities and is suitable for a first course in programming for computer scientists, engineers, and students in other disciplines. No prior programming experience is required, and only a modest amount of high school algebra is needed.

Here are the key features of this book:

Start objects early, teach object orientation gradually.

In Chapter 2, students learn how to use objects and classes from the standard library. Chapter 3 shows the mechanics of implementing classes from a given specification. Students then use simple objects as they master branches, loops, and arrays. Object-oriented design starts in Chapter 8. This gradual approach allows students to use objects throughout their study of the core algorithmic topics, without teaching bad habits that must be un-learned later.

Guidance and worked examples help students succeed.

Beginning programmers often ask "How do I start? Now what do I do?" Of course, an activity as complex as programming cannot be reduced to cookbook-style instructions. However, step-by-step guidance is immensely helpful for building confidence and providing an outline for the task at hand. "How To" guides help students with common programming tasks. Additional Worked Examples are available online.

Problem solving strategies are made explicit.

Practical, step-by-step illustrations of techniques help students devise and evaluate solutions to programming problems. Introduced where they are most relevant, these strategies address barriers to success for many students. Strategies included are:

- Algorithm Design (with pseudocode)
- Tracing Objects
- First Do It By Hand (doing sample calculations by hand)
- Flowcharts
- Selecting Test Cases
- Hand-Tracing
- Storyboards
- Solve a Simpler Problem First
- Adapting Algorithms
- Discovering Algorithms by Manipulating Physical Objects
- Patterns for Object Data
- Thinking Recursively
- Estimating the Running Time of an Algorithm

Practice makes perfect.

Of course, programming students need to be able to implement nontrivial programs, but they first need to have the confidence that they can succeed. This book contains a substantial number of self-check questions at the end of each section. "Practice It" pointers suggest exercises to try after each section. And additional practice opportunities, including automatically-graded programming exercises and skill-oriented multiple-choice questions, are available online.

A visual approach motivates the reader and eases navigation.

Photographs present visual analogies that explain the nature and behavior of computer concepts. Step-by-step figures illustrate complex program operations. Syntax boxes and example tables present a variety of typical and special cases in a compact format. It is easy to get the "lay of the land" by browsing the visuals, before focusing on the textual material.

Visual features help the reader with navigation.

Focus on the essentials while being technically accurate.

An encyclopedic coverage is not helpful for a beginning programmer, but neither is the opposite—reducing the material to a list of simplistic bullet points. In this book, the essentials are presented in digestible chunks, with separate notes that go deeper into good practices or language features when the reader is ready for the additional information. You will not find artificial over-simplifications that give an illusion of knowledge.

Reinforce sound engineering practices.

A multitude of useful tips on software quality and common errors encourage the development of good programming habits. The optional testing track focuses on test-driven development, encouraging students to test their programs systematically.

Provide an optional graphics track.

Graphical shapes are splendid examples of objects. Many students enjoy writing programs that create drawings or use graphical user interfaces. If desired, these topics can be integrated into the course by using the materials at the end of Chapters 2, 3, and 10.

Engage with optional science and business exercises.

End-of-chapter exercises are enhanced with problems from scientific and business domains. Designed to engage students, the exercises illustrate the value of programming in applied fields.

New to This Edition

Updated for Java 8

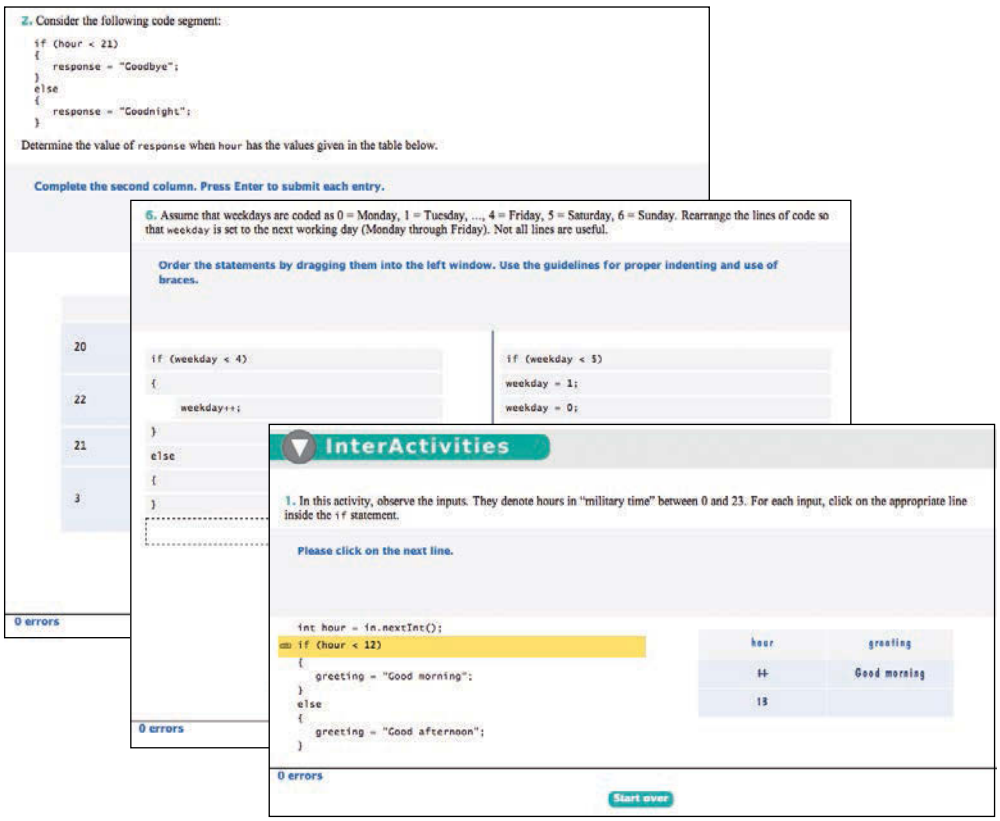
Java 8 introduces many exciting features, and this edition has been updated to take advantage of them. Interfaces can now have default and static methods, and lambda expressions make it easy to provide instances of interfaces with a single method. The chapter on interfaces and the sections that cover sorting have been updated to make these innovations optionally available. A new chapter covers the Java 8 stream library and its applications for "big data" processing.

In addition, Java 7 features such as the `try`-with-resources statement are now integrated into the text. Chapter 21 covers the utilities provided by the `Paths` and `Files` classes.

Interactive Learning

Additional interactive content is available that integrates with this text and immerses students in activities designed to foster in-depth learning. Students don't just watch

animations and code traces, they work on generating them. The activities provide instant feedback to show students what they did right and where they need to study more. To find out more about how to make this content available in your course, visit `http://wiley.com/go/bjeo6interactivities`.



"CodeCheck" is an innovative online service that students can use to work on programming problems. You can assign exercises that have already been prepared, and you can easily add your own. Visit `http://codecheck.it` to learn more and to try it out.

A Tour of the Book

The book can be naturally grouped into four parts, as illustrated by Figure 1 on page vi. The organization of chapters offers the same flexibility as the previous edition; dependencies among the chapters are also shown in the figure.

Part A: Fundamentals (Chapters 1–7)

Chapter 1 contains a brief introduction to computer science and Java programming. Chapter 2 shows how to manipulate objects of predefined classes. In Chapter 3, you will build your own simple classes from given specifications. Fundamental data types, branches, loops, and arrays are covered in Chapters 4–7.

Part B: Object-Oriented Design (Chapters 8–12)

Chapter 8 takes up the subject of class design in a systematic fashion, and it introduces a very simple subset of the UML notation. The discussion of polymorphism and inheritance is split into two chapters. Chapter 9 covers inheritance and polymorphism, whereas Chapter 10 covers interfaces. Exception handling and basic file input/output are covered in Chapter 11. The exception hierarchy gives a useful example for

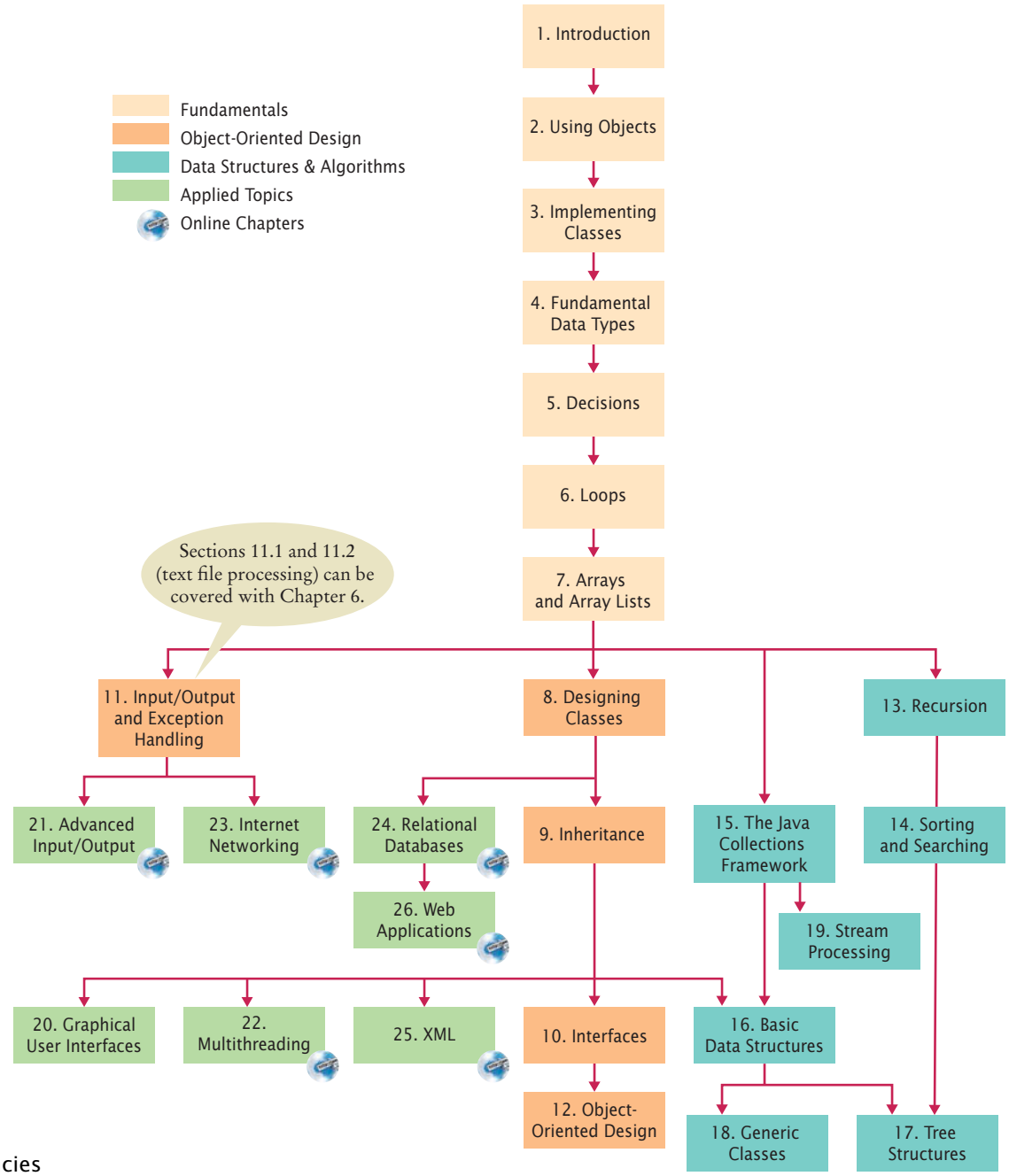


Figure 1
Chapter Dependencies

inheritance. Chapter 12 contains an introduction to object-oriented design, including two significant case studies.

Part C: Data Structures and Algorithms (Chapters 13–19)

Chapters 13 through 19 contain an introduction to algorithms and data structures, covering recursion, sorting and searching, linked lists, binary trees, and hash tables. These topics may be outside the scope of a one-semester course, but can be covered as desired after Chapter 7 (see Figure 1). Recursion, in Chapter 13, starts with simple examples and progresses to meaningful applications that would be difficult to implement iteratively. Chapter 14 covers quadratic sorting algorithms as well as merge sort, with an informal introduction to big-Oh notation. Each data structure is presented in the context of the standard Java collections library. You will learn the essential abstractions of the standard library (such as iterators, sets, and maps) as well as the performance characteristics of the various collections. Chapter 18 introduces Java generics. This chapter is suitable for advanced students who want to implement their own generic classes and methods. Finally, Chapter 19 introduces the Java 8 streams library and shows how it can be used to analyze complex real-world data.

Part D: Applied Topics (Chapters 20–26)

Chapters 20 through 26 cover Java programming techniques that definitely go beyond a first course in Java (21–26 are on the book's companion site). Although, as already mentioned, a comprehensive coverage of the Java library would span many volumes, many instructors prefer that a textbook should give students additional reference material valuable beyond their first course. Some institutions also teach a second-semester course that covers more practical programming aspects such as database and network programming, rather than the more traditional in-depth material on data structures and algorithms. This book can be used in a two-semester course to give students an introduction to programming fundamentals and broad coverage of applications. Alternatively, the material in the final chapters can be useful for student projects. The applied topics include graphical user-interface design, advanced file handling, multithreading, and those technologies that are of particular interest to server-side programming: networking, databases, XML, and web applications. The Internet has made it possible to deploy many useful applications on servers, often accessed by nothing more than a browser. This server-centric approach to application development was in part made possible by the Java language and libraries, and today, much of the industrial use of Java is in server-side programming.

Appendices

Many instructors find it highly beneficial to require a consistent style for all assignments. If the style guide in Appendix E conflicts with instructor sentiment or local customs, however, it is available in electronic form so that it can be modified. Appendices F–J are available on the Web.

A. The Basic Latin and Latin-1 Subsets of Unicode
B. Java Operator Summary
C. Java Reserved Word Summary
D. The Java Library
E. Java Language Coding Guidelines
F. Tool Summary
G. Number Systems
H. UML Summary
I. Java Syntax Summary
J. HTML Summary

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Big Java is also available in an electronic eBook format with three key advantages:

- The price is significantly lower than for the printed book.
- The eBook contains all material in the printed book plus the web chapters and worked examples in one easy-to-browse format.
- You can customize the eBook to include your choice of chapters.

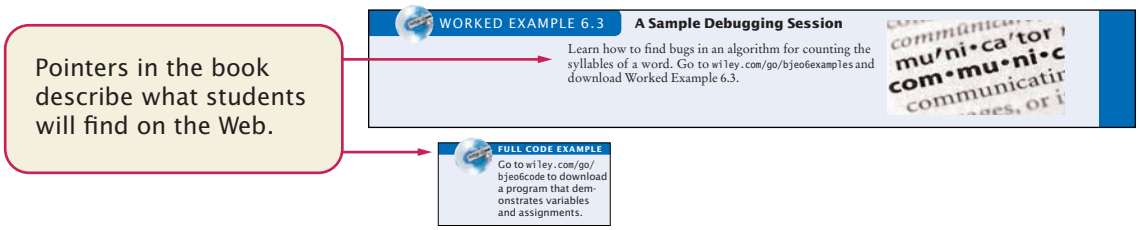
The interactive edition of *Big Java* adds even more value by integrating a wealth of interactive exercises into the eBook. See `http://wiley.com/go/bjeo6interactivities` to find out more about this new format.

Please contact your Wiley sales rep for more information about any of these options or check `www.wiley.com/college/horstmann` for available versions.

Web Resources

This book is complemented by a complete suite of online resources. Go to `www.wiley.com/college/horstmann` to visit the online companion sites, which include

- Source code for all example programs in the book and its Worked Examples, plus additional example programs.
- Worked Examples that apply the problem-solving steps in the book to other realistic examples.
- Lecture presentation slides (for instructors only).
- Solutions to all review and programming exercises (for instructors only).
- A test bank that focuses on skills, not just terminology (for instructors only). This extensive set of multiple-choice questions can be used with a word processor or imported into a course management system.
- "CodeCheck" assignments that allow students to work on programming problems presented in an innovative online service and receive immediate feedback. Instructors can assign exercises that have already been prepared, or easily add their own.



Walkthrough of the Learning Aids

The pedagogical elements in this book work together to focus on and reinforce key concepts and fundamental principles of programming, with additional tips and detail organized to support and deepen these fundamentals. In addition to traditional features, such as chapter objectives and a wealth of exercises, each chapter contains elements geared to today's visual learner.

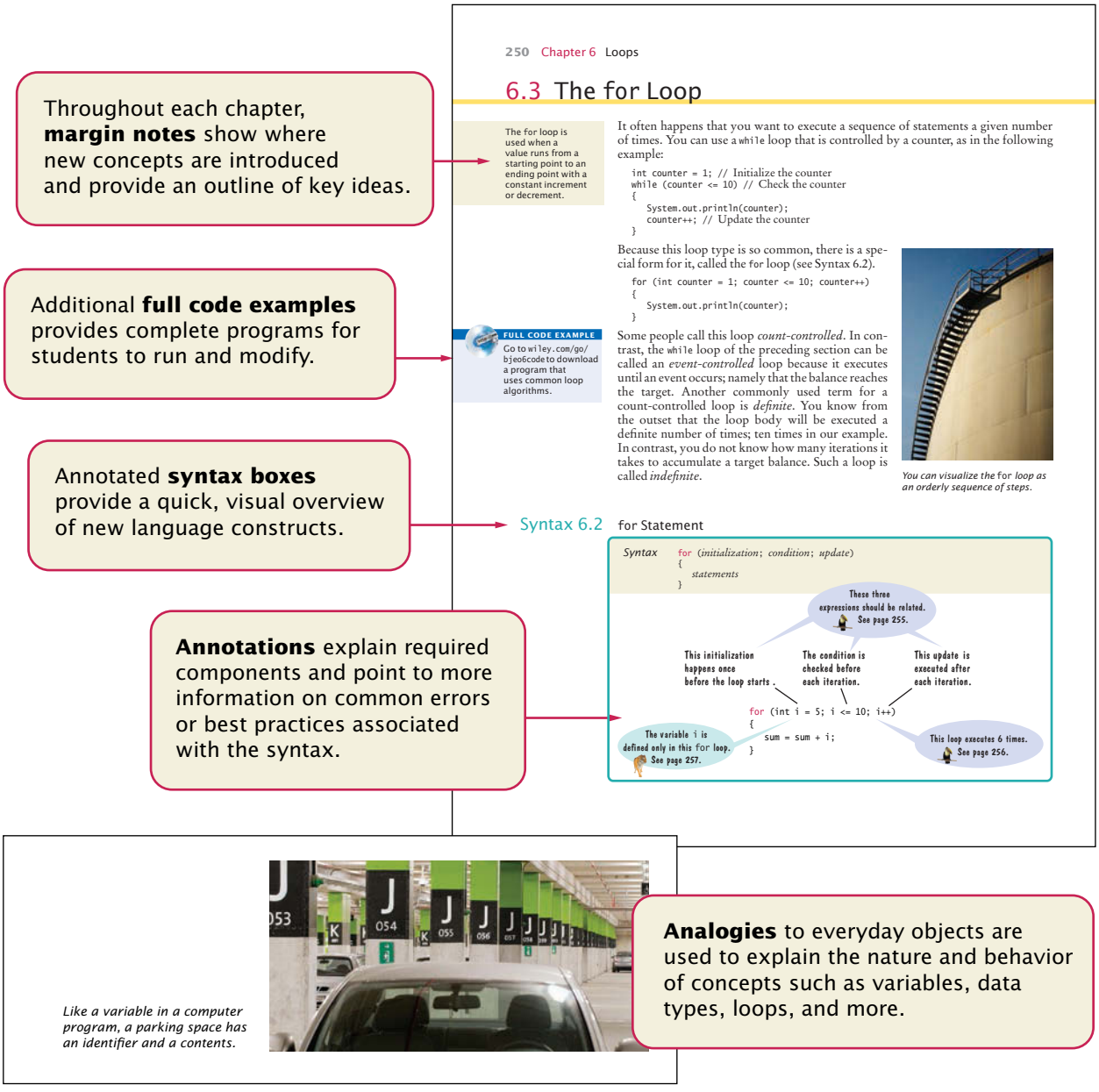
Throughout each chapter, **margin notes** show where new concepts are introduced and provide an outline of key ideas.

Additional **full code examples** provides complete programs for students to run and modify.

Annotated **syntax boxes** provide a quick, visual overview of new language constructs.

Annotations explain required components and point to more information on common errors or best practices associated with the syntax.

Analogies to everyday objects are used to explain the nature and behavior of concepts such as variables, data types, loops, and more.



250 Chapter 6 Loops

6.3 The for Loop

The for loop is used when a value runs from a starting point to an ending point with a constant increment or decrement.

It often happens that you want to execute a sequence of statements a given number of times. You can use a `while` loop that is controlled by a counter, as in the following example:

```
int counter = 1; // Initialize the counter
while (counter <= 10) // Check the counter
{
   System.out.println(counter);
   counter++; // Update the counter
}
```

Because this loop type is so common, there is a special form for it, called the for loop (see Syntax 6.2).

```
for (int counter = 1; counter <= 10; counter++)
{
   System.out.println(counter);
}
```

FULL CODE EXAMPLE
Go to wiley.com/go/bjeo6code to download a program that uses common loop algorithms.

Some people call this loop *count-controlled*. In contrast, the `while` loop of the preceding section can be called an *event-controlled* loop because it executes until an event occurs; namely that the balance reaches the target. Another commonly used term for a count-controlled loop is *definite*. You know from the outset that the loop body will be executed a definite number of times; ten times in our example. In contrast, you do not know how many iterations it takes to accumulate a target balance. Such a loop is called *indefinite*.

You can visualize the for *loop as an orderly sequence of steps.*

Syntax 6.2 for Statement

Syntax

```
for (initialization; condition; update)
{
   statements
}
```

These three expressions should be related. See page 255.

This initialization happens once before the loop starts.

The condition is checked before each iteration.

This update is executed after each iteration.

```
for (int i = 5; i <= 10; i++)
{
   sum = sum + i;
}
```

The variable i is defined only in this for loop. See page 257.

This loop executes 6 times. See page 256.

Like a variable in a computer program, a parking space has an identifier and a contents.

Memorable photos reinforce analogies and help students remember the concepts.

In the same way that there can be a street named "Main Street" in different cities, a Java program can have multiple variables with the same name.

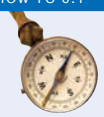
Problem Solving sections teach techniques for generating ideas and evaluating proposed solutions, often using pencil and paper or other artifacts. These sections emphasize that most of the planning and problem solving that makes students successful happens away from the computer.

Now how does that help us with our problem, switching the first and the second half of the array?

Let's put the first coin into place, by swapping it with the fifth coin. However, as Java programmers, we will say that we swap the coins in positions 0 and 4:

Next, we swap the coins in positions 1 and 5:

HOW TO 6.1 **Writing a Loop**



This How To walks you through the process of implementing a loop statement. We will illustrate the steps with the following example problem.

Problem Statement Read twelve temperature values (one for each month) and display the number of the month with the highest temperature. For example, according to `worldclimate.com`, the average maximum temperatures for Death Valley are (in order by month, in degrees Celsius):

18.2 22.6 26.4 31.1 36.6 42.2 45.7 44.5 40.2 33.1 24.2 17.6

In this case, the month with the highest temperature (45.7 degrees Celsius) is July, and the program should display 7.

How To guides give step-by-step guidance for common programming tasks, emphasizing planning and testing. They answer the beginner's question, "Now what do I do?" and integrate key concepts into a problem-solving sequence.

Step 1 Decide what work must be done *inside* the loop.

Every loop needs to do some kind of repetitive work, such as

- Reading another item.
- Updating a value (such as a bank balance or total).
- Incrementing a counter.

If you can't figure out what needs to go inside the loop, start by writing down the steps that

WORKED EXAMPLE 6.1 **Credit Card Processing**

Learn how to use a loop to remove spaces from a credit card number. Go to `wiley.com/go/bjeo6examples` and download Worked Example 6.1.

Worked Examples apply the steps in the How To to a different example, showing how they can be used to plan, implement, and test a solution to another programming problem.

Table 1 Variable Declarations in Java

Variable Name	Comment
`int width = 20;`	Declares an integer variable and initializes it with 20.
`int perimeter = 4 * width;`	The initial value need not be a fixed value. (Of course, `width` must have been previously declared.)
`String greeting = "Hi!";`	This variable has the type `String` and is initialized with the string "Hi".
`height = 30;`	**Error:** The type is missing. This statement is not a declaration but an assignment of a new value to an existing variable—see Section 2.2.5.
`int width = "20";`	**Error:** You cannot initialize a number with the string "20". (Note the quotation marks.)
`int width;`	Declares an integer variable without initializing it. This can be a cause for errors—see Common Error 2.1 on page 40.
`int width, height;`	Declares two integer variables in a single statement. In this book, we will declare each variable in a separate statement.

Example tables support beginners with multiple, concrete examples. These tables point out common errors and present another quick reference to the section's topic.

This means "compute the value of `width + 10` ❶ and store that value in the variable `width` ❷" (see Figure 4).

In Java, it is not a problem that the variable `width` is used on both sides of the = symbol. Of course, in mathematics, the equation *width* = *width* + 10 has no solution.

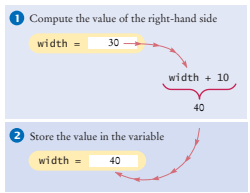
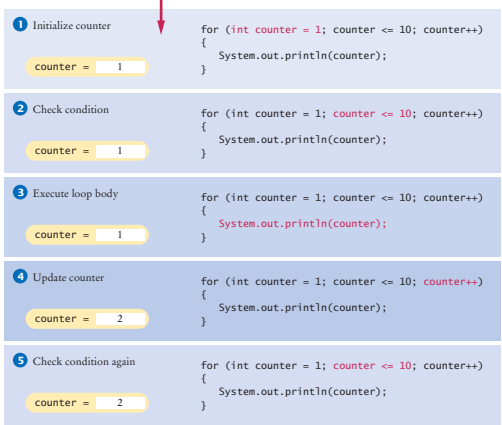


Figure 4
Executing the Statement `width = width + 10`

Progressive figures trace code segments to help students visualize the program flow. Color is used consistently to make variables and other elements easily recognizable.

Figure 3
Execution of a for Loop



The `for` loop neatly groups the initialization, condition, and update expressions together. However, it is important to realize that these expressions are not executed together (see Figure 3).

- The initialization is executed once, before the loop is entered. ❶
- The condition is checked before each iteration. ❷ ❺

Self-check exercises at the end of each section are designed to make students think through the new material—and can spark discussion in lecture.

SELF CHECK

11. Write the `for` loop of the `Investment` class as a `while` loop.
12. How many numbers does this loop print?

```
for (int n = 10; n >= 0; n--)
{
   System.out.println(n);
}
```

13. Write a `for` loop that prints all even numbers between 10 and 20 (inclusive).
14. Write a `for` loop that computes the sum of the integers from 1 to `n`.

Practice It Now you can try these exercises at the end of the chapter: R6.4, R6.10, E6.8, E6.12.

Optional **science and business exercises** engage students with realistic applications of Java.

■■ **Business E6.17** *Currency conversion.* Write a program that first asks the user to type today's price for one dollar in Japanese yen, then reads U.S. dollar values and converts each to yen. Use 0 as a sentinel.

■ **Science P6.15** Radioactive decay of radioactive materials can be modeled by the equation $A = A_0 e^{-t(\log 2/b)}$, where A is the amount of the material at time t, A_0 is the amount at time 0, and b is the half-life.

Technetium-99 is a radioisotope that is used in imaging of the brain. It has a half-life of 6 hours. Your program should display the relative amount A / A_0 in a patient body every hour for 24 hours after receiving a dose.

section_1/Investment.java

```
/**
   A class to monitor the growth of an investment that
   accumulates interest at a fixed annual rate.
*/
public class Investment
{
   private double balance;
   private double rate;
   private int year;

   /**
      Constructs an Investment object from a starting balance and
      interest rate.
      @param aBalance the starting balance
      @param aRate the interest rate in percent
   */
   public Investment(double aBalance, double aRate)
   {
      balance = aBalance;
      rate = aRate;
      year = 0;
   }

   /**
      Keeps accumulating interest until a target balance has
      been reached.
      @param targetBalance the desired balance
   */
```

Program listings are carefully designed for easy reading, going well beyond simple color coding. Methods are set off by a subtle outline.

Common Errors describe the kinds of errors that students often make, with an explanation of why the errors occur, and what to do about them.

Programming Tips explain good programming practices, and encourage students to be more productive with tips and techniques such as hand-tracing.

Special Topics present optional topics and provide additional explanation of others.

Java 8 Notes provide detail about new features in Java 8.

Computing & Society presents social and historical topics on computing—for interest and to fulfill the "historical and social context" requirements of the ACM/IEEE curriculum guidelines.

Common Error 7.4

Length and Size

Unfortunately, the Java syntax for determining the number of elements in an array, an array list, and a string is not at all consistent. It is a common error to confuse these. You just have to remember the correct syntax for every data type.

Data Type	Number of Elements
Array	`a.length`
Array list	`a.size()`
String	`a.length()`

Programming Tip 5.5

Hand-Tracing

A very useful technique for understanding whether a program works correctly is called *hand-tracing*. You simulate the program's activity on a sheet of paper. You can use this method with pseudocode or Java code.

Get an index card, a cocktail napkin, or whatever sheet of paper is within reach. Make a column for each variable. Have the program code ready. Use a marker, such as a paper clip, to mark the current statement. In your mind, execute statements one at a time. Every time the value of a variable changes, cross out the old value and write the new value below the old one.

For example, let's trace the `getTax` method with the data from the program run above.

When the `TaxReturn` object is constructed, the `income` instance variable is set to 80,000 and `status` is set to `MARRIED`. Then the `getTax` method is called. In lines 31 and 32 of `TaxReturn.java`, `tax1` and `tax2` are initialized to 0.

Hand-tracing helps you understand whether a program works correctly.

```
29 public double getTax()
30 {
31    double tax1 = 0;
32    double tax2 = 0;
33
```

income	status	tax1	tax2
80000	MARRIED	0	0

Because `status` is not `SINGLE`, we move to the `else` branch of the outer if statement (line 46).

```
34    if (status == SINGLE)
35    {
36       if (income <= RATE1_SINGLE_LIMIT)
37       {
38          tax1 = RATE1 * income;
39       }
40       else
41       {
42          tax1 = RATE1 * RATE1_SINGLE_LIMIT;
43          tax2 = RATE2 * (income - RATE1_SINGLE_LIMIT);
```

Special Topic 11.2

File Dialog Boxes

In a program with a graphical user interface, you will want to use a file dialog box (such as the one shown in the figure below) whenever the users of your program need to pick a file. The `JFileChooser` class implements a file dialog box for the Swing user-interface toolkit.

The `JFileChooser` class has many options to fine-tune the display of the dialog box, but in its most basic form it is quite simple: Construct a file chooser object; then call the `showOpenDialog` or `showSaveDialog` method. Both methods show the same dialog box, but the button for selecting a file is labeled "Open" or "Save", depending on which method you call.

For better placement of the dialog box on the screen, you can specify the user-interface component over which to pop up the dialog box. If you don't care where the dialog box pops up, you can simply pass `null`. The `showOpenDialog` and `showSaveDialog` methods return either `JFileChooser.APPROVE_OPTION`, if the user has chosen a file, or `JFileChooser.CANCEL_OPTION`, if the user canceled the selection. If a file was chosen, then you can call the `getSelectedFile` method to obtain a `File` object that describes the file. Here is a complete example:

```
JFileChooser chooser = new JFileChooser();
```

Java 8 Note 10.4

Lambda Expressions

In the preceding section, you saw how to use interfaces for specifying variations in behavior. The `average` method needs to measure each object, and it does so by calling the `measure` method of the supplied `Measurer` object.

Unfortunately, the caller of the `average` method has to do a fair amount of work; namely, to define a class that implements the `Measurer` interface and to construct an object of that class. Java 8 has a convenient shortcut for these steps, provided that the interface has a *single abstract method*. Such an interface is called a *functional interface* because its purpose is to define a single function. The `Measurer` interface is an example of a functional interface.

To specify that single function, you can use a *lambda expression*, an expression that defines the parameters and return value of a method in a compact notation. Here is an example:

```
(Object obj) -> ((BankAccount) obj).getBalance()
```

This expression defines a function that, given an object, casts it to a `BankAccount` and returns the balance.

Computing & Society 1.1 Computers Are Everywhere

When computers were first invented in the 1940s, a computer filled an entire room. The photo below shows the ENIAC (*e*lectronic *n*umerical *i*nte*g*rator *a*nd *c*omputer), completed in 1946 at the University of Pennsylvania. The ENIAC was used by the military to compute the trajectories of projectiles. Nowadays, computing facilities of search engines, Internet shops, and social networks fill huge buildings called data centers. At the other end of the spectrum, computers are all around us. Your cell phone has a computer inside, as do many credit cards and fare cards for public transit. A modern car has several computers—to control the engine, brakes, lights, and the radio.

The advent of ubiquitous computing changed many aspects of our lives. Factories used to employ people to do repetitive assembly tasks that are today carried out by computer-controlled robots, operated by a few people who know how to work with those computers. Books, music, and movies are nowadays often consumed on computers, and computers are almost always involved in their production. The book that you are reading right now could not have been written without computers.

This transit card contains a computer.

Acknowledgments

Many thanks to Bryan Gambrel, Don Fowley, Jenny Welter, Jessy Moor, Jennifer Lartz, Billy Ray, and Tim Lindner at John Wiley & Sons, and Vickie Piercey at Publishing Services for their help with this project. An especially deep acknowledgment and thanks goes to Cindy Johnson for her hard work, sound judgment, and amazing attention to detail.

I am grateful to Jose Cordova, *The University of Louisiana at Monroe*, Suzanne Dietrich, *Arizona State University,West Campus*, Mike Domaratzki, *University of Manitoba*, Guy Helmer, *Iowa State University,* Peter Lutz, *Rochester Institute of Technology*, Carolyn Schauble, *Colorado State University*, Brent Seales, *University of Kentucky*, and Brent Wilson, *George Fox University* for their excellent contributions to the supplementary materials.

Many thanks to the individuals who reviewed the manuscript for this edition, made valuable suggestions, and brought an embarrassingly large number of errors and omissions to my attention. They include:

Robin Carr, *Drexel University*
Gerald Cohen, *The Richard Stockton College of New Jersey*
Aaron Keen, *California Polytechnic State University, San Luis Obispo*
Aurelia Smith, *Columbus State University*
Aakash Taneja, *The Richard Stockton College of New Jersey*
Craig Tanis, *University of Tennessee at Chattanooga*
Katherine Winters, *University of Tennessee at Chattanooga*

Every new edition builds on the suggestions and experiences of prior reviewers and users. I am grateful for the invaluable contributions these individuals have made:

Eric Aaron, *Wesleyan University*
James Agnew, *Anne Arundel Community College*
Tim Andersen, *Boise State University*
Ivan Bajic, *San Diego State University*
Greg Ballinger, *Miami Dade College*
Ted Bangay, *Sheridan Institute of Technology*
Ian Barland, *Radford University*
George Basham, *Franklin University*
Jon Beck, *Truman State University*
Sambit Bhattacharya, *Fayetteville State University*
Rick Birney, *Arizona State University*
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Matt Boutell, *Rose-Hulman Institute of Technology*
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John Bundy, *DeVry University Chicago*
Robert P. Burton, *Brigham Young University*
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Jerry Cain, *Stanford University*
Adam Cannon, *Columbia University*
Michael Carney, *Finger Lakes Community College*
Christopher Cassa, *Massachusetts Institute of Technology*
Nancy Chase, *Gonzaga University*
Dr. Suchindran S. Chatterjee, *Arizona State University*
Archana Chidanandan, *Rose-Hulman Institute of Technology*
Vincent Cicirello, *The Richard Stockton College of New Jersey*
Teresa Cole, *Boise State University*
Deborah Coleman, *Rochester Institute of Technology*
Tina Comston, *Franklin University*
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Jose Cordova, *University of Louisiana, Monroe*
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Curt Jones, *Bloomsburg University*
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Ronald Krawitz, *DeVry University*
Norm Krumpe, *Miami University Ohio*
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Kevin Lillis, *St. Ambrose University*
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Hong Lin, *DeVry University*
Kathy Liszka, *University of Akron*
Hunter Lloyd, *Montana State University*
Youmin Lu, *Bloomsburg University*
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Patricia McDermott-Wells, *Florida International University*
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Charlie Shu, *Franklin University*
Jeffrey Six, *University of Delaware*
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Ken Slonneger, *University of Iowa*
Donald Smith, *Columbia College*
Joslyn A. Smith, *Florida International University*
Stephanie Smullen, *University of Tennessee, Chattanooga*
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CHAPTER 1

INTRODUCTION

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CHAPTER GOALS

To learn about computers and programming

To compile and run your first Java program

To recognize compile-time and run-time errors

To describe an algorithm with pseudocode

CHAPTER CONTENTS

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Just as you gather tools, study a project, and make a plan for tackling it, in this chapter you will gather up the basics you need to start learning to program. After a brief introduction to computer hardware, software, and programming in general, you will learn how to write and run your first Java program. You will also learn how to diagnose and fix programming errors, and how to use pseudocode to describe an algorithm—a step-by-step description of how to solve a problem—as you plan your computer programs.

1.1 Computer Programs

Computers execute very basic instructions in rapid succession.

You have probably used a computer for work or fun. Many people use computers for everyday tasks such as electronic banking or writing a term paper. Computers are good for such tasks. They can handle repetitive chores, such as totaling up numbers or placing words on a page, without getting bored or exhausted.

The flexibility of a computer is quite an amazing phenomenon. The same machine can balance your checkbook, lay out your term paper, and play a game. In contrast, other machines carry out a much narrower range of tasks; a car drives and a toaster toasts. Computers can carry out a wide range of tasks because they execute different programs, each of which directs the computer to work on a specific task.

A computer program is a sequence of instructions and decisions.

The computer itself is a machine that stores data (numbers, words, pictures), interacts with devices (the monitor, the sound system, the printer), and executes programs. A **computer program** tells a computer, in minute detail, the sequence of steps that are needed to fulfill a task. The physical computer and peripheral devices are collectively called the **hardware**. The programs the computer executes are called the **software**.

Today's computer programs are so sophisticated that it is hard to believe that they are composed of extremely primitive instructions. A typical instruction may be one of the following:

- Put a red dot at a given screen position.
- Add up two numbers.
- If this value is negative, continue the program at a certain instruction.

The computer user has the illusion of smooth interaction because a program contains a huge number of such instructions, and because the computer can execute them at great speed.

Programming is the act of designing and implementing computer programs.

The act of designing and implementing computer programs is called **programming**. In this book, you will learn how to program a computer—that is, how to direct the computer to execute tasks.

To write a computer game with motion and sound effects or a word processor that supports fancy fonts and pictures is a complex task that requires a team of many highly-skilled programmers. Your first programming efforts will be more mundane. The concepts and skills you learn in this book form an important foundation, and you should not be disappointed if your first programs do not rival the sophisticated software that is familiar to you. Actually, you will find that there is an immense thrill even in simple programming tasks. It is an amazing experience to see the computer precisely and quickly carry out a task that would take you hours of drudgery, to

make small changes in a program that lead to immediate improvements, and to see the computer become an extension of your mental powers.

1. What is required to play music on a computer?
2. Why is a CD player less flexible than a computer?
3. What does a computer user need to know about programming in order to play a video game?

1.2 The Anatomy of a Computer

To understand the programming process, you need to have a rudimentary understanding of the building blocks that make up a computer. We will look at a personal computer. Larger computers have faster, larger, or more powerful components, but they have fundamentally the same design.

The central processing unit (CPU) performs program control and data processing.

At the heart of the computer lies the **central processing unit (CPU)** (see Figure 1). The inside wiring of the CPU is enormously complicated. For example, the Intel Core processor (a popular CPU for personal computers at the time of this writing) is composed of several hundred million structural elements, called *transistors*.

The CPU performs program control and data processing. That is, the CPU locates and executes the program instructions; it carries out arithmetic operations such as addition, subtraction, multiplication, and division; it fetches data from external memory or devices and places processed data into storage.

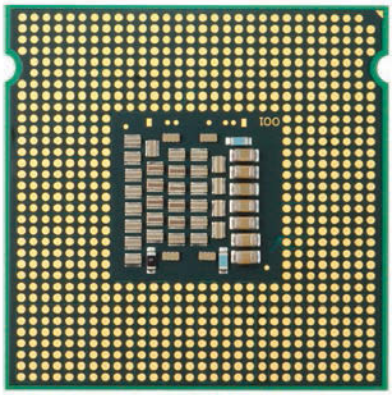

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Figure 1 Central Processing Unit

Storage devices include memory and secondary storage.

There are two kinds of storage. Primary storage, or memory, is made from electronic circuits that can store data, provided they are supplied with electric power. **Secondary storage**, usually a **hard disk** (see Figure 2) or a solid-state drive, provides slower and less expensive storage that persists without

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Figure 2 A Hard Disk

electricity. A hard disk consists of rotating platters, which are coated with a magnetic material. A solid-state drive uses electronic components that can retain information without power, and without moving parts.

To interact with a human user, a computer requires peripheral devices. The computer transmits information (called *output*) to the user through a display screen, speakers, and printers. The user can enter information (called *input*) for the computer by using a keyboard or a pointing device such as a mouse.

Some computers are self-contained units, whereas others are interconnected through **networks**. Through the network cabling, the computer can read data and programs from central storage locations or send data to other computers. To the user of a networked computer, it may not even be obvious which data reside on the computer itself and which are transmitted through the network.

Figure 3 gives a schematic overview of the architecture of a personal computer. Program instructions and data (such as text, numbers, audio, or video) reside in secondary storage or elsewhere on the network. When a program is started, its instructions are brought into memory, where the CPU can read them. The CPU reads and executes one instruction at a time. As directed by these instructions, the CPU reads data, modifies it, and writes it back to memory or secondary storage. Some program instructions will cause the CPU to place dots on the display screen or printer or to vibrate the speaker. As these actions happen many times over and at great speed, the human user will perceive images and sound. Some program instructions read user input from the keyboard, mouse, touch sensor, or microphone. The program analyzes the nature of these inputs and then executes the next appropriate instruction.

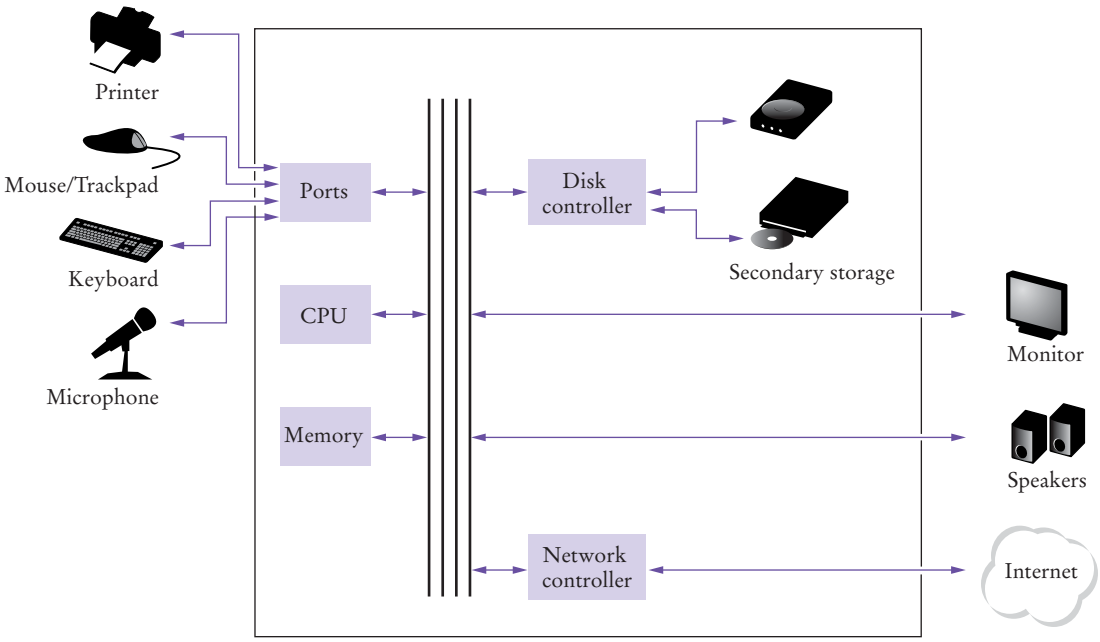

Figure 3 Schematic Design of a Personal Computer

4. Where is a program stored when it is not currently running?
5. Which part of the computer carries out arithmetic operations, such as addition and multiplication?
6. A modern smartphone is a computer, comparable to a desktop computer. Which components of a smartphone correspond to those shown in Figure 3?

Practice It Now you can try these exercises at the end of the chapter: R1.2, R1.3.

Computing & Society 1.1 Computers Are Everywhere

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The advent of ubiquitous computing changed many aspects of our lives. Factories used to employ people to do repetitive assembly tasks that are today carried out by computer-controlled robots, operated by a few people who know how to work with those computers. Books, music, and movies nowadays are often consumed on computers, and computers are almost always involved in their production. The book that you are reading right now could not have been written without computers.

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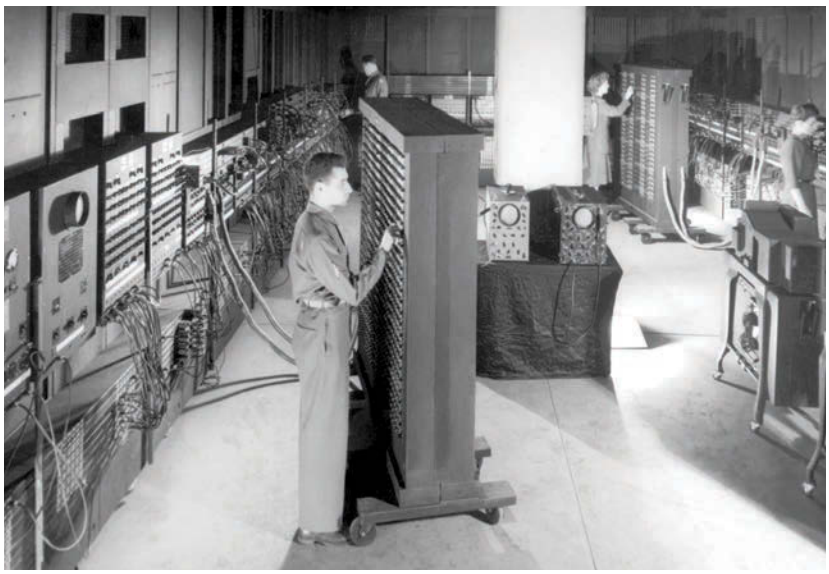
This transit card contains a computer.

Knowing about computers and how to program them has become an essential skill in many careers. Engineers design computer-controlled cars and medical equipment that preserve lives. Computer scientists develop programs that help people come together to support social causes. For example, activists used social networks to share videos showing abuse by repressive regimes, and this information was instrumental in changing public opinion.

As computers, large and small, become ever more embedded in our everyday lives, it is increasingly important for everyone to understand how they work, and how to work with them. As you use this book to learn how to program a computer, you will develop a good understanding of computing fundamentals that will make you a more informed citizen and, perhaps, a computing professional.



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The ENIAC

1.3 The Java Programming Language

James Sullivan/Getty Images.

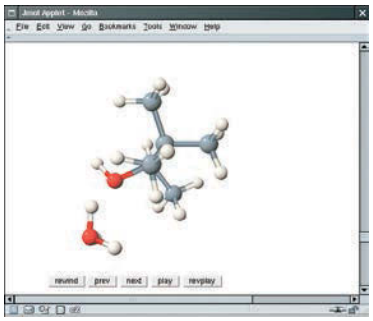
James Gosling

In order to write a computer program, you need to provide a sequence of instructions that the CPU can execute. A computer program consists of a large number of simple CPU instructions, and it is tedious and error-prone to specify them one by one. For that reason, **high-level programming languages** have been created. In a high-level language, you specify the actions that your program should carry out. A **compiler** translates the high-level instructions into the more detailed instructions (called **machine code**)required by the CPU. Many different programming languages have been designed for different purposes.

In 1991, a group led by James Gosling and Patrick Naughton at Sun Microsystems designed a programming language, code-named "Green", for use in consumer devices, such as intelligent television "set-top" boxes. The language was designed to be simple, secure, and usable for many different processor types. No customer was ever found for this technology.

Java was originally designed for programming consumer devices, but it was first successfully used to write Internet applets.

Gosling recounts that in 1994 the team realized, "We could write a really cool browser. It was one of the few things in the client/server mainstream that needed some of the weird things we'd done: architecture neutral, real-time, reliable, secure." Java was introduced to an enthusiastic crowd at the SunWorld exhibition in 1995, together with a browser that ran **applets**—Java code that can be located anywhere on the Internet. The figure at right shows a typical example of an applet.



An Applet for Visualizing Molecules

Since then, Java has grown at a phenomenal rate. Programmers have embraced the language because it is easier to use than its closest rival, C++. In addition, Java has a rich **library** that makes it possible to write portable programs that can bypass proprietary operating systems—a feature that was eagerly sought by those who wanted to be independent of those proprietary systems and was bitterly fought by their vendors. A "micro edition" and an "enterprise edition" of the Java library allow Java programmers to target hardware ranging from smart cards to the largest Internet servers.

Java was designed to be safe and portable, benefiting both Internet users and students.

Because Java was designed for the Internet, it has two attributes that make it very suitable for beginners: safety and portability.

Table 1 Java Versions (since Version 1.0 in 1996)

Version	Year	Important New Features	Version	Year	Important New Features
1.1	1997	Inner classes	5	2004	Generic classes, enhanced for loop, auto-boxing, enumerations, annotations
1.2	1998	Swing, Collections framework	6	2006	Library improvements
1.3	2000	Performance enhancements	7	2011	Small language changes and library improvements
1.4	2002	Assertions, XML support	8	2014	Function expressions, streams, new date/time library

Java was designed so that anyone can execute programs in their browser without fear. The safety features of the Java language ensure that a program is terminated if it tries to do something unsafe. Having a safe environment is also helpful for anyone learning Java. When you make an error that results in unsafe behavior, your program is terminated and you receive an accurate error report.

The other benefit of Java is portability. The same Java program will run, without change, on Windows, UNIX, Linux, or Macintosh. In order to achieve portability, the Java compiler does not translate Java programs directly into CPU instructions. Instead, compiled Java programs contain instructions for the Java **virtual machine**, a program that simulates a real CPU. Portability is another benefit for the beginning student. You do not have to learn how to write programs for different platforms.

Java programs are distributed as instructions for a virtual machine, making them platform-independent.

At this time, Java is firmly established as one of the most important languages for general-purpose programming as well as for computer science instruction. However, although Java is a good language for beginners, it is not perfect, for three reasons.

Because Java was not specifically designed for students, no thought was given to making it really simple to write basic programs. A certain amount of technical machinery is necessary to write even the simplest programs. This is not a problem for professional programmers, but it can be a nuisance for beginning students. As you learn how to program in Java, there will be times when you will be asked to be satisfied with a preliminary explanation and wait for more complete detail in a later chapter.

Java has been extended many times during its life—see Table 1. In this book, we assume that you have Java version 7 or later.

Java has a very large library. Focus on learning those parts of the library that you need for your programming projects.

Finally, you cannot hope to learn all of Java in one course. The Java language itself is relatively simple, but Java contains a vast set of *library packages* that are required to write useful programs. There are packages for graphics, user-interface design, cryptography, networking, sound, database storage, and many other purposes. Even expert Java programmers cannot hope to know the contents of all of the packages—they just use those that they need for particular projects.

Using this book, you should expect to learn a good deal about the Java language and about the most important packages. Keep in mind that the central goal of this book is not to make you memorize Java minutiae, but to teach you how to think about programming.

7. What are the two most important benefits of the Java language?
8. How long does it take to learn the entire Java library?

Practice It Now you can try this exercise at the end of the chapter: R1.5.

1.4 Becoming Familiar with Your Programming Environment

Set aside time to become familiar with the programming environment that you will use for your class work.

Many students find that the tools they need as programmers are very different from the software with which they are familiar. You should spend some time making yourself familiar with your programming environment. Because computer systems vary widely, this book can only give an outline of the steps you need to follow. It is a good idea to participate in a hands-on lab, or to ask a knowledgeable friend to give you a tour.

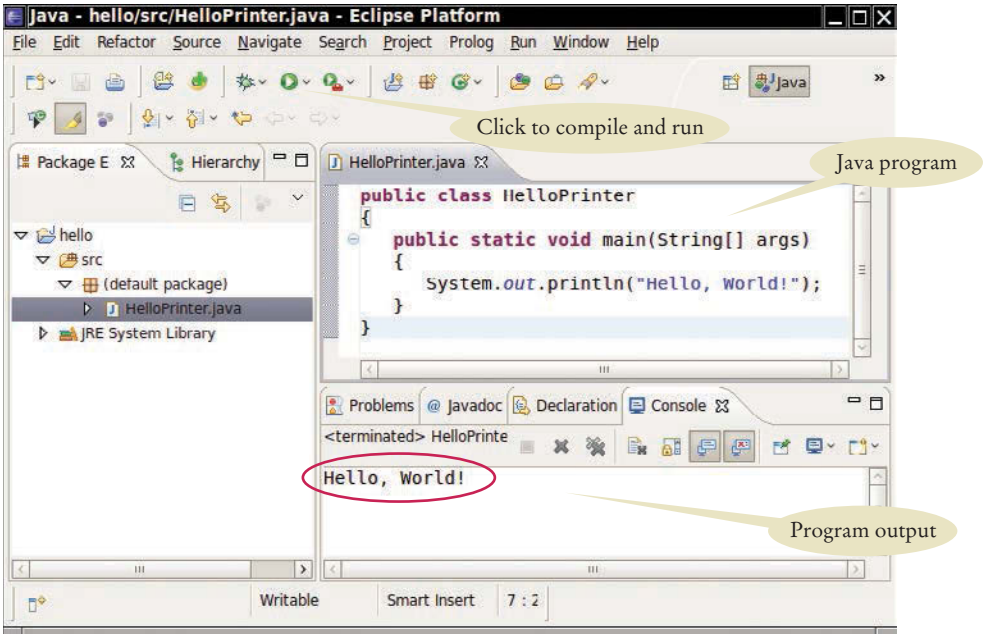


Figure 4 Running the `HelloPrinter` Program in an Integrated Development Environment

An editor is a program for entering and modifying text, such as a Java program.

Step 1 Start the Java development environment.

Computer systems differ greatly in this regard. On many computers there is an **integrated development environment** in which you can write and test your programs. On other computers you first launch an **editor**, a program that functions like a word processor, in which you can enter your Java instructions; you then open a *console window* and type commands to execute your program. You need to find out how to get started with your environment.

Step 2 Write a simple program.

The traditional choice for the very first program in a new programming language is a program that displays a simple greeting: "Hello, World!". Let us follow that tradition. Here is the "Hello, World!" program in Java:

```
public class HelloPrinter
{
   public static void main(String[] args)
   {
      System.out.println("Hello, World!");
   }
}
```

We will examine this program in the next section.

No matter which programming environment you use, you begin your activity by typing the program statements into an editor window.

Create a new file and call it `HelloPrinter.java`, using the steps that are appropriate for your environment. (If your environment requires that you supply a project name in addition to the file name, use the name `hello` for the project.) Enter the program instructions *exactly* as they are given above. Alternatively, locate the electronic copy in this book's companion code and paste it into your editor.

Figure 5
Running the `HelloPrinter` Program in a Console Window

Java is case sensitive. You must be careful about distinguishing between upper- and lowercase letters.

As you write this program, pay careful attention to the various symbols, and keep in mind that Java is **case sensitive**. You must enter upper- and lowercase letters exactly as they appear in the program listing. You cannot type `MAIN` or `PrintLn`. If you are not careful, you will run into problems—see Common Error 1.2 on page 15.

Step 3 Run the program.

The process for running a program depends greatly on your programming environment. You may have to click a button or enter some commands. When you run the test program, the message

```
Hello, World!
```

will appear somewhere on the screen (see Figures 4 and 5).

The Java compiler translates source code into class files that contain instructions for the Java virtual machine.

In order to run your program, the Java compiler translates your **source files** (that is, the statements that you wrote) into *class files*. (A class file contains instructions for the Java virtual machine.) After the compiler has translated your **source code** into virtual machine instructions, the virtual machine executes them. During execution, the virtual machine accesses a library of pre-written code, including the implementations of the `System` and `PrintStream` classes that are necessary for displaying the program's output. Figure 6 summarizes the process of creating and running a Java program. In some programming environments, the compiler and virtual machine are essentially invisible to the programmer—they are automatically executed whenever you ask to run a Java program. In other environments, you need to launch the compiler and virtual machine explicitly.

Step 4 Organize your work.

As a programmer, you write programs, try them out, and improve them. You store your programs in **files**. Files are stored in **folders** or **directories**. A folder can contain

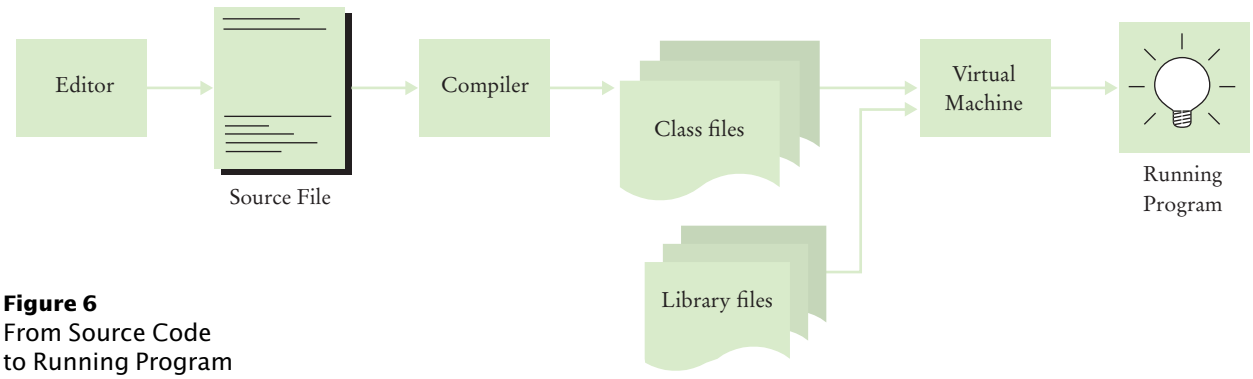


Figure 6
From Source Code to Running Program

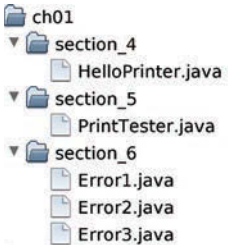


Figure 7
A Folder Hierarchy

files as well as other folders, which themselves can contain more files and folders (see Figure 7). This hierarchy can be quite large, and you need not be concerned with all of its branches. However, you should create folders for organizing your work. It is a good idea to make a separate folder for your programming coursework. Inside that folder, make a separate folder for each program.

Some programming environments place your programs into a default location if you don't specify a folder yourself. In that case, you need to find out where those files are located.

Be sure that you understand where your files are located in the folder hierarchy. This information is essential when you submit files for grading, and for making backup copies (see Programming Tip 1.1).

9. Where is the `HelloPrinter.java` file stored on your computer?
10. What do you do to protect yourself from data loss when you work on programming projects?

Practice It Now you can try this exercise at the end of the chapter: R1.6.

Programming Tip 1.1

Backup Copies

You will spend many hours creating and improving Java programs. It is easy to delete a file by accident, and occasionally files are lost because of a computer malfunction. Retyping the contents of lost files is frustrating and time-consuming. It is therefore crucially important that you learn how to safeguard files and get in the habit of doing so *before* disaster strikes. Backing up files on a memory stick is an easy and convenient storage method for many people. Another increasingly popular form of backup is Internet file storage. Here are a few pointers to keep in mind:

Develop a strategy for keeping backup copies of your work before disaster strikes.

- *Back up often.* Backing up a file takes only a few seconds, and you will hate yourself if you have to spend many hours recreating work that you could have saved easily. I recommend that you back up your work once every thirty minutes.
- *Rotate backups.* Use more than one directory for backups, and rotate them. That is, first back up onto the first directory. Then back up onto the second directory. Then use the third, and then go back to the first. That way you always have three recent backups. If your recent changes made matters worse, you can then go back to the older version.
- *Pay attention to the backup direction.* Backing up involves copying files from one place to another. It is important that you do this right—that is, copy from your work location to the backup location. If you do it the wrong way, you will overwrite a newer file with an older version.
- *Check your backups once in a while.* Double-check that your backups are where you think they are. There is nothing more frustrating than to find out that the backups are not there when you need them.
- *Relax, then restore.* When you lose a file and need to restore it from a backup, you are likely to be in an unhappy, nervous state. Take a deep breath and think through the recovery process before you start. It is not uncommon for an agitated computer user to wipe out the last backup when trying to restore a damaged file.

1.5 Analyzing Your First Program

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In this section, we will analyze the first Java program in detail. Here again is the source code:

section_5/HelloPrinter.java

```
1  public class HelloPrinter
2  {
3     public static void main(String[] args)
4     {
5        // Display a greeting in the console window
6
7        System.out.println("Hello, World!");
8     }
9  }
```

The line

```
public class HelloPrinter
```

indicates the declaration of a **class** called `HelloPrinter`.

Classes are the fundamental building blocks of Java programs.

Every Java program consists of one or more classes. We will discuss classes in more detail in Chapters 2 and 3.

The word `public` denotes that the class is usable by the "public". You will later encounter `private` features.

In Java, every source file can contain at most one public class, and the name of the public class must match the name of the file containing the class. For example, the class `HelloPrinter` must be contained in a file named `HelloPrinter.java`.

Every Java application contains a class with a `main` method. When the application starts, the instructions in the `main` method are executed.

The construction

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

declares a **method** called `main`. A method contains a collection of programming instructions that describe how to carry out a particular task. Every Java application must have a **`main` method**. Most Java programs contain other methods besides `main`, and you will see in Chapter 3 how to write other methods.

The term `static` is explained in more detail in Chapter 8, and the meaning of `String[] args` is covered in Chapter 11. At this time, simply consider

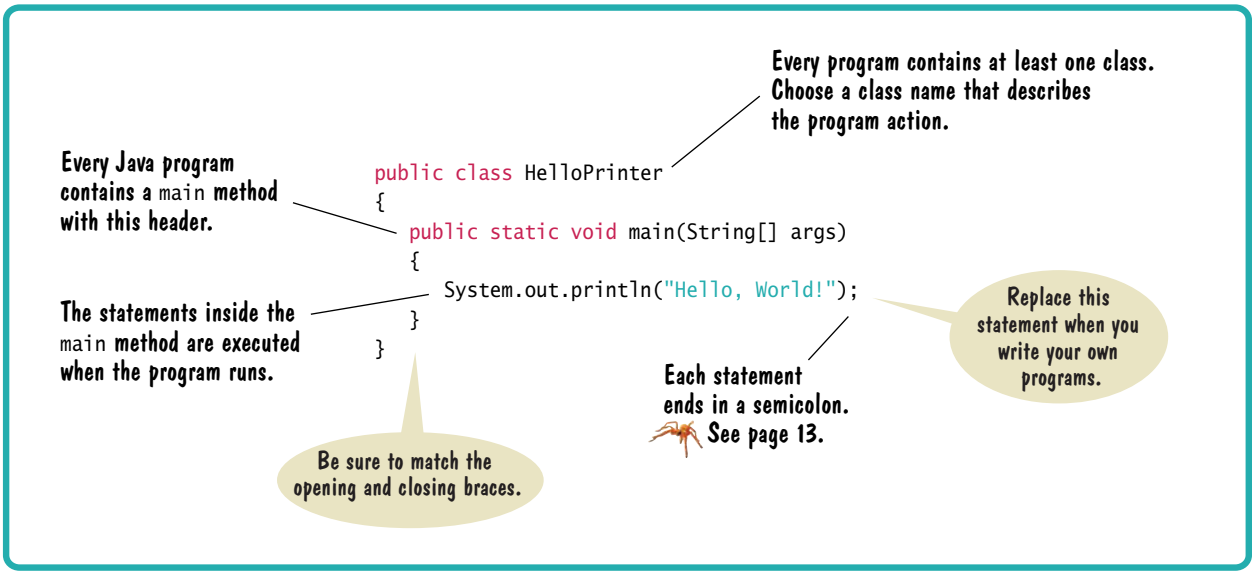
Each class contains declarations of methods. Each method contains a sequence of instructions.

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

as a part of the "plumbing" that is required to create a Java program. Our first program has all instructions inside the `main` method of the class.

The `main` method contains one or more instructions called **statements**. Each statement ends in a semicolon (;). When a program runs, the statements in the `main` method are executed one by one.

Syntax 1.1 Java Program



In our example program, the `main` method has a single statement:

```
System.out.println("Hello, World!");
```

This statement prints a line of text, namely "Hello, World!". In this statement, we *call* a method which, for reasons that we will not explain here, is specified by the rather long name `System.out.println`.

We do not have to implement this method—the programmers who wrote the Java library already did that for us. We simply want the method to perform its intended task, namely to print a value.

A method is called by specifying the method and its arguments.

Whenever you call a method in Java, you need to specify

1. The method you want to use (in this case, `System.out.println`).
2. Any values the method needs to carry out its task (in this case, `"Hello, World!"`). The technical term for such a value is an **argument**. Arguments are enclosed in parentheses. Multiple arguments are separated by commas.

A sequence of characters enclosed in quotation marks

```
"Hello, World!"
```

A string is a sequence of characters enclosed in quotation marks.

is called a **string**. You must enclose the contents of the string inside quotation marks so that the compiler knows you literally mean `"Hello, World!"`. There is a reason for this requirement. Suppose you need to print the word *main*. By enclosing it in quotation marks, `"main"`, the compiler knows you mean the sequence of characters `m a i n`, not the method named `main`. The rule is simply that you must enclose all text strings in quotation marks, so that the compiler considers them plain text and does not try to interpret them as program instructions.

You can also print numerical values. For example, the statement

```
System.out.println(3 + 4);
```

evaluates the expression 3 + 4 and displays the number 7.

The `System.out.println` method prints a string or a number and then starts a new line. For example, the sequence of statements

```
System.out.println("Hello");
System.out.println("World!");
```

prints two lines of text:

```
Hello
World!
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program to demonstrate print commands.

There is a second method, `System.out.print`, that you can use to print an item without starting a new line. For example, the output of the two statements

```
System.out.print("00");
System.out.println(3 + 4);
```

is the single line

```
007
```

SELF CHECK

11. How do you modify the `HelloPrinter` program to greet you instead?

12. How would you modify the `HelloPrinter` program to print the word "Hello" vertically?

13. Would the program continue to work if you replaced line 7 with this statement?

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

14. What does the following set of statements print?

```
System.out.print("My lucky number is");
System.out.println(3 + 4 + 5);
```

15. What do the following statements print?

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

Practice It Now you can try these exercises at the end of the chapter: R1.7, R1.8, E1.5, E1.8.

Common Error 1.1

Omitting Semicolons

In Java every statement must end in a semicolon. Forgetting to type a semicolon is a common error. It confuses the compiler, because the compiler uses the semicolon to find where one statement ends and the next one starts. The compiler does not use line breaks or closing braces to recognize the end of statements. For example, the compiler considers

```
System.out.println("Hello")
System.out.println("World!");
```

a single statement, as if you had written

```
System.out.println("Hello") System.out.println("World!");
```

Then it doesn't understand that statement, because it does not expect the word `System` following the closing parenthesis after `"Hello"`.

The remedy is simple. Scan every statement for a terminating semicolon, just as you would check that every English sentence ends in a period. However, do not add a semicolon at the end of `public class Hello` or `public static void main`. These lines are not statements.

1.6 Errors

Experiment a little with the `HelloPrinter` program. What happens if you make a typing error such as

```
System.ou.println("Hello, World!");
System.out.println("Hello, Word!");
```

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Programmers spend a fair amount of time fixing compile-time and run-time errors.

A compile-time error is a violation of the programming language rules that is detected by the compiler.

In the first case, the compiler will complain. It will say that it has no clue what you mean by `ou`. The exact wording of the error message is dependent on your development environment, but it might be something like "Cannot find symbol ou". This is a **compile-time error**. Something is wrong according to the rules of the language and the compiler finds it. For this reason, compile-time errors are often called **syntax errors**. When the compiler finds one or more errors, it refuses to translate the program into Java virtual machine instructions, and as a consequence you have no program that you can run. You must fix the error and compile again. In fact, the compiler is quite picky, and it is common to go through several rounds of fixing compile-time errors before compilation succeeds for the first time.

If the compiler finds an error, it will not simply stop and give up. It will try to report as many errors as it can find, so you can fix them all at once.

Sometimes, an error throws the compiler off track. Suppose, for example, you forget the quotation marks around a string: `System.out.println(Hello, World!)`. The compiler will not complain about the missing quotation marks. Instead, it will report "Cannot find symbol Hello". Unfortunately, the compiler is not very smart and it does not realize that you meant to use a string. It is up to you to realize that you need to enclose strings in quotation marks.

The error in the second line above is of a different kind. The program will compile and run, but its output will be wrong. It will print

```
Hello, Word!
```

A run-time error causes a program to take an action that the programmer did not intend.

This is a **run-time error**. The program is syntactically correct and does something, but it doesn't do what it is supposed to do. Because run-time errors are caused by logical flaws in the program, they are often called **logic errors**.

This particular run-time error did not include an error message. It simply produced the wrong output. Some kinds of run-time errors are so severe that they generate an **exception**: an error message from the Java virtual machine. For example, if your program includes the statement

```
System.out.println(1 / 0);
```

you will get a run-time error message "Division by zero".

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download three programs that illustrate errors.

During program development, errors are unavoidable. Once a program is longer than a few lines, it would require superhuman concentration to enter it correctly without slipping up once. You will find yourself omitting semicolons or quotation marks more often than you would like, but the compiler will track down these problems for you.

Run-time errors are more troublesome. The compiler will not find them—in fact, the compiler will cheerfully translate any program as long as its syntax is correct—

but the resulting program will do something wrong. It is the responsibility of the program author to test the program and find any run-time errors.

16. Suppose you omit the "" characters around `Hello, World!` from the `HelloPrinter.java` program. Is this a compile-time error or a run-time error?
17. Suppose you change `println` to `printline` in the `HelloPrinter.java` program. Is this a compile-time error or a run-time error?
18. Suppose you change `main` to `hello` in the `HelloPrinter.java` program. Is this a compile-time error or a run-time error?
19. When you used your computer, you may have experienced a program that "crashed" (quit spontaneously) or "hung" (failed to respond to your input). Is that behavior a compile-time error or a run-time error?
20. Why can't you test a program for run-time errors when it has compiler errors?

Practice It Now you can try these exercises at the end of the chapter: R1.9, R1.10, R1.11.

Common Error 1.2

Misspelling Words

If you accidentally misspell a word, then strange things may happen, and it may not always be completely obvious from the error messages what went wrong. Here is a good example of how simple spelling errors can cause trouble:

```
public class HelloPrinter
{
   public static void Main(String[] args)
   {
      System.out.println("Hello, World!");
   }
}
```

This class declares a method called `Main`. The compiler will not consider this to be the same as the `main` method, because `Main` starts with an uppercase letter and the Java language is case sensitive. Upper- and lowercase letters are considered to be completely different from each other, and to the compiler `Main` is no better match for `main` than `rain`. The compiler will cheerfully compile your `Main` method, but when the Java virtual machine reads the compiled file, it will complain about the missing `main` method and refuse to run the program. Of course, the message "missing main method" should give you a clue where to look for the error.

If you get an error message that seems to indicate that the compiler or virtual machine is on the wrong track, check for spelling and capitalization. If you misspell the name of a symbol (for example, `ou` instead of `out`), the compiler will produce a message such as "cannot find symbol ou". That error message is usually a good clue that you made a spelling error.

1.7 Problem Solving: Algorithm Design

You will soon learn how to program calculations and decision making in Java. But before we look at the mechanics of implementing computations in the next chapter, let's consider how you can describe the steps that are necessary for finding the solution to a problem.

1.7.1 The Algorithm Concept

Finding the perfect partner is not a problem that a computer can solve.

You may have run across advertisements that encourage you to pay for a computerized service that matches you up with a love partner. Think how this might work. You fill out a form and send it in. Others do the same. The data are processed by a computer program. Is it reasonable to assume that the computer can perform the task of finding the best match for you? Suppose your younger brother, not the computer, had all the forms on his desk. What instructions could you give him? You can't say, "Find the best-looking person who likes inline skating and browsing the Internet". There is no objective standard for good looks, and your brother's opinion (or that of a computer program analyzing the photos of prospective partners) will likely be different from yours. If you can't give written instructions for someone to solve the problem, there is no way the computer can magically find the right solution. The computer can only do what you tell it to do. It just does it faster, without getting bored or exhausted.

For that reason, a computerized match-making service cannot guarantee to find the optimal match for you. Instead, you may be presented with a set of potential partners who share common interests with you. That is a task that a computer program can solve.

In order for a computer program to provide an answer to a problem that computes an answer, it must follow a sequence of steps that is

- Unambiguous
- Executable
- Terminating

An algorithm for solving a problem is a sequence of steps that is unambiguous, executable, and terminating.

The step sequence is *unambiguous* when there are precise instructions for what to do at each step and where to go next. There is no room for guesswork or personal opinion. A step is *executable* when it can be carried out in practice. For example, a computer can list all people that share your hobbies, but it can't predict who will be your life-long partner. Finally, a sequence of steps is *terminating* if it will eventually come to an end. A program that keeps working without delivering an answer is clearly not useful.

A sequence of steps that is unambiguous, executable, and terminating is called an **algorithm**. Although there is no algorithm for finding a partner, many problems do have algorithms for solving them. The next section gives an example.

An algorithm is a recipe for finding a solution.

1.7.2 An Algorithm for Solving an Investment Problem

Consider the following investment problem:

> You put $10,000 into a bank account that earns 5 percent interest per year. How many years does it take for the account balance to be double the original?

Could you solve this problem by hand? Sure, you could. You figure out the balance as follows:

year	interest	balance
0		10000
1	10000.00 x 0.05 = 500.00	10000.00 + 500.00 = 10500.00
2	10500.00 x 0.05 = 525.00	10500.00 + 525.00 = 11025.00
3	11025.00 x 0.05 = 551.25	11025.00 + 551.25 = 11576.25
4	11576.25 x 0.05 = 578.81	11576.25 + 578.81 = 12155.06

You keep going until the balance is at least $20,000. Then the last number in the year column is the answer.

Of course, carrying out this computation is intensely boring to you or your younger brother. But computers are very good at carrying out repetitive calculations quickly and flawlessly. What is important to the computer is a description of the steps for finding the solution. Each step must be clear and unambiguous, requiring no guesswork. Here is such a description:

Start with a year value of 0, a column for the interest, and a balance of $10,000.

year	interest	balance
0		10000

Repeat the following steps while the balance is less than $20,000
- **Add 1 to the year value.**
- **Compute the interest as balance x 0.05 (i.e., 5 percent interest).**
- **Add the interest to the balance.**

year	interest	balance
0		10000
1	500.00	10500.00
14	942.82	19799.32
15	989.96	20789.28

Report the final year value as the answer.

These steps are not yet in a language that a computer can understand, but you will soon learn how to formulate them in Java. This informal description is called **pseudocode**. We examine the rules for writing pseudocode in the next section.

1.7.3 Pseudocode

Pseudocode is an informal description of a sequence of steps for solving a problem.

There are no strict requirements for pseudocode because it is read by human readers, not a computer program. Here are the kinds of pseudocode statements and how we will use them in this book:

- Use statements such as the following to describe how a value is set or changed:

  ```
  total cost = purchase price + operating cost
  Multiply the balance value by 1.05.
  Remove the first and last character from the word.
  ```

- Describe decisions and repetitions as follows:

  ```
  If total cost 1 < total cost 2
  While the balance is less than $20,000
  For each picture in the sequence
  ```

  Use indentation to indicate which statements should be selected or repeated:

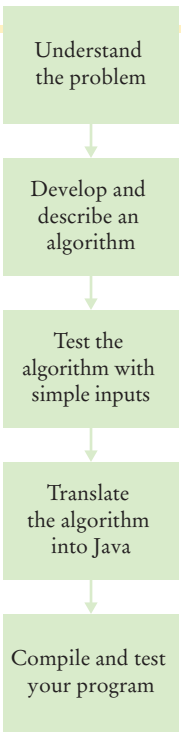
  ```
  For each car
     operating cost = 10 x annual fuel cost
     total cost = purchase price + operating cost
  ```

  Here, the indentation indicates that both statements should be executed for each car.

- Indicate results with statements such as:

  ```
  Choose car1.
  Report the final year value as the answer.
  ```

1.7.4 From Algorithms to Programs



In Section 1.7.2, we developed pseudocode for finding how long it takes to double an investment. Let's double-check that the pseudocode represents an algorithm; that is, that it is unambiguous, executable, and terminating.

Our pseudocode is unambiguous. It simply tells how to update values in each step. The pseudocode is executable because we use a fixed interest rate. Had we said to use the actual interest rate that will be charged in years to come, and not a fixed rate of 5 percent per year, the instructions would not have been executable. There is no way for anyone to know what the interest rate will be in the future. It requires a bit of thought to see that the steps are terminating: With every step, the balance goes up by at least $500, so eventually it must reach $20,000.

Therefore, we have found an algorithm to solve our investment problem, and we know we can find the solution by programming a computer. The existence of an algorithm is an essential prerequisite for programming a task. You need to first discover and describe an algorithm for the task before you start programming (see Figure 8). In the chapters that follow, you will learn how to express algorithms in the Java language.

Figure 8 The Software Development Process

21. Suppose the interest rate was 20 percent. How long would it take for the investment to double?
22. Suppose your cell phone carrier charges you $29.95 for up to 300 minutes of calls, and $0.45 for each additional minute, plus 12.5 percent taxes and fees. Give an algorithm to compute the monthly charge from a given number of minutes.
23. Consider the following pseudocode for finding the most attractive photo from a sequence of photos:

```
Pick the first photo and call it "the best so far".
For each photo in the sequence
   If it is more attractive than the "best so far"
      Discard "the best so far".
      Call this photo "the best so far".
The photo called "the best so far" is the most attractive photo in the sequence.
```

Is this an algorithm that will find the most attractive photo?

24. Suppose each photo in Self Check 23 had a price tag. Give an algorithm for finding the most expensive photo.
25. Suppose you have a random sequence of black and white marbles and want to rearrange it so that the black and white marbles are grouped together. Consider this algorithm:

```
Repeat until sorted
   Locate the first black marble that is preceded by a white marble, and switch them.
```

What does the algorithm do with the sequence ❍●❍●●? Spell out the steps until the algorithm stops.

26. Suppose you have a random sequence of colored marbles. Consider this pseudocode:

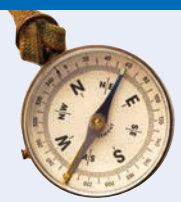
```
Repeat until sorted
   Locate the first marble that is preceded by a marble of a different color, and switch them.
```

Why is this not an algorithm?

Practice It Now you can try these exercises at the end of the chapter: R1.16, E1.4, P1.1.

HOW TO 1.1

Describing an Algorithm with Pseudocode



This is the first of many "How To" sections in this book that give you step-by-step procedures for carrying out important tasks in developing computer programs.

Before you are ready to write a program in Java, you need to develop an algorithm—a method for arriving at a solution for a particular problem. Describe the algorithm in pseudocode—a sequence of precise steps formulated in English. To illustrate, we'll devise an algorithm for this problem:

Problem Statement You have the choice of buying one of two cars. One is more fuel efficient than the other, but also more expensive. You know the price and fuel efficiency (in miles per gallon, mpg) of both cars. You plan to keep the car for ten years. Assume a price of $4 per gallon of gas and usage of 15,000 miles per year. You will pay cash for the car and not worry about financing costs. Which car is the better deal?

Step 1 Determine the inputs and outputs.

In our sample problem, we have these inputs:

- **purchase price1** and **fuel efficiency1**, the price and fuel efficiency (in mpg) of the first car
- **purchase price2** and **fuel efficiency2**, the price and fuel efficiency of the second car

We simply want to know which car is the better buy. That is the desired output.

Step 2 Break down the problem into smaller tasks.

For each car, we need to know the total cost of driving it. Let's do this computation separately for each car. Once we have the total cost for each car, we can decide which car is the better deal.

The total cost for each car is **purchase price + operating cost**.

We assume a constant usage and gas price for ten years, so the operating cost depends on the cost of driving the car for one year.

The operating cost is **10 x annual fuel cost**.

The annual fuel cost is **price per gallon x annual fuel consumed**.

The annual fuel consumed is **annual miles driven / fuel efficiency**. For example, if you drive the car for 15,000 miles and the fuel efficiency is 15 miles/gallon, the car consumes 1,000 gallons.

Step 3 Describe each subtask in pseudocode.

In your description, arrange the steps so that any intermediate values are computed before they are needed in other computations. For example, list the step

```
total cost = purchase price + operating cost
```

after you have computed **operating cost**.

Here is the algorithm for deciding which car to buy:

```
For each car, compute the total cost as follows:
   annual fuel consumed = annual miles driven / fuel efficiency
   annual fuel cost = price per gallon x annual fuel consumed
   operating cost = 10 x annual fuel cost
   total cost = purchase price + operating cost
If total cost1 < total cost2
   Choose car1.
Else
   Choose car2.
```

Step 4 Test your pseudocode by working a problem.

We will use these sample values:

Car 1: $25,000, 50 miles/gallon

Car 2: $20,000, 30 miles/gallon

Here is the calculation for the cost of the first car:

```
annual fuel consumed = annual miles driven / fuel efficiency = 15000 / 50 = 300
annual fuel cost = price per gallon x annual fuel consumed = 4 x 300 = 1200
operating cost = 10 x annual fuel cost = 10 x 1200 = 12000
total cost = purchase price + operating cost = 25000 + 12000 = 37000
```

Similarly, the total cost for the second car is $40,000. Therefore, the output of the algorithm is to choose car 1.

The following Worked Example demonstrates how to use the concepts in this chapter and the steps in the How To to solve another problem. In this case, you will see how to develop an algorithm for laying tile in an alternating pattern of colors. You should read the Worked Example to review what you have learned, and for help in tackling another problem.

In future chapters, Worked Examples are provided for you on the book's companion Web site. A brief description of the problem tackled in the example will appear with a reminder to download it from `www.wiley.com/go/bjeo6examples`. You will find any code related to the Worked Example included with the book's companion code for the chapter. When you see the Worked Example description, download the example and the code to learn how the problem was solved.

WORKED EXAMPLE 1.1 Writing an Algorithm for Tiling a Floor

Problem Statement Write an algorithm for tiling a rectangular bathroom floor with alternating black and white tiles measuring 4 × 4 inches. The floor dimensions, measured in inches, are multiples of 4.

Step 1 Determine the inputs and outputs.

The inputs are the floor dimensions (length × width), measured in inches. The output is a tiled floor.

© rban/iStockphoto.

Step 2 Break down the problem into smaller tasks.

A natural subtask is to lay one row of tiles. If you can solve that task, then you can solve the problem by laying one row next to the other, starting from a wall, until you reach the opposite wall.

How do you lay a row? Start with a tile at one wall. If it is white, put a black one next to it. If it is black, put a white one next to it. Keep going until you reach the opposite wall. The row will contain **width / 4** tiles.

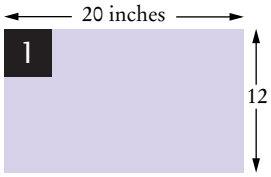
Step 3 Describe each subtask in pseudocode.

In the pseudocode, you want to be more precise about exactly where the tiles are placed.

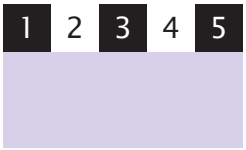
```
Place a black tile in the northwest corner.
While the floor is not yet filled, repeat the following steps:
   Repeat this step width / 4 – 1 times:
      Place a tile east of the previously placed tile. If the previously placed tile was white, pick a black one;
         otherwise, a white one.
   Locate the tile at the beginning of the row that you just placed. If there is space to the south, place a tile of
   the opposite color below it.
```

Step 4 Test your pseudocode by working a problem.

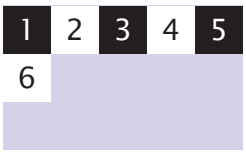
Suppose you want to tile an area measuring 20 × 12 inches. The first step is to place a black tile in the northwest corner.



Next, alternate four tiles until reaching the east wall. (**width / 4 – 1 = 20 / 4 – 1 = 4**)



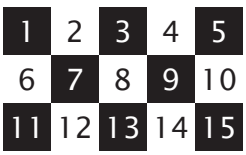
There is room to the south. Locate the tile at the beginning of the completed row. It is black. Place a white tile south of it.



Complete the row.

There is still room to the south. Locate the tile at the beginning of the completed row. It is white. Place a black tile south of it.

Complete the row.



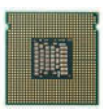
Now the entire floor is filled, and you are done.

CHAPTER SUMMARY

Define "computer program" and programming.

- Computers execute very basic instructions in rapid succession.
- A computer program is a sequence of instructions and decisions.
- Programming is the act of designing and implementing computer programs.

Describe the components of a computer.



- The central processing unit (CPU) performs program control and data processing.
- Storage devices include memory and secondary storage.

Describe the process of translating high-level languages to machine code.

- Java was originally designed for programming consumer devices, but it was first successfully used to write Internet applets.
- Java was designed to be safe and portable, benefiting both Internet users and students.
- Java programs are distributed as instructions for a virtual machine, making them platform-independent.
- Java has a very large library. Focus on learning those parts of the library that you need for your programming projects.

Become familiar with your Java programming environment.

- Set aside time to become familiar with the programming environment that you will use for your class work.
- An editor is a program for entering and modifying text, such as a Java program.
- Java is case sensitive. You must be careful about distinguishing between upper- and lowercase letters.
- The Java compiler translates source code into class files that contain instructions for the Java virtual machine.
- Develop a strategy for keeping backup copies of your work before disaster strikes.

Describe the building blocks of a simple program.

- Classes are the fundamental building blocks of Java programs.
- Every Java application contains a class with a `main` method. When the application starts, the instructions in the `main` method are executed.
- Each class contains declarations of methods. Each method contains a sequence of instructions.
- A method is called by specifying the method and its arguments.
- A string is a sequence of characters enclosed in quotation marks.

Classify program errors as compile-time and run-time errors.

- A compile-time error is a violation of the programming language rules that is detected by the compiler.
- A run-time error causes a program to take an action that the programmer did not intend.

Write pseudocode for simple algorithms.

- An algorithm for solving a problem is a sequence of steps that is unambiguous, executable, and terminating.
- Pseudocode is an informal description of a sequence of steps for solving a problem.

STANDARD LIBRARY ITEMS INTRODUCED IN THIS CHAPTER

java.io.PrintStream	java.lang.System
print	out
println	

REVIEW EXERCISES

■ **R1.1** Explain the difference between using a computer program and programming a computer.

■ **R1.2** Which parts of a computer can store program code? Which can store user data?

■ **R1.3** Which parts of a computer serve to give information to the user? Which parts take user input?

■■ **R1.4** A toaster is a single-function device, but a computer can be programmed to carry out different tasks. Is your cell phone a single-function device, or is it a programmable computer? (Your answer will depend on your cell phone model.)

■■ **R1.5** Explain two benefits of using Java over machine code.

■■ **R1.6** On your own computer or on a lab computer, find the exact location (folder or directory name) of

a. The sample file `HelloPrinter.java`, which you wrote with the editor.

b. The Java program launcher `java.exe` or `java`.

c. The library file `rt.jar` that contains the run-time library.

■■ **R1.7** What does this program print?

```
public class Test
{
   public static void main(String[] args)
   {
      System.out.println("39 + 3");
      System.out.println(39 + 3);
   }
}
```

■■ **R1.8** What does this program print? Pay close attention to spaces.

```
public class Test
{
   public static void main(String[] args)
   {
      System.out.print("Hello");
      System.out.println("World");
   }
}
```

■■ **R1.9** What is the compile-time error in this program?

```
public class Test
{
   public static void main(String[] args)
   {
      System.out.println("Hello", "World!");
   }
}
```

■■ **R1.10** Write three versions of the `HelloPrinter.java` program that have different compile-time errors. Write a version that has a run-time error.

■ **R1.11** How do you discover syntax errors? How do you discover logic errors?

■■■ **R1.12** The cafeteria offers a discount card for sale that entitles you, during a certain period, to a free meal whenever you have bought a given number of meals at the regular price. The exact details of the offer change from time to time. Describe an algorithm that lets you determine whether a particular offer is a good buy. What other inputs do you need?

■■ **R1.13** Write an algorithm to settle the following question: A bank account starts out with $10,000. Interest is compounded monthly at 6 percent per year (0.5 percent per month). Every month, $500 is withdrawn to meet college expenses. After how many years is the account depleted?

■■■ **R1.14** Consider the question in Exercise R1.13. Suppose the numbers ($10,000, 6 percent, $500) were user selectable. Are there values for which the algorithm you developed would not terminate? If so, change the algorithm to make sure it always terminates.

■■■ **R1.15** In order to estimate the cost of painting a house, a painter needs to know the surface area of the exterior. Develop an algorithm for computing that value. Your inputs are the width, length, and height of the house, the number of windows and doors, and their dimensions. (Assume the windows and doors have a uniform size.)

■■ **R1.16** In How To 1.1, you made assumptions about the price of gas and annual usage to compare cars. Ideally, you would like to know which car is the better deal without making these assumptions. Why can't a computer program solve that problem?

■■ **R1.17** Suppose you put your younger brother in charge of backing up your work. Write a set of detailed instructions for carrying out his task. Explain how often he should do it, and what files he needs to copy from which folder to which location. Explain how he should verify that the backup was carried out correctly.

■ **R1.18** Write pseudocode for an algorithm that describes how to prepare Sunday breakfast in your household.

■■ **R1.19** The ancient Babylonians had an algorithm for determining the square root of a number a. Start with an initial guess of $a / 2$. Then find the average of your guess g and a / g. That's your next guess. Repeat until two consecutive guesses are close enough. Write pseudocode for this algorithm.

PRACTICE EXERCISES

■ **E1.1** Write a program that prints a greeting of your choice, perhaps in a language other than English.

■■ **E1.2** Write a program that prints the sum of the first ten positive integers, $1 + 2 + \cdots + 10$.

■■ **E1.3** Write a program that prints the product of the first ten positive integers, $1 \times 2 \times \cdots \times 10$. (Use `*` to indicate multiplication in Java.)

■■ **E1.4** Write a program that prints the balance of an account after the first, second, and third year. The account has an initial balance of $1,000 and earns 5 percent interest per year.

■ **E1.5** Write a program that displays your name inside a box on the screen, like this: `Dave` Do your best to approximate lines with characters such as `|` `-` `+`.

■■■ **E1.6** Write a program that prints your name in large letters, such as

```
*   *    **    ****    ****   *   *
*   *   *  *   *   *   *   *  *   *
*****  *    *  ****    ****    * *
*   *  ******  *   *   *   *    *
*   *  *    *  *    *  *    *   *
```

■■ **E1.7** Write a program that prints your name in Morse code, like this:

```
.... .- .-. .-. -.--
```

Use a separate call to `System.out.print` for each letter.

■■ **E1.8** Write a program that prints a face similar to (but different from) the following:

```
  /////
 +"""""+
(| o o |)
 |  ^  |
 | '-' |
 +-----+
```

■■ **E1.9** Write a program that prints an imitation of a Piet Mondrian painting. (Search the Internet if you are not familiar with his paintings.) Use character sequences such as `@@@` or `:::` to indicate different colors, and use `-` and `|` to form lines.

■■ **E1.10** Write a program that prints a house that looks exactly like the following:

```
    +
   + +
  +   +
 +-----+
 | .-. |
 | | | |
 +-+-+-+
```

■■■ **E1.11** Write a program that prints an animal speaking a greeting, similar to (but different from) the following:

```
 /\_/\     -----
( ' ' )  / Hello \
(  -  ) <  Junior |
 | | |   \ Coder!/
(__|__)    -----
```

■ **E1.12** Write a program that prints three items, such as the names of your three best friends or favorite movies, on three separate lines.

■ **E1.13** Write a program that prints a poem of your choice. If you don't have a favorite poem, search the Internet for "Emily Dickinson" or "e e cummings".

■■ **E1.14** Write a program that prints the United States flag, using `*` and `=` characters.

■■ **E1.15** Type in and run the following program. Then modify it to show the message "Hello, *your name*!".

```
import javax.swing.JOptionPane;

public class DialogViewer
{
   public static void main(String[] args)
   {
      JOptionPane.showMessageDialog(null, "Hello, World!");
```

```
   }
}
```

■■ **E1.16** Type in and run the following program. Then modify it to print "Hello, *name*!", displaying the name that the user typed in.

```
import javax.swing.JOptionPane;

public class DialogViewer
{
   public static void main(String[] args)
   {
      String name = JOptionPane.showInputDialog("What is your name?");
      System.out.println(name);
   }
}
```

■■■ **E1.17** Modify the program from Exercise E1.16 so that the dialog continues with the message "My name is Hal! What would you like me to do?" Discard the user's input and display a message such as

```
I'm sorry, Dave. I'm afraid I can't do that.
```

Replace `Dave` with the name that was provided by the user.

■■ **E1.18** Type in and run the following program. Then modify it to show a different greeting and image.

```
import java.net.URL;
import javax.swing.ImageIcon;
import javax.swing.JOptionPane;

public class Test
{
   public static void main(String[] args) throws Exception
   {
      URL imageLocation = new URL(
            "http://horstmann.com/java4everyone/duke.gif");
      JOptionPane.showMessageDialog(null, "Hello", "Title",
            JOptionPane.PLAIN_MESSAGE, new ImageIcon(imageLocation));
   }
}
```

■ **Business E1.19** Write a program that prints a two-column list of your friends' birthdays. In the first column, print the names of your best friends; in the second, print their birthdays.

■ **Business E1.20** In the United States there is no federal sales tax, so every state may impose its own sales taxes. Look on the Internet for the sales tax charged in five U.S. states, then write a program that prints the tax rate for five states of your choice.

```
Sales Tax Rates
---------------
Alaska:      0%
Hawaii:      4%
. . .
```

■ **Business E1.21** To speak more than one language is a valuable skill in the labor market today. One of the basic skills is learning to greet people. Write a program that prints a two-column list with the greeting phrases shown in the table. In the first column, print the phrase in English, in the second column, print the phrase in a language of your choice. If you don't speak a language other than English, use an online translator or ask a friend.

List of Phrases to Translate
Good morning.
It is a pleasure to meet you.
Please call me tomorrow.
Have a nice day!

PROGRAMMING PROJECTS

■■ **P1.1** You want to decide whether you should drive your car to work or take the train. You know the one-way distance from your home to your place of work, and the fuel efficiency of your car (in miles per gallon). You also know the one-way price of a train ticket. You assume the cost of gas at $4 per gallon, and car maintenance at 5 cents per mile. Write an algorithm to decide which commute is cheaper.

■■ **P1.2** You want to find out which fraction of your car's use is for commuting to work, and which is for personal use. You know the one-way distance from your home to work. For a particular period, you recorded the beginning and ending mileage on the odometer and the number of work days. Write an algorithm to settle this question.

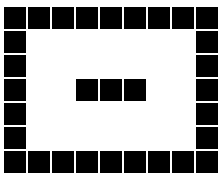
■■■ **P1.3** The value of π can be computed according to the following formula:

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \frac{1}{9} - \cdots$$

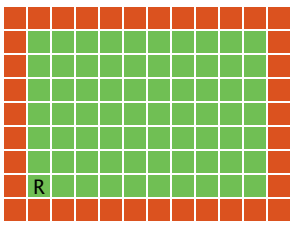
Write an algorithm to compute π. Because the formula is an infinite series and an algorithm must stop after a finite number of steps, you should stop when you have the result determined to six significant digits.

■ **Business P1.4** Imagine that you and a number of friends go to a luxury restaurant, and when you ask for the bill you want to split the amount and the tip (15 percent) between all. Write pseudocode for calculating the amount of money that everyone has to pay. Your program should print the amount of the bill, the tip, the total cost, and the amount each person has to pay. It should also print how much of what each person pays is for the bill and for the tip.

■■ **P1.5** Write an algorithm to create a tile pattern composed of black and white tiles, with a fringe of black tiles all around and two or three black tiles in the center, equally spaced from the boundary. The inputs to your algorithm are the total number of rows and columns in the pattern.



■■■ **P1.6** Write an algorithm that allows a robot to mow a rectangular lawn, provided it has been placed in a corner, like this:

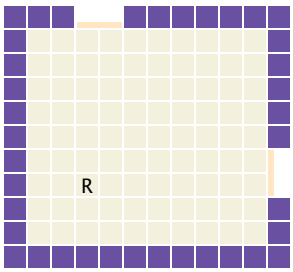


The robot can:

- Move forward by one unit.
- Turn left or right.
- Sense the color of the ground one unit in front of it.

■■■ **P1.7** Consider a robot that is placed in a room. The robot can:

- Move forward by one unit.
- Turn left or right.
- Sense what is in front of it: a wall, a window, or neither.



Write an algorithm that enables the robot, placed anywhere in the room, to count the number of windows. For example, in the room at right, the robot (marked as R) should find that it has two windows.

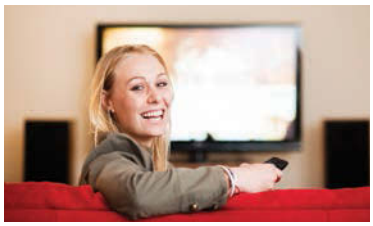
■■■ **P1.8** Consider a robot that has been placed in a maze. The right-hand rule tells you how to escape from a maze: Always have the right hand next to a wall, and eventually you will find an exit. The robot can:

- Move forward by one unit.
- Turn left or right.
- Sense what is in front of it: a wall, an exit, or neither.

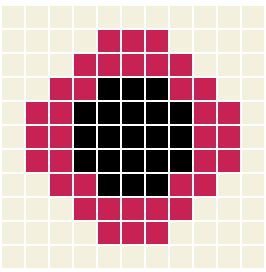
Write an algorithm that lets the robot escape the maze. You may assume that there is an exit that is reachable by the right-hand rule. Your challenge is to deal with situations in which the path turns. The robot can't see turns. It can only see what is directly in front of it.

■■■ **Business P1.9** Suppose you received a loyalty promotion that lets you purchase one item, valued up to $100, from an online catalog. You want to make the best of the offer. You have a list of all items for sale, some of which are less than $100, some more. Write an algorithm to produce the item that is closest to $100. If there is more than one such item, list them all. Remember that a computer will inspect one item at a time—it can't just glance at a list and find the best one.

■■ **Science P1.10** A television manufacturer advertises that a television set has a certain size, measured diagonally. You wonder how the set will fit into your living room. Write an algorithm that yields the horizontal and vertical size of the television. Your inputs are the diagonal size and the aspect ratio (the ratio of width to height, usually 16 : 9 for television sets).



■■■ **Science P1.11** Cameras today can correct "red eye" problems caused when the photo flash makes eyes look red. Write pseudocode for an algorithm that can detect red eyes. Your input is a pattern of colors, such as that at right.



You are given the number of rows and columns. For any row or column number, you can query the color, which will be red, black, or something else. If you find that the center of the black pixels coincides with the center of the red pixels, you have found a red eye, and your output should be "yes". Otherwise, your output is "no".

ANSWERS TO SELF-CHECK QUESTIONS

1. A program that reads the data on the CD and sends output to the speakers and the screen.
2. A CD player can do one thing—play music CDs. It cannot execute programs.
3. Nothing.
4. In secondary storage, typically a hard disk.
5. The central processing unit.
6. A smartphone has a CPU and memory, like any computer. A few smartphones have keyboards. Generally, the touchpad is used instead of a mouse. Secondary storage is in the form of a solid state drive. Of course, smartphones have a display, speaker, and microphone. The network connection uses the wireless radio to connect to a cell tower.

7. Safety and portability.
8. No one person can learn the entire library—it is too large.
9. The answer varies among systems. A typical answer might be `/home/dave/cs1/hello/HelloPrinter.java` or `c:\Users\Dave\Workspace\hello\HelloPrinter.java`
10. You back up your files and folders.
11. Change `World` to your name (here, `Dave`):

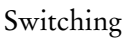
```
System.out.println("Hello, Dave!");
```

12.
```
System.out.println("H");
System.out.println("e");
System.out.println("l");
System.out.println("l");
System.out.println("o");
```

13. No. The compiler would look for an item whose name is `Hello`. You need to enclose `Hello` in quotation marks:

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

14. The printout is `My lucky number is12`. It would be a good idea to add a space after the `is`.
15. `Hello`
a blank line
`World`
16. This is a compile-time error. The compiler will complain that it does not know the meanings of the words `Hello` and `World`.
17. This is a compile-time error. The compiler will complain that `System.out` does not have a method called `printline`.
18. This is a run-time error. It is perfectly legal to give the name `hello` to a method, so the compiler won't complain. But when the program is run, the virtual machine will look for a `main` method and won't find one.
19. It is a run-time error. After all, the program had been compiled in order for you to run it.
20. When a program has compiler errors, no class file is produced, and there is nothing to run.
21. 4 years:
0 10,000
1 12,000
2 14,400
3 17,280
4 20,736
22. Is the number of minutes at most 300?
    a. If so, the answer is $29.95 × 1.125 = $33.70.
    b. If not,
        1. Compute the difference: (number of minutes) – 300.
        2. Multiply that difference by 0.45.
        3. Add $29.95.
        4. Multiply the total by 1.125. That is the answer.
23. No. The step **If it is more attractive than the "best so far"** is not executable because there is no objective way of deciding which of two photos is more attractive.
24.
Pick the first photo and call it "the most expensive so far".
For each photo in the sequence
If it is more expensive than "the most expensive so far"
Discard "the most expensive so far".
Call this photo "the most expensive so far".
The photo called "the most expensive so far" is the most expensive photo in the sequence.
25. The first black marble that is preceded by a white one is marked in blue:



Switching the two yields

The next black marble to be switched is

yielding

The next steps are

Now the sequence is sorted.
26. The sequence doesn't terminate. Consider the input ○●○●○. The first two marbles keep getting switched.

CHAPTER 2

USING OBJECTS

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CHAPTER GOALS

To learn about variables

To understand the concepts of classes and objects

To be able to call methods

To learn about arguments and return values

To be able to browse the API documentation

To implement test programs

To understand the difference between objects and object references

To write programs that display simple shapes

CHAPTER CONTENTS

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Most useful programs don't just manipulate numbers and strings. Instead, they deal with data items that are more complex and that more closely represent entities in the real world. Examples of these data items include bank accounts, employee records, and graphical shapes.

The Java language is ideally suited for designing and manipulating such data items, or *objects*. In Java, you implement *classes* that describe the behavior of these objects. In this chapter, you will learn how to manipulate objects that belong to classes that have already been implemented. This will prepare you for the next chapter, in which you will learn how to implement your own classes.

2.1 Objects and Classes

When you write a computer program, you put it together from certain "building blocks". In Java, you build programs from objects. Each object has a particular behavior, and you can manipulate it to achieve certain effects.

As an analogy, think of a home builder who constructs a house from certain parts: doors, windows, walls, pipes, a furnace, a water heater, and so on. Each of these elements has a particular function, and they work together to fulfill a common purpose. Note that the home builder is not concerned with how to build a window or a water heater. These elements are readily available, and the builder's job is to integrate them into the house.

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Each part that a home builder uses, such as a furnace or a water heater, fulfills a particular function. Similarly, you build programs from objects, each of which has a particular behavior.

Of course, computer programs are more abstract than houses, and the objects that make up a computer program aren't as tangible as a window or a water heater. But the analogy holds well: A programmer produces a working program from elements with the desired functionality—the objects. In this chapter, you will learn the basics about using objects written by other programmers.

2.1.1 Using Objects

Objects are entities in your program that you manipulate by calling methods.

An **object** is an entity that you can manipulate by calling one or more of its **methods**. A method consists of a sequence of instructions that can access the internal data of an object. When you call the method, you do not know exactly what those instructions are, or even how the object is organized internally. However, the behavior of the method is well defined, and that is what matters to us when we use it.

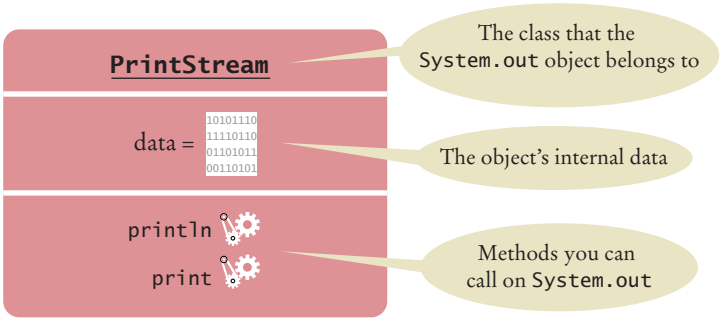

Figure 1 Representation of the `System.out` Object

A method is a sequence of instructions that accesses the data of an object.

For example, you saw in Chapter 1 that `System.out` refers to an object. You manipulate it by calling the `println` method. When the `println` method is called, some activities occur inside the object, and the ultimate effect is that text appears in the console window. You don't know how that happens, and that's OK. What matters is that the method carries out the work that you requested.

Figure 1 shows a representation of the `System.out` object. The internal data is symbolized by a sequence of zeroes and ones. Think of each method (symbolized by the gears) as a piece of machinery that carries out its assigned task.

In general, think of an object as an entity that can do work for you when you call its methods. How the work is done is not important to the programmer using the object.

In the remainder of this chapter, you will see other objects and the methods that they can carry out.

You can think of a water heater as an object that can carry out the "get hot water" method. When you call that method to enjoy a hot shower, you don't care whether the water heater uses gas or solar power.

2.1.2 Classes

In Chapter 1, you encountered two objects:

- `System.out`
- `"Hello, World!"`

A class describes a set of objects with the same behavior.

Each of these objects belongs to a different **class**. The `System.out` object belongs to the `PrintStream` class. The `"Hello, World!"` object belongs to the `String` class. Of course, there are many more `String` objects, such as `"Goodbye"` or `"Mississippi"`. They all have something in common—you can invoke the same methods on all strings. You will see some of these methods in Section 2.3.

As you will see in Chapter 11, you can construct objects of the `PrintStream` class other than `System.out`. Those objects write data to files or other destinations instead of the console. Still, all `PrintStream` objects share common behavior. You can invoke the `println` and `print` methods on any `PrintStream` object, and the printed values are sent to their destination.

Of course, the objects of the `PrintStream` class have a completely different behavior than the objects of the `String` class. You could not call `println` on a `String` object. A string wouldn't know how to send itself to a console window or file.

As you can see, different classes have different responsibilities. A string knows about the letters that it contains, but it does not know how to display them to a human or to save them to a file.

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All objects of a `Window` *class share the same behavior.*

1. In Java, objects are grouped into classes according to their behavior. Would a window object and a water heater object belong to the same class or to different classes? Why?
2. Some light bulbs use a glowing filament, others use a fluorescent gas. If you consider a light bulb a Java object with an "illuminate" method, would you need to know which kind of bulb it is?
3. What actually happens when you try to call the following?

```
"Hello, World".println(System.out)
```

Practice It Now you can try these exercises at the end of the chapter: R2.1, R2.2.

2.2 Variables

Before we continue with the main topic of this chapter—the behavior of objects—we need to go over some basic programming terminology. In the following sections, you will learn about the concepts of variables, types, and assignment.

2.2.1 Variable Declarations

When your program manipulates objects, you will want to store the objects and the values that their methods return, so that you can use them later. In a Java program, you use variables to store values. The following statement declares a variable named `width`:

```
int width = 20;
```

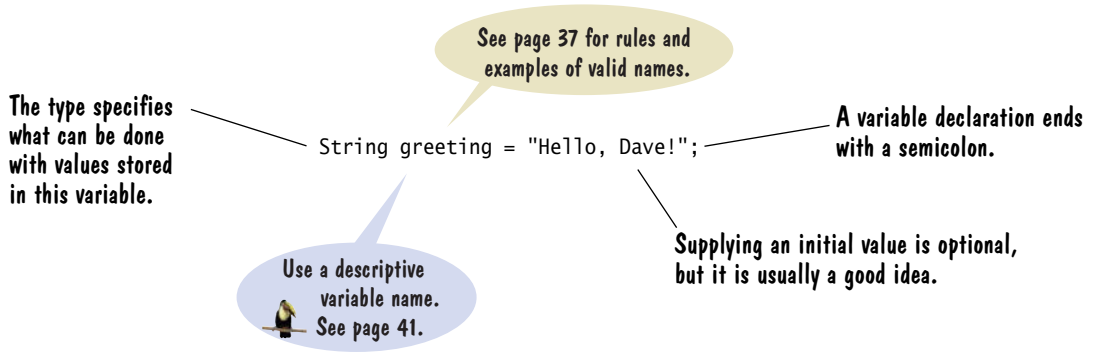
Javier Larrea/Age Fotostock.

Like a variable in a computer program, a parking space has an identifier and a contents.

Syntax 2.1 Variable Declaration

Syntax

typeName variableName = value;
or
typeName variableName;



A variable is a storage location with a name.

When declaring a variable, you usually specify an initial value.

When declaring a variable, you also specify the type of its values.

A **variable** is a storage location in a computer program. Each variable has a name and holds a value.

A variable is similar to a parking space in a parking garage. The parking space has an identifier (such as "J 053"), and it can hold a vehicle. A variable has a name (such as `width`), and it can hold a value (such as 20). When declaring a variable, you usually want to **initialize** it. That is, you specify the value that should be stored in the variable. Consider again this variable declaration:

```
int width = 20;
```

The variable `width` is initialized with the value 20.

Like a parking space that is restricted to a certain type of vehicle (such as a compact car, motorcycle, or electric vehicle), a variable in Java stores data of a specific type. Java supports quite a few data types: numbers, text strings, files, dates, and many others. You must specify the type whenever you declare a variable (see Syntax 2.1).

The `width` variable is an **integer**, a whole number without a fractional part. In Java, this type is called `int`.

Note that the type comes before the variable name:

```
int width = 20;
```

After you have declared and initialized a variable, you can use it. For example,

```
int width = 20;
System.out.println(width);
int area = width * width;
```

Table 1 shows several examples of variable declarations.

Each parking space is suitable for a particular type of vehicle, just as each variable holds a value of a particular type.

Table 1 Variable Declarations in Java

Variable Name	Comment
`int width = 20;`	Declares an integer variable and initializes it with 20.
`int perimeter = 4 * width;`	The initial value need not be a fixed value. (Of course, `width` must have been previously declared.)
`String greeting = "Hi!";`	This variable has the type `String` and is initialized with the string "Hi".
`height = 30;`	**Error:** The type is missing. This statement is not a declaration but an assignment of a new value to an existing variable—see Section 2.2.5.
`int width = "20";`	**Error:** You cannot initialize a number with the string "20". (Note the quotation marks.)
`int width;`	Declares an integer variable without initializing it. This can be a cause for errors—see Common Error 2.1 on page 40.
`int width, height;`	Declares two integer variables in a single statement. In this book, we will declare each variable in a separate statement.

2.2.2 Types

Use the `int` type for numbers that cannot have a fractional part.

In Java, there are several different types of numbers. You use the `int` type to denote a whole number without a fractional part. For example, suppose you count the number of cars in a parking lot. The counter must be an integer number—you cannot have a fraction of a car.

When a fractional part is required (such as in the number 22.5), we use **floating-point numbers**. The most commonly used type for floating-point numbers in Java is called `double`. Here is the declaration of a floating-point variable:

```
double milesPerGallon = 22.5;
```

Use the `double` type for floating-point numbers.

You can combine numbers with the `+` and `-` operators, as in `width + 10` or `width - 1`. To multiply two numbers, use the `*` operator. For example, $2 \times \textit{width}$ is written as `2 * width`. Use the `/` operator for division, such as `width / 2`.

Numbers can be combined by arithmetic operators such as `+`, `-`, and `*`.

As in mathematics, the `*` and `/` operator bind more strongly than the `+` and `-` operators. That is, `width + height * 2` means the sum of `width` and the product `height * 2`. If you want to multiply the sum by 2, use parentheses: `(width + height) * 2`.

Not all types are number types. For example, the value `"Hello"` has the type `String`. You need to specify that type when you define a variable that holds a string:

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

A type specifies the operations that can be carried out with its values.

Types are important because they indicate what you can do with a variable. For example, consider the variable `width`. It's type is `int`. Therefore, you can multiply the value that it holds with another number. But the type of `greeting` is `String`. You can't multiply a string with another number. (You will see in Section 2.3.1 what you can do with strings.)

2.2.3 Names

When you declare a variable, you should pick a name that explains its purpose. For example, it is better to use a descriptive name, such as `milesPerGallon`, than a terse name, such as `mpg`.

In Java, there are a few simple rules for the names of variables, methods, and classes:

1. Names must start with a letter or the underscore (_) character, and the remaining characters must be letters, numbers, or underscores. (Technically, the `$` symbol is allowed as well, but you should not use it—it is intended for names that are automatically generated by tools.)
2. You cannot use other symbols such as `?` or `%`. Spaces are not permitted inside names either. You can use uppercase letters to denote word boundaries, as in `milesPerGallon`. This naming convention is called *camel case* because the uppercase letters in the middle of the name look like the humps of a camel.)
3. Names are **case sensitive**, that is, `milesPerGallon` and `milespergallon` are different names.
4. You cannot use **reserved words** such as `double` or `class` as names; these words are reserved exclusively for their special Java meanings. (See Appendix C for a listing of all reserved words in Java.)

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By convention, variable names should start with a lowercase letter.

It is a convention among Java programmers that names of variables and methods start with a lowercase letter (such as `milesPerGallon`). Class names should start with an uppercase letter (such as `HelloPrinter`). That way, it is easy to tell them apart.

Table 2 shows examples of legal and illegal variable names in Java.

Table 2 Variable Names in Java

Variable Name	Comment
`distance_1`	Names consist of letters, numbers, and the underscore character.
`x`	In mathematics, you use short variable names such as x or y. This is legal in Java, but not very common, because it can make programs harder to understand (see Programming Tip 2.1 on page 41).
⚠ `CanVolume`	**Caution:** Names are case sensitive. This variable name is different from `canVolume`, and it violates the convention that variable names should start with a lowercase letter.
⊘ `6pack`	**Error:** Names cannot start with a number.
⊘ `can volume`	**Error:** Names cannot contain spaces.
⊘ `double`	**Error:** You cannot use a reserved word as a name.
⊘ `miles/gal`	**Error:** You cannot use symbols such as / in names.

2.2.4 Comments

As your programs get more complex, you should add **comments**, explanations for human readers of your code. For example, here is a comment that explains the value used to initialize a variable:

```
double milesPerGallon = 35.5; // The average fuel efficiency of new U.S. cars in 2013
```

This comment explains the significance of the value 35.5 to a human reader. The compiler does not process comments at all. It ignores everything from a // delimiter to the end of the line.

Use comments to add explanations for humans who read your code. The compiler ignores comments.

It is a good practice to provide comments. This helps programmers who read your code understand your intent. In addition, you will find comments helpful when you review your own programs.

You use the // delimiter for short comments. If you have a longer comment, enclose it between /* and */ delimiters. The compiler ignores these delimiters and everything in between. For example,

```
/*
   In most countries, fuel efficiency is measured in liters per hundred
   kilometer. Perhaps that is more useful—it tells you how much gas you need
   to purchase to drive a given distance. Here is the conversion formula.
*/
double fuelEfficiency = 235.214583 / milesPerGallon;
```

2.2.5 Assignment

Use the assignment operator (=) to change the value of a variable.

You can change the value of a variable with the assignment operator (=). For example, consider the variable declaration

```
int width = 10;
```
1

If you want to change the value of the variable, simply assign the new value:

```
width = 20;
```
2

The assignment replaces the original value of the variable (see Figure 2).

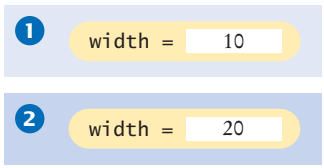


Figure 2
Assigning a New Value to a Variable

It is an error to use a variable that has never had a value assigned to it. For example, the following assignment statement has an error:

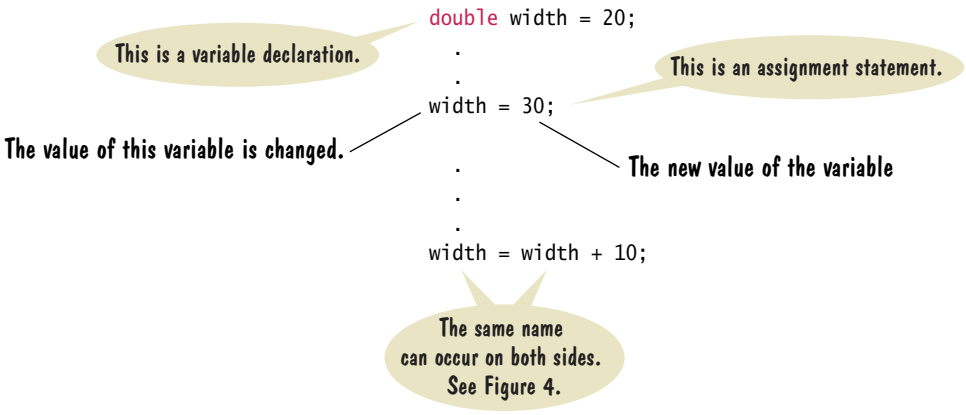
```
int height;
int width = height;    // ERROR—uninitialized variable height
```

The compiler will complain about an "**uninitialized variable**" when you use a variable that has never been assigned a value. (See Figure 3.)

Figure 3
An Uninitialized Variable

Syntax 2.2 Assignment

Syntax *variableName* = *value*;



All variables must be initialized before you access them.

The remedy is to assign a value to the variable before you use it:

```
int height = 20;
int width = height; // OK
```

The right-hand side of the = symbol can be a mathematical expression. For example,

```
width = height + 10;
```

This means "compute the value of `height + 10` and store that value in the variable `width`".

The assignment operator = does *not* denote mathematical equality.

In the Java programming language, the = operator denotes an *action*, namely to replace the value of a variable. This usage differs from the mathematical usage of the = symbol as a statement about equality. For example, in Java, the following statement is entirely legal:

```
width = width + 10;
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that demonstrates variables and assignments.

This means "compute the value of `width + 10` (1) and store that value in the variable `width` (2)" (see Figure 4).

In Java, it is not a problem that the variable `width` is used on both sides of the = symbol. Of course, in mathematics, the equation *width* = *width* + 10 has no solution.

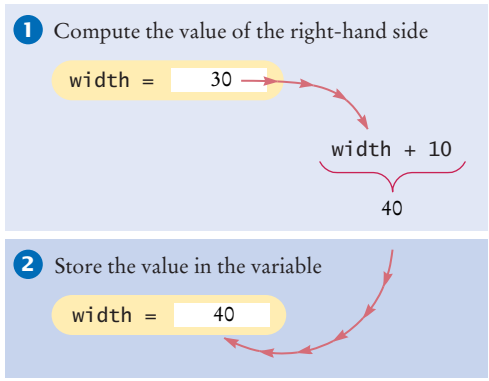


Figure 4
Executing the Statement `width = width + 10`

4. What is wrong with the following variable declaration?

```
int miles per gallon = 39.4
```

5. Declare and initialize two variables, `unitPrice` and `quantity`, to contain the unit price of a single item and the number of items purchased. Use reasonable initial values.
6. Use the variables declared in Self Check 5 to display the total purchase price.
7. What are the types of the values `0` and `"0"`?
8. Which number type would you use for storing the area of a circle?
9. Which of the following are legal identifiers?

```
Greeting1
g
void
101dalmatians
Hello, World
<greeting>
```

10. Declare a variable to hold your name. Use camel case in the variable name.
11. Is `12 = 12` a valid expression in the Java language?
12. How do you change the value of the `greeting` variable to `"Hello, Nina!"`?
13. How would you explain assignment using the parking space analogy?

Practice It Now you can try these exercises at the end of the chapter: R2.4, R2.5, R2.7.

Common Error 2.1

Using Undeclared or Uninitialized Variables

You must declare a variable before you use it for the first time. For example, the following sequence of statements would not be legal:

```
int perimeter = 4 * width; // ERROR: width not yet declared
int width = 20;
```

In your program, the statements are compiled in order. When the compiler reaches the first statement, it does not know that `width` will be declared in the next line, and it reports an error. The remedy is to reorder the declarations so that each variable is declared before it is used.

A related error is to leave a variable uninitialized:

```
int width;
int perimeter = 4 * width; // ERROR: width not yet initialized
```

The Java compiler will complain that you are using a variable that has not yet been given a value. The remedy is to assign a value to the variable before it is used.

Common Error 2.2

Confusing Variable Declarations and Assignment Statements

Suppose your program declares a variable as follows:

```
int width = 20;
```

If you want to change the value of the variable, you use an assignment statement:

```
width = 30;
```

It is a common error to accidentally use another variable declaration:

```
int width = 30; // ERROR—starts with int and is therefore a declaration
```

But there is already a variable named `width`. The compiler will complain that you are trying to declare another variable with the same name.

Programming Tip 2.1

Choose Descriptive Variable Names

In algebra, variable names are usually just one letter long, such as p or A, maybe with a subscript such as p_1. You might be tempted to save yourself a lot of typing by using short variable names in your Java programs:

```
int a = w * h;
```

Compare that statement with the following one:

```
int area = width * height;
```

The advantage is obvious. Reading `width` is much easier than reading `w` and then figuring out that it must mean "width".

In practical programming, descriptive variable names are particularly important when programs are written by more than one person. It may be obvious to you that `w` stands for width, but is it obvious to the person who needs to update your code years later? For that matter, will you yourself remember what `w` means when you look at the code a month from now?

2.3 Calling Methods

A program performs useful work by calling methods on its objects. In this section, we examine how to supply values in a method, and how to obtain the result of the method.

2.3.1 The Public Interface of a Class

You use an object by calling its methods. All objects of a given class share a common set of methods. For example, the `PrintStream` class provides methods for its objects (such as `println` and `print`). Similarly, the `String` class provides methods that you can apply to `String` objects. One of them is the `length` method. The `length` method counts the number of characters in a string. You can apply that method to any object of type `String`. For example, the sequence of statements:

```
String greeting = "Hello, World!";
int numberOfCharacters = greeting.length();
```

sets `numberOfCharacters` to the length of the `String` object `"Hello, World!"`. After the instructions in the `length` method are executed, `numberOfCharacters` is set to 13. (The quotation marks are not part of the string, and the `length` method does not count them.)

When calling the `length` method, you do not supply any values inside the parentheses. Also note that the `length` method does not produce any visible output. It returns a value that is subsequently used in the program.

Let's look at another method of the `String` class. When you apply the `toUpperCase` method to a `String` object, the method creates another `String` object that contains the characters of the original string, with lowercase letters converted to uppercase. For example, the sequence of statements

```
String river = "Mississippi";
String bigRiver = river.toUpperCase();
```

sets `bigRiver` to the `String` object `"MISSISSIPPI"`.

The public interface of a class specifies what you can do with its objects. The hidden implementation describes how these actions are carried out.

The `String` class declares many other methods besides the `length` and `toUpperCase` methods—you will learn about many of them in Chapter 4. Collectively, the methods form the **public interface** of the class, telling you what you can do with the objects of the class. A class also declares a *private implementation*, describing the data inside its objects and the instructions for its methods. Those details are hidden from the programmers who use objects and call methods.

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The controls of a car form its public interface. The private implementation is under the hood.

Figure 5 shows two objects of the `String` class. Each object stores its own data (drawn as boxes that contain characters). Both objects support the same set of methods—the public interface that is specified by the `String` class.

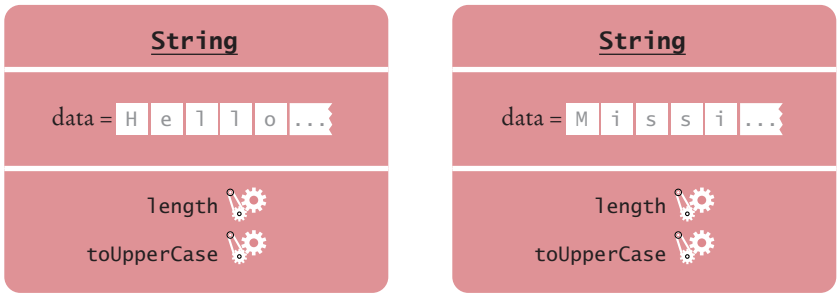


Figure 5 A Representation of Two `String` Objects

2.3.2 Method Arguments

An argument is a value that is supplied in a method call.

Most methods require values that give details about the work that the method needs to do. For example, when you call the `println` method, you must supply the string that should be printed. Computer scientists use the technical term **argument** for method inputs. We say that the string `greeting` is an argument of the method call

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

Figure 6 illustrates passing the argument to the method.

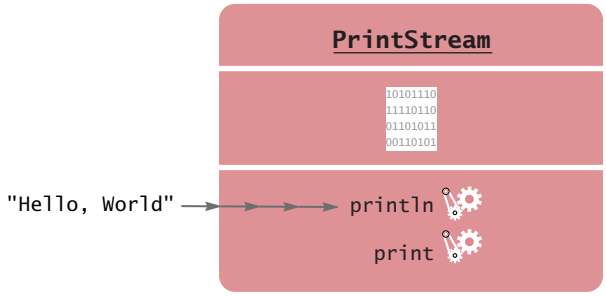


Figure 6 Passing an Argument to the `println` Method

At this tailor shop, the customer's measurements and the fabric are the arguments of the `sew` *method. The return value is the finished garment.*

Some methods require multiple arguments; others don't require any arguments at all. An example of the latter is the `length` method of the `String` class (see Figure 7). All the information that the `length` method requires to do its job—namely, the character sequence of the string—is stored in the object that carries out the method.

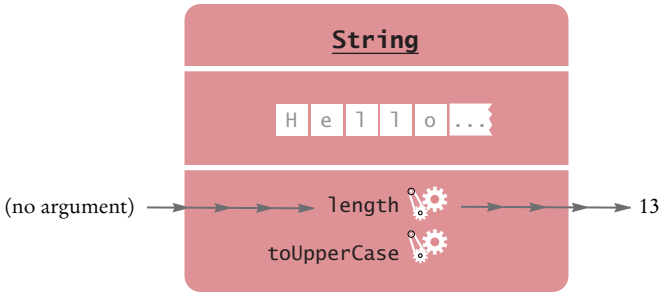


Figure 7
Invoking the `length` Method on a `String` Object

2.3.3 Return Values

The return value of a method is a result that the method has computed.

Some methods, such as the `println` method, carry out an action for you. Other methods compute and return a value. For example, the `length` method *returns a value*, namely the number of characters in the string. You can store the return value in a variable:

```
int numberOfCharacters = greeting.length();
```

You can also use the return value of one method as an argument of another method:

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

The method call `greeting.length()` returns a value—the integer 13. The return value becomes an argument of the `println` method. Figure 8 shows the process.

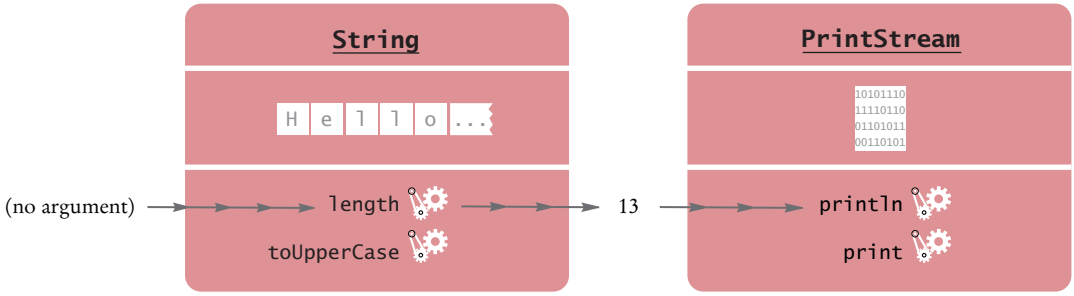


Figure 8 Passing the Result of a Method Call to Another Method

Not all methods return values. One example is the `println` method. The `println` method interacts with the operating system, causing characters to appear in a window. But it does not return a value to the code that calls it.

Let us analyze a more complex method call. Here, we will call the `replace` method of the `String` class. The `replace` method carries out a search-and-replace operation, similar to that of a word processor. For example, the call

```
river.replace("issipp", "our")
```

constructs a new string that is obtained by replacing all occurrences of `"issipp"` in `"Mississippi"` with `"our"`. (In this situation, there was only one replacement.) The method returns the `String` object `"Missouri"`. You can save that string in a variable:

```
river = river.replace("issipp", "our");
```

Or you can pass it to another method:

```
System.out.println(river.replace("issipp", "our"));
```

As Figure 9 shows, this method call

- Is invoked on a `String` object: `"Mississippi"`
- Has two arguments: the strings `"issipp"` and `"our"`
- Returns a value: the string `"Missouri"`

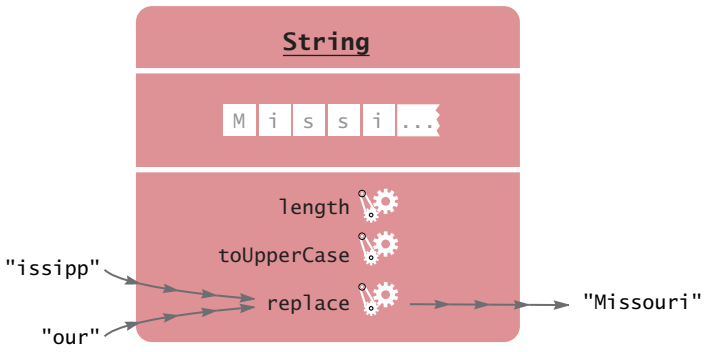


Figure 9 Calling the `replace` Method

Table 3 Method Arguments and Return Values

Example	Comments
`System.out.println(greeting)`	`greeting` is an argument of the `println` method.
`greeting.replace("e","3")`	The `replace` method has two arguments, in this case `"e"` and `"3"`.
`greeting.length()`	The `length` method has no arguments.
`int n = greeting.length();`	The `length` method returns an integer value.
`System.out.println(n);`	The `println` method returns no value. In the API documentation, its return type is `void`.
`System.out.println(greeting.length());`	The return value of one method can become the argument of another.

2.3.4 Method Declarations

When a method is declared in a class, the declaration specifies the types of the arguments and the return value. For example, the `String` class declares the `length` method as

```
public int length()
```

That is, there are no arguments, and the return value has the type `int`. (For now, all the methods that we consider will be "public" methods—see Chapter 9 for more restricted methods.)

The `replace` method is declared as

```
public String replace(String target, String replacement)
```

To call the `replace` method, you supply two arguments, `target` and `replacement`, which both have type `String`. The returned value is another string.

When a method returns no value, the return type is declared with the reserved word **`void`**. For example, the `PrintStream` class declares the `println` method as

```
public void println(String output)
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that demonstrates method calls.

Occasionally, a class declares two methods with the same name and different argument types. For example, the `PrintStream` class declares a second method, also called `println`, as

```
public void println(int output)
```

That method is used to print an integer value. We say that the `println` name is **overloaded** because it refers to more than one method.

14. How can you compute the length of the string `"Mississippi"`?
15. How can you print out the uppercase version of `"Hello, World!"`?
16. Is it legal to call `river.println()`? Why or why not?
17. What are the arguments in the method call `river.replace("p", "s")`?
18. What is the result of the call `river.replace("p", "s")`?
19. What is the result of the call `greeting.replace("World", "Dave").length()`?
20. How is the `toUpperCase` method declared in the `String` class?

Practice It Now you can try these exercises at the end of the chapter: R2.8, R2.9, R2.10.

Programming Tip 2.2

Learn By Trying

When you learn about a new method, write a small program to try it out. For example, you can go right now to your Java development environment and run this program:

```
public class ReplaceDemo
{
   public static void main(String[] args)
   {
      String river = "Mississippi";
      System.out.println(river.replace("issipp", "our"));
   }
}
```

Then you can see with your own eyes what the `replace` method does. Also, you can run experiments. Does `replace` change every match, or only the first one? Try it out:

```
System.out.println(river.replace("i", "x"));
```

Set up your work environment to make this kind of experimentation easy and natural. Keep a file with the blank outline of a Java program around, so you can copy and paste it when needed. Alternatively, some development environments will automatically type the class and `main` method. Find out if yours does. Some environments even let you type commands into a window and show you the result right away, without having to make a `main` method to call `System.out.println` (see Figure 10).

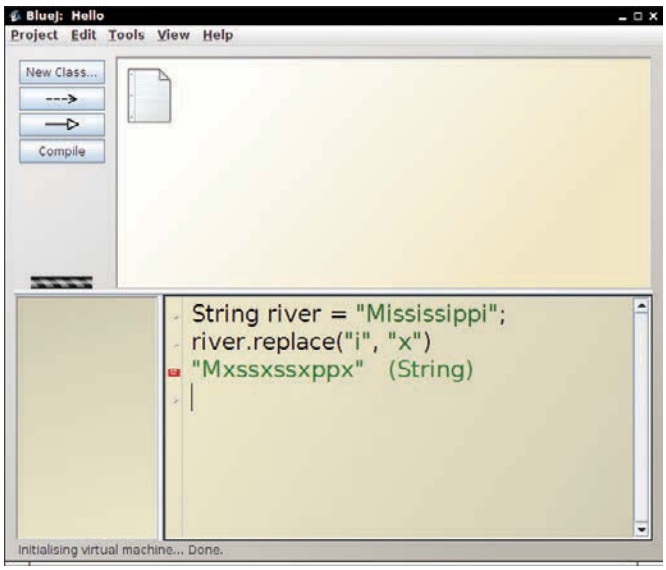


Figure 10 The Code Pad in BlueJ

2.4 Constructing Objects

Generally, when you want to use objects in your program, you need to specify their initial properties by *constructing* them.

To learn about object construction, we need to go beyond `String` objects and the `System.out` object. Let us turn to another class in the Java library: the `Rectangle` class. Objects of type `Rectangle` describe rectangular shapes. These objects are useful for a variety of purposes. You can assemble rectangles into bar charts, and you can program simple games by moving rectangles inside a window.

Note that a `Rectangle` object isn't a rectangular shape—it's an object that contains a set of numbers. The numbers *describe* the rectangle (see Figure 11). Each rectangle is described by the *x*- and *y*-coordinates of its top-left corner, its width, and its height.

Objects of the `Rectangle` *class describe rectangular shapes.*

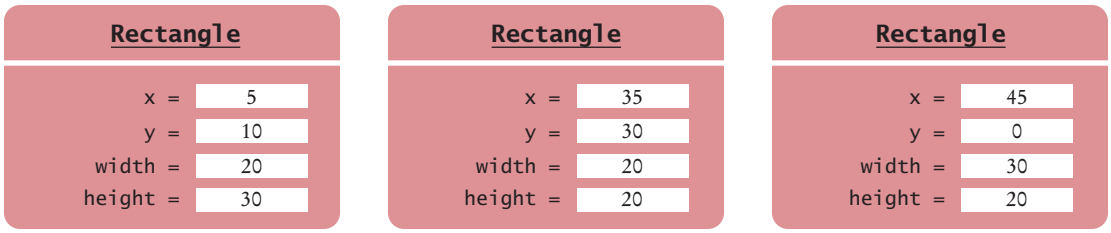


Figure 11 `Rectangle` Objects

It is very important that you understand this distinction. In the computer, a `Rectangle` object is a block of memory that holds four numbers, for example $x = 5$, $y = 10$, *width* = 20, *height* = 30. In the imagination of the programmer who uses a `Rectangle` object, the object describes a geometric figure.

Use the `new` operator, followed by a class name and arguments, to construct new objects.

To make a new rectangle, you need to specify the x, y, *width*, and *height* values. Then *invoke the* `new` *operator*, specifying the name of the class and the argument(s) required for constructing a new object. For example, you can make a new rectangle with its top-left corner at (5, 10), width 20, and height 30 as follows:

```
new Rectangle(5, 10, 20, 30)
```

Here is what happens in detail:

1. The `new` operator makes a `Rectangle` object.
2. It uses the arguments (in this case, 5, 10, 20, and 30) to initialize the object's data.
3. It returns the object.

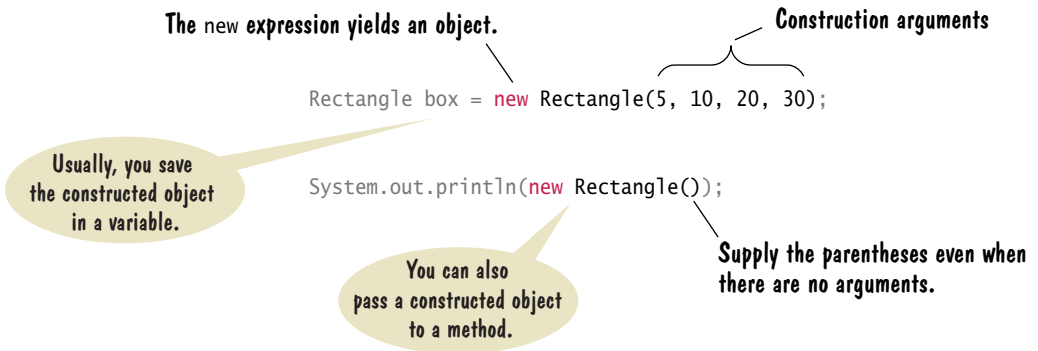
The process of creating a new object is called **construction**. The four values 5, 10, 20, and 30 are called the *construction arguments*.

The `new` expression yields an object, and you need to store the object if you want to use it later. Usually you assign the output of the `new` operator to a variable. For example,

```
Rectangle box = new Rectangle(5, 10, 20, 30);
```

Syntax 2.3 Object Construction

Syntax `new` *ClassName*(*arguments*)



FULL CODE EXAMPLE

Go to wiley.com/go/bjeo6code to download a program that demonstrates constructors.

Some classes let you construct objects in multiple ways. For example, you can also obtain a `Rectangle` object by supplying no construction arguments at all (but you must still supply the parentheses):

```
new Rectangle()
```

This expression constructs a (rather useless) rectangle with its top-left corner at the origin (0, 0), width 0, and height 0.

SELF CHECK

21. How do you construct a square with center (100, 100) and side length 20?
22. Initialize the variables `box` and `box2` with two rectangles that touch each other.
23. The `getWidth` method returns the width of a `Rectangle` object. What does the following statement print?

```
System.out.println(new Rectangle().getWidth());
```

24. The `PrintStream` class has a constructor whose argument is the name of a file. How do you construct a `PrintStream` object with the construction argument `"output.txt"`?
25. Write a statement to save the object that you constructed in Self Check 24 in a variable.

Practice It Now you can try these exercises at the end of the chapter: R2.13, R2.16, R2.18.

Common Error 2.3

Trying to Invoke a Constructor Like a Method

Constructors are not methods. You can only use a constructor with the `new` operator, not to reinitialize an existing object:

```
box.Rectangle(20, 35, 20, 30); // Error—can't reinitialize object
```

The remedy is simple: Make a new object and overwrite the current one stored by `box`.

```
box = new Rectangle(20, 35, 20, 30); // OK
```

2.5 Accessor and Mutator Methods

An accessor method does not change the internal data of the object on which it is invoked. A mutator method changes the data.

In this section we introduce a useful terminology for the methods of a class. A method that accesses an object and returns some information about it, without changing the object, is called an **accessor method**. In contrast, a method whose purpose is to modify the internal data of an object is called a **mutator method**.

For example, the `length` method of the `String` class is an accessor method. It returns information about a string, namely its length. But it doesn't modify the string at all when counting the characters.

The `Rectangle` class has a number of accessor methods. The `getX`, `getY`, `getWidth`, and `getHeight` methods return the x- and y-coordinates of the top-left corner, the width, and the height values. For example,

```
double width = box.getWidth();
```

Now let us consider a mutator method. Programs that manipulate rectangles frequently need to move them around, for example, to display animations. The `Rectangle` class has a method for that purpose, called `translate`. (Mathematicians use the term "translation" for a rigid motion of the plane.) This method moves a rectangle by a certain distance in the x- and y-directions. The method call,

```
box.translate(15, 25);
```

moves the rectangle by 15 units in the x-direction and 25 units in the y-direction (see Figure 12). Moving a rectangle doesn't change its width or height, but it changes the top-left corner. Afterward, the rectangle that had its top-left corner at (5, 10) now has it at (20, 35).

This method is a mutator because it modifies the object on which the method is invoked.

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that demonstrates accessors and mutators.

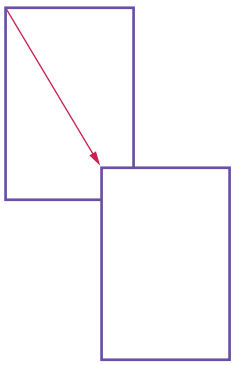


Figure 12 Using the `translate` Method to Move a Rectangle

SELF CHECK

26. What does this sequence of statements print?

```
Rectangle box = new Rectangle(5, 10, 20, 30);
System.out.println("Before: " + box.getX());
box.translate(25, 40);
System.out.println("After: " + box.getX());
```

27. What does this sequence of statements print?

```
Rectangle box = new Rectangle(5, 10, 20, 30);
System.out.println("Before: " + box.getWidth());
box.translate(25, 40);
System.out.println("After: " + box.getWidth());
```

28. What does this sequence of statements print?

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

29. Is the `toUpperCase` method of the `String` class an accessor or a mutator?

30. Which call to `translate` is needed to move the rectangle declared by `Rectangle box = new Rectangle(5, 10, 20, 30)` so that its top-left corner is the origin (0, 0)?

Practice It Now you can try these exercises at the end of the chapter: R2.19, E2.7, E2.9.

2.6 The API Documentation

The API (Application Programming Interface) documentation lists the classes and methods of the Java library.

The classes and methods of the Java library are listed in the **API documentation**. The API is the "application programming interface". A programmer who uses the Java classes to put together a computer program (or *application*) is an *application programmer*. That's you. In contrast, the programmers who designed and implemented the library classes such as `PrintStream` and `Rectangle` are *system programmers*.

You can find the API documentation on the Web. Point your web browser to `http://docs.oracle.com/javase/8/docs/api/index.html`. An abbreviated version of the API documentation is provided in Appendix D that may be easier to use at first, but you should eventually move on to the real thing.

2.6.1 Browsing the API Documentation

The API documentation documents all classes in the Java library—there are thousands of them (see Figure 13, top). Most of the classes are rather specialized, and only a few are of interest to the beginning programmer.

Locate the `Rectangle` link in the left pane, preferably by using the search function of your browser. Click on the link, and the right pane shows all the features of the `Rectangle` class (see Figure 13, bottom).

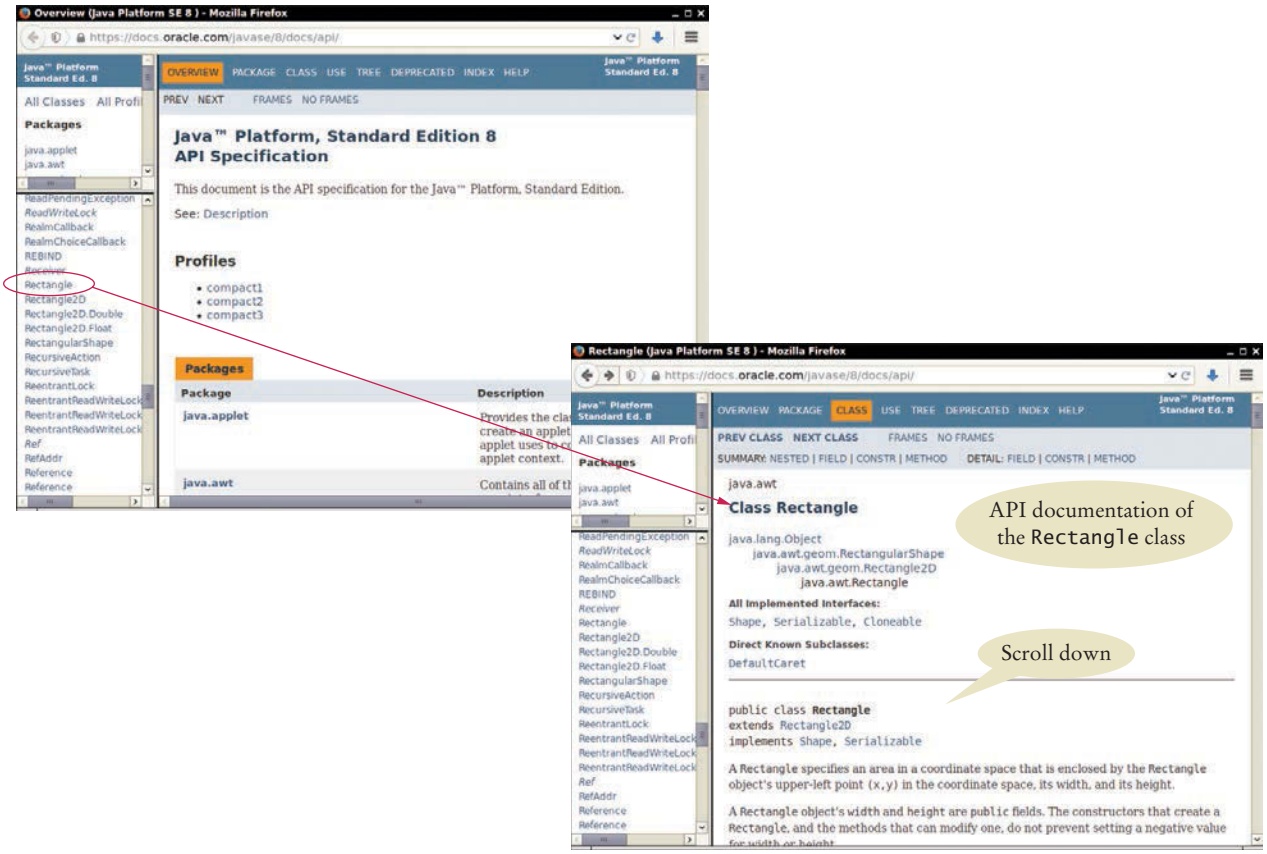


Figure 13 The API Documentation of the Standard Java Library

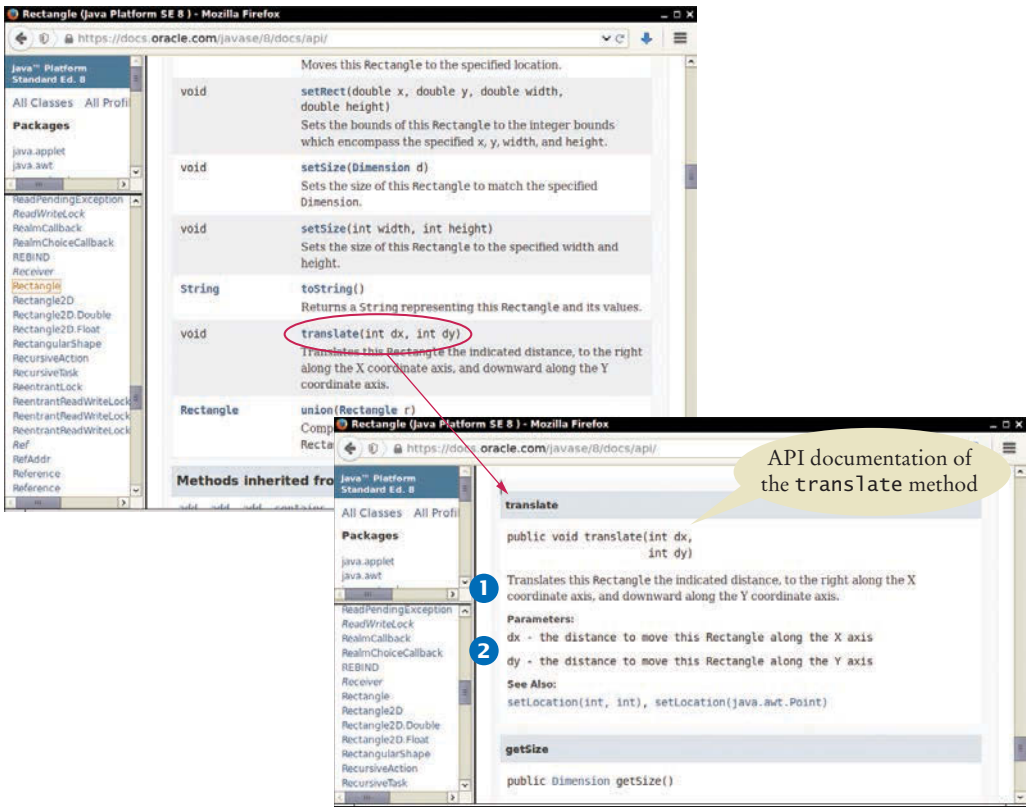


Figure 14 The Method Summary for the `Rectangle` Class

The API documentation for each class starts out with a section that describes the purpose of the class. Then come summary tables for the constructors and methods (see Figure 14, top). Click on a method's link to get a detailed description (see Figure 14, bottom).

The detailed description of a method shows

- The action that the method carries out. 1
- The types and names of the parameter variables that receive the arguments when the method is called. 2
- The value that it returns (or the reserved word `void` if the method doesn't return any value).

As you can see, the `Rectangle` class has quite a few methods. While occasionally intimidating for the beginning programmer, this is a strength of the standard library. If you ever need to do a computation involving rectangles, chances are that there is a method that does all the work for you.

For example, suppose you want to change the width or height of a rectangle. If you browse through the API documentation, you will find a `setSize` method with the description "Sets the size of this `Rectangle` to the specified width and height." The method has two arguments, described as

- `width` - the new width for this `Rectangle`
- `height` - the new height for this `Rectangle`

We can use this information to change the box object so that it is a square of side length 40. The name of the method is setSize, and we supply two arguments: the new width and height:

```
box.setSize(40, 40);
```

2.6.2 Packages

The API documentation contains another important piece of information about each class. The classes in the standard library are organized into **packages**. A package is a collection of classes with a related purpose. The Rectangle class belongs to the package java.awt (where awt is an abbreviation for "Abstract Windowing Toolkit"), which contains many classes for drawing windows and graphical shapes. You can see the package name java.awt in Figure 13, just above the class name.

Java classes are grouped into packages. Use the import statement to use classes that are declared in other packages.

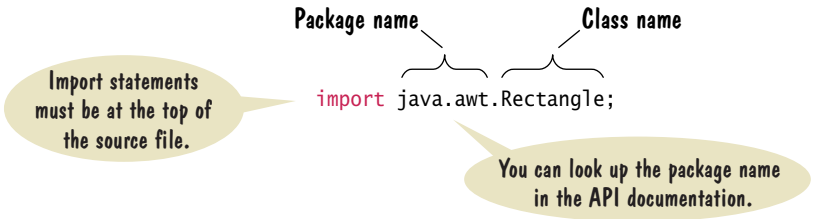
To use the Rectangle class from the java.awt package, you must *import* the package. Simply place the following line at the top of your program:

```
import java.awt.Rectangle;
```

Why don't you have to import the System and String classes? Because the System and String classes are in the java.lang package, and all classes from this package are automatically imported, so you never need to import them yourself.

Syntax 2.4 Importing a Class from a Package

Syntax `import` *packageName.ClassName*;



31. Look at the API documentation of the String class. Which method would you use to obtain the string "hello, world!" from the string "Hello, World!"?
32. In the API documentation of the String class, look at the description of the trim method. What is the result of applying trim to the string " Hello, Space ! "? (Note the spaces in the string.)
33. Look into the API documentation of the Rectangle class. What is the difference between the methods void translate(int x, int y) and void setLocation(int x, int y)?
34. The Random class is declared in the java.util package. What do you need to do in order to use that class in your program?

35. In which package is the `BigInteger` class located? Look it up in the API documentation.

Practice It Now you can try these exercises at the end of the chapter: R2.20, E2.5, E2.12.

Programming Tip 2.3

Don't Memorize—Use Online Help

The Java library has thousands of classes and methods. It is neither necessary nor useful trying to memorize them. Instead, you should become familiar with using the API documentation. Because you will need to use the API documentation all the time, it is best to download and install it onto your computer, particularly if your computer is not always connected to the Internet. You can download the documentation from `http://www.oracle.com/technetwork/java/javase/downloads/index.html`.

2.7 Implementing a Test Program

A test program verifies that methods behave as expected.

In this section, we discuss the steps that are necessary to implement a test program. The purpose of a test program is to verify that one or more methods have been implemented correctly. A test program calls methods and checks that they return the expected results. Writing test programs is a very important skill.

In this section, we will develop a simple program that tests a method in the `Rectangle` class using these steps:

1. Provide a tester class.
2. Supply a `main` method.
3. Inside the `main` method, construct one or more objects.
4. Apply methods to the objects.
5. Display the results of the method calls.
6. Display the values that you expect to get.

Our sample test program tests the behavior of the `translate` method. Here are the key steps (which have been placed inside the `main` method of the `MoveTester` class).

```
Rectangle box = new Rectangle(5, 10, 20, 30);

// Move the rectangle
box.translate(15, 25);

// Print information about the moved rectangle
System.out.print("x: ");
System.out.println(box.getX());
System.out.println("Expected: 20");
```

We print the value that is returned by the `getX` method, and then we print a message that describes the value we expect to see.

Determining the expected result in advance is an important part of testing.

This is a very important step. You want to spend some time thinking about the expected result before you run a test program. This thought process will help you understand how your program should behave, and it can help you track down errors at an early stage. Finding and fixing errors early is a very effective strategy that can save you a great deal of time.

In our case, the rectangle has been constructed with the top-left corner at (5, 10). The x-direction is moved by 15, so we expect an x-value of 5 + 15 = 20 after the move.

Here is the program that tests the moving of a rectangle:

section_7/MoveTester.java

```
1  import java.awt.Rectangle;
2
3  public class MoveTester
4  {
5     public static void main(String[] args)
6     {
7        Rectangle box = new Rectangle(5, 10, 20, 30);
8
9        // Move the rectangle
10       box.translate(15, 25);
11
12       // Print information about the moved rectangle
13       System.out.print("x: ");
14       System.out.println(box.getX());
15       System.out.println("Expected: 20");
16
17       System.out.print("y: ");
18       System.out.println(box.getY());
19       System.out.println("Expected: 35");
20    }
21 }
```

Program Run

```
x: 20
Expected: 20
y: 35
Expected: 35
```

36. Suppose we had called `box.translate(25, 15)` instead of `box.translate(15, 25)`. What are the expected outputs?

37. Why doesn't the `MoveTester` program need to print the width and height of the rectangle?

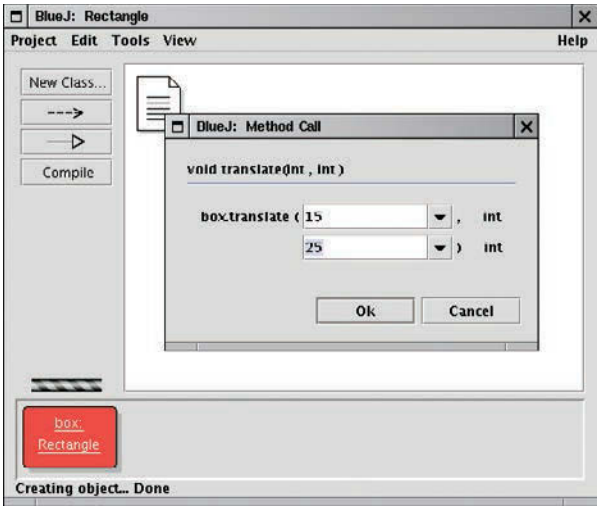
Practice It Now you can try these exercises at the end of the chapter: E2.1, E2.8, E2.14.

Special Topic 2.1

Testing Classes in an Interactive Environment

Some development environments are specifically designed to help students explore objects without having to provide tester classes. These environments can be very helpful for gaining insight into the behavior of objects, and for promoting object-oriented thinking. The BlueJ environment (shown in the figure) displays objects as blobs on a workbench.

You can construct new objects, put them on the workbench, invoke methods, and see the return values, all without writing a line of code. You can download BlueJ at no charge from `www.bluej.org`. Another excellent environment for interactively exploring objects is Dr. Java at `drjava.sourceforge.net`.



Testing a Method Call in BlueJ

WORKED EXAMPLE 2.1 **How Many Days Have You Been Alive?**

Explore the API of a class `Day` that represents a calendar day. Using that class, learn to write a program that computes how many days have elapsed since the day you were born. Go to `wiley.com/go/bjeo6examples` and download Worked Example 2.1.

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WORKED EXAMPLE 2.2 **Working with Pictures**

Learn how to use the API of a `Picture` class to edit photos. Go to `wiley.com/go/bjeo6examples` and download Worked Example 2.2.

Cay Horstmann.

2.8 Object References

In Java, an object variable (that is, a variable whose type is a class) does not actually hold an object. It merely holds the *memory location* of an object. The object itself is stored elsewhere—see Figure 15.

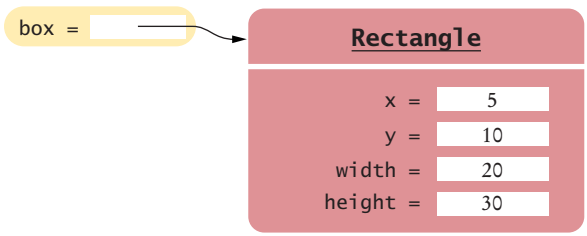


Figure 15 An Object Variable Containing an Object Reference

There is a reason for this behavior. Objects can be very large. It is more efficient to store only the memory location instead of the entire object.

An object reference describes the location of an object.

We use the technical term **object reference** to denote the memory location of an object. When a variable contains the memory location of an object, we say that it *refers* to an object. For example, after the statement

```
Rectangle box = new Rectangle(5, 10, 20, 30);
```

the variable `box` refers to the `Rectangle` object that the `new` operator constructed. Technically speaking, the `new` operator returned a reference to the new object, and that reference is stored in the `box` variable.

It is very important that you remember that the `box` variable *does not contain* the object. It *refers* to the object. Two object variables can refer to the same object:

```
Rectangle box2 = box;
```

Now you can access the same `Rectangle` object as `box` and as `box2`, as shown in Figure 16.

Multiple object variables can contain references to the same object.

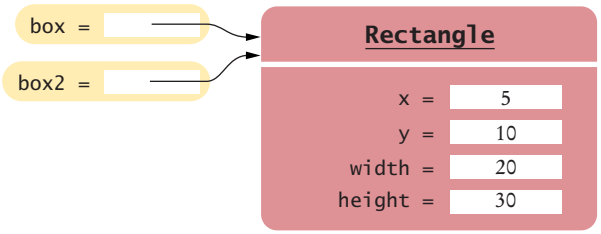


Figure 16 Two Object Variables Referring to the Same Object

In Java, numbers are not objects. Number variables actually store numbers. When you declare

```
int luckyNumber = 13;
```

then the `luckyNumber` variable holds the number 13, not a reference to the number (see Figure 17). The reason is again efficiency. Because numbers require little storage, it is more efficient to store them directly in a variable.

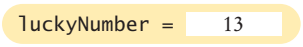


Figure 17 A Number Variable Stores a Number

Number variables store numbers. Object variables store references.

You can see the difference between number variables and object variables when you make a copy of a variable. When you copy a number, the original and the copy of the number are independent values. But when you copy an object reference, both the original and the copy are references to the same object.

Consider the following code, which copies a number and then changes the copy (see Figure 18):

```
int luckyNumber = 13; 1
int luckyNumber2 = luckyNumber; 2
luckyNumber2 = 12; 3
```

Now the variable `luckyNumber` contains the value 13, and `luckyNumber2` contains 12.

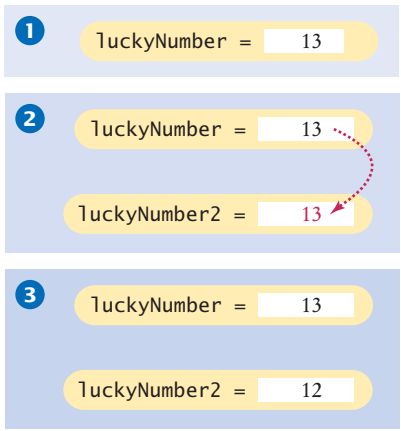


Figure 18
Copying Numbers

FULL CODE EXAMPLE
Go to wiley.com/go/bjeo6code to download a program that demonstrates the difference between copying numbers and object references.

Now consider the seemingly analogous code with `Rectangle` objects (see Figure 19).

```
Rectangle box = new Rectangle(5, 10, 20, 30); 1
Rectangle box2 = box; 2
box2.translate(15, 25); 3
```

Because `box` and `box2` refer to the same rectangle after step 2, both variables refer to the moved rectangle after the call to the `translate` method.

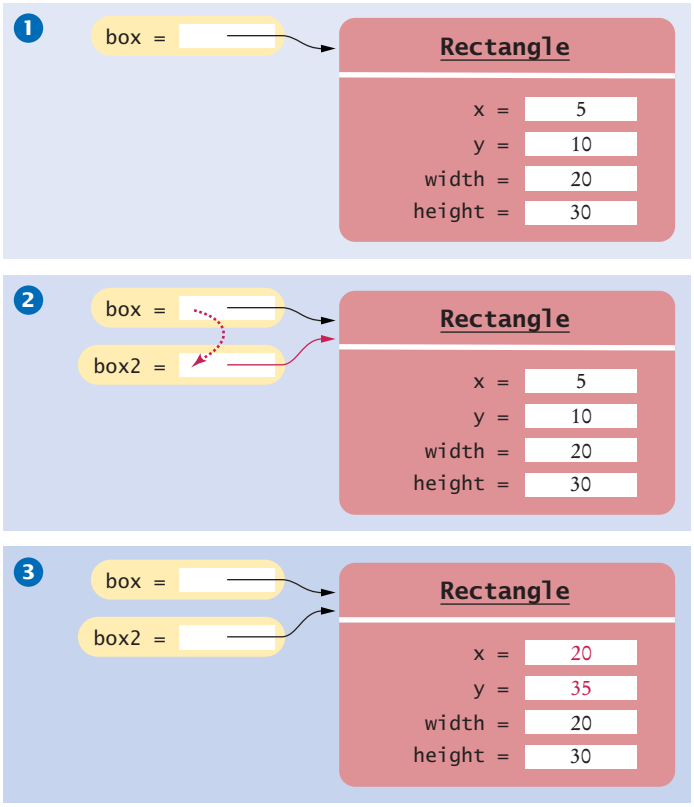


Figure 19 Copying Object References

You need not worry too much about the difference between objects and object references. Much of the time, you will have the correct intuition when you think of the "object `box`" rather than the technically more accurate "object reference stored in variable `box`". The difference between objects and object references only becomes apparent when you have multiple variables that refer to the same object.

38. What is the effect of the assignment `String greeting2 = greeting`?

39. After calling `greeting2.toUpperCase()`, what are the contents of `greeting` and `greeting2`?

Practice It Now you can try these exercises at the end of the chapter: R2.17, R2.21.

Computing & Society 2.1 Computer Monopoly

When International Business Machines Corporation (IBM), a successful manufacturer of punched-card equipment for tabulating data, first turned its attention to designing computers in the early 1950s, its planners assumed that there was a market for perhaps 50 such devices, for installation by the government, the military, and a few of the country's largest corporations. Instead, they sold about 1,500 machines of their System 650 model and went on to build and sell more powerful computers.

These computers, called mainframes, were huge. They filled rooms, which had to be climate-controlled to protect the delicate equipment. IBM was not the first company to build mainframe computers; that honor belongs to the Univac Corporation. However, IBM soon became the major player, partially because of its technical excellence and attention to customer needs and partially because it exploited its strengths and structured its products and services in a way that made it difficult for customers to mix them with those of other vendors.

As all of IBM's competitors fell on hard times, the U.S. government brought an antitrust suit against IBM in 1969. In the United States, it is legal to be a monopoly supplier, but it is not legal to use one's monopoly in one market to gain supremacy in another. IBM was accused of forcing customers to buy bundles of computers, software, and peripherals, making it impossible for other vendors of software and peripherals to compete.

The suit went to trial in 1975 and dragged on until 1982, when it was abandoned, largely because new waves of smaller computers had made it irrelevant.

In fact, when IBM offered its first personal computers, its operating system was supplied by an outside vendor, Microsoft, which became so dominant that it too was sued by the U.S. government for abusing its monopoly position in 1998. Microsoft was accused of bundling its web browser with its operating system. At the time, Microsoft allegedly threatened hardware makers that they would not receive a Windows license if they distributed the competing Netscape browser. In 2000, the company was found guilty of antitrust violations, and the judge ordered it broken up into an operating systems unit and an applications unit. The breakup was reversed on appeal, and a settlement in 2001 was largely unsuccessful in establishing alternatives for desktop software.

Now the computing landscape is shifting once again, toward mobile devices and cloud computing. As you observe that change, you may well see new monopolies in the making. When a software vendor needs the permission of a hardware vendor in order to place a product into an "app store", or when a maker of a digital book reader tries to coerce publishers into a particular pricing structure, the question arises whether such conduct is illegal exploitation of a monopoly position.

A Mainframe Computer

Corbis Digital Stock.

2.9 Graphical Applications

The following optional sections teach you how to write *graphical applications:* applications that display drawings inside a window. The drawings are made up of shape objects: rectangles, ellipses, and lines. The shape objects provide another source of examples, and many students enjoy the visual feedback.

2.9.1 Frame Windows

To show a frame, construct a `JFrame` object, set its size, and make it visible.

A graphical application shows information inside a **frame**: a window with a title bar, as shown in Figure 20. In this section, you will learn how to display a frame. In Section 2.9.2, you will learn how to create a drawing inside the frame.

A graphical application shows information inside a frame.

To show a frame, carry out the following steps:

1. Construct an object of the `JFrame` class:

   ```
   JFrame frame = new JFrame();
   ```

2. Set the size of the frame:

   ```
   frame.setSize(300, 400);
   ```

   This frame will be 300 pixels wide and 400 pixels tall. If you omit this step the frame will be 0 by 0 pixels, and you won't be able to see it. (Pixels are the tiny dots from which digital images are composed.)

3. If you'd like, set the title of the frame:

   ```
   frame.setTitle("An empty frame");
   ```

   If you omit this step, the title bar is simply left blank.

4. Set the "default close operation":

   ```
   frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
   ```

   When the user closes the frame, the program automatically exits. Don't omit this step. If you do, the program keeps running even after the frame is closed.

5. Make the frame visible:

   ```
   frame.setVisible(true);
   ```

The simple program below shows all of these steps. It produces the empty frame shown in Figure 20.

The `JFrame` class is a part of the `javax.swing` package. Swing is the nickname for the graphical user interface library in Java. The "x" in `javax` denotes the fact that Swing started out as a Java *extension* before it was added to the standard library.

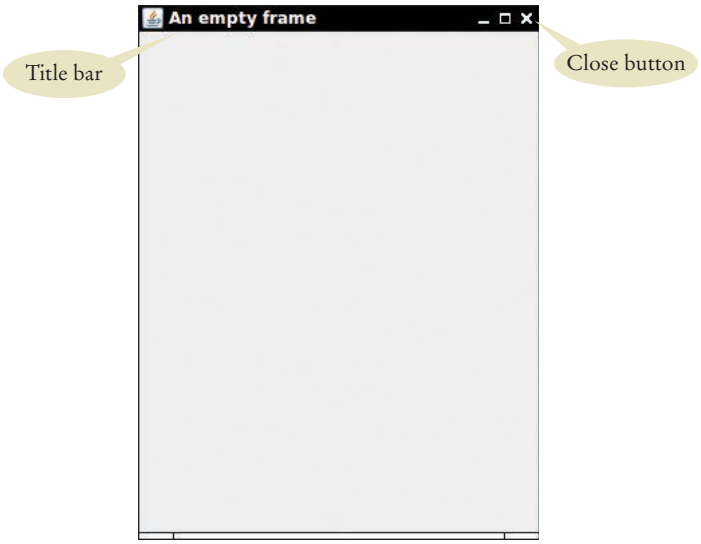


Figure 20 A Frame Window

We will go into much greater detail about Swing programming in Chapters 3, 10, and 20. For now, consider this program to be the essential plumbing that is required to show a frame.

section_9_1/EmptyFrameViewer.java

```
1  import javax.swing.JFrame;
2
3  public class EmptyFrameViewer
4  {
5     public static void main(String[] args)
6     {
7        JFrame frame = new JFrame();
8        frame.setSize(300, 400);
9        frame.setTitle("An empty frame");
10       frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
11       frame.setVisible(true);
12    }
13 }
```

2.9.2 Drawing on a Component

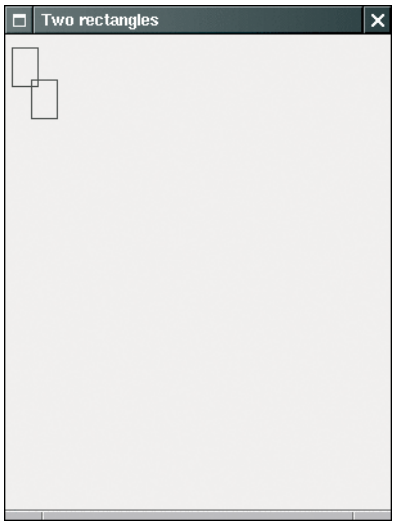
In this section, you will learn how to make shapes appear inside a frame window. The first drawing will be exceedingly modest: just two rectangles (see Figure 21). You'll soon see how to produce more interesting drawings. The purpose of this example is to show you the basic outline of a program that creates a drawing.

You cannot draw directly onto a frame. Instead, drawing happens in a **component** object. In the Swing toolkit, the `JComponent` class represents a blank component.

In order to display a drawing in a frame, declare a class that extends the `JComponent` class.

Because we don't want to add a blank component, we have to modify the `JComponent` class and specify how the component should be painted. The solution is to declare a new class that extends the `JComponent` class. You will learn about the process of extending classes in Chapter 9.

Figure 21
Drawing Rectangles



For now, simply use the following code as a template:

```
public class RectangleComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Drawing instructions.
   }
}
```

Place drawing instructions inside the `paintComponent` method. That method is called whenever the component needs to be repainted.

The `extends` reserved word indicates that our component class, `RectangleComponent`, can be used like a `JComponent`. However, the `RectangleComponent` class will be different from the plain `JComponent` class in one respect: Its `paintComponent` method will contain instructions to draw the rectangles.

When the component is shown for the first time, the `paintComponent` method is called automatically. The method is also called when the window is resized, or when it is shown again after it was hidden.

Use a cast to recover the `Graphics2D` object from the `Graphics` argument of the `paintComponent` method.

The `paintComponent` method receives an object of type `Graphics` as its argument. The `Graphics` object stores the graphics state—the current color, font, and so on—that are used for drawing operations. However, the `Graphics` class is not very useful. When programmers clamored for a more object-oriented approach to drawing graphics, the designers of Java created the `Graphics2D` class, which extends the `Graphics` class. Whenever the Swing toolkit calls the `paintComponent` method, it actually passes an object of type `Graphics2D` as the argument. Because we want to use the more sophisticated methods to draw two-dimensional graphics objects, we need to use the `Graphics2D` class. This is accomplished by using a **cast**:

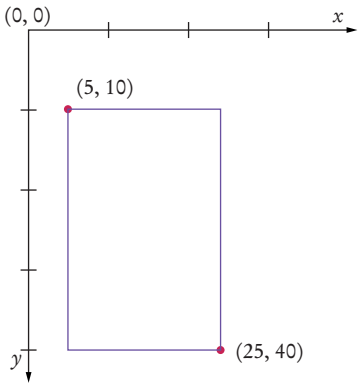
```
public class RectangleComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      // Recover Graphics2D
      Graphics2D g2 = (Graphics2D) g;
      . . .
   }
}
```

Chapter 9 has more information about casting. For now, you should simply include the cast at the top of your `paintComponent` methods.

Now you are ready to draw shapes. The `draw` method of the `Graphics2D` class can draw shapes, such as rectangles, ellipses, line segments, polygons, and arcs. Here we draw a rectangle:

```
public class RectangleComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      . . .
      Rectangle box = new Rectangle(5, 10, 20, 30);
      g2.draw(box);
      . . .
   }
}
```

When positioning the shapes, you need to pay attention to the coordinate system. It is different from the one used in mathematics. The origin (0, 0) is at the upper-left corner of the component, and the *y*-coordinate grows downward.



Following is the source code for the `RectangleComponent` class. Note that the `paintComponent` method of the `RectangleComponent` class draws two rectangles. As you can see from the `import` statements, the `Graphics` and `Graphics2D` classes are part of the `java.awt` package.

section_9_2/RectangleComponent.java

```
1  import java.awt.Graphics;
2  import java.awt.Graphics2D;
3  import java.awt.Rectangle;
4  import javax.swing.JComponent;
5
6  /**
7     A component that draws two rectangles.
8  */
9  public class RectangleComponent extends JComponent
10 {
11    public void paintComponent(Graphics g)
12    {
13       // Recover Graphics2D
14       Graphics2D g2 = (Graphics2D) g;
15
```

```
16         // Construct a rectangle and draw it
17         Rectangle box = new Rectangle(5, 10, 20, 30);
18         g2.draw(box);
19
20         // Move rectangle 15 units to the right and 25 units down
21         box.translate(15, 25);
22
23         // Draw moved rectangle
24         g2.draw(box);
25      }
26   }
```

2.9.3 Displaying a Component in a Frame

In a graphical application, you need a frame to show the application, and you need a component for the drawing. In this section, you will see how to combine the two. Follow these steps:

1. Construct a frame object and configure it.
2. Construct an object of your component class:

   ```
   RectangleComponent component = new RectangleComponent();
   ```

3. Add the component to the frame:

   ```
   frame.add(component);
   ```

4. Make the frame visible.

The following listing shows the complete process.

section_9_3/RectangleViewer.java

```
1  import javax.swing.JFrame;
2
3  public class RectangleViewer
4  {
5     public static void main(String[] args)
6     {
7        JFrame frame = new JFrame();
8
9        frame.setSize(300, 400);
10       frame.setTitle("Two rectangles");
11       frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
12
13       RectangleComponent component = new RectangleComponent();
14       frame.add(component);
15
16       frame.setVisible(true);
17    }
18 }
```

Note that the rectangle drawing program consists of two classes:

- The `RectangleComponent` class, whose `paintComponent` method produces the drawing.
- The `RectangleViewer` class, whose `main` method constructs a frame and a `RectangleComponent`, adds the component to the frame, and makes the frame visible.

40. How do you display a square frame with a title bar that reads "Hello, World!"?
41. How can a program display two frames at once?
42. How do you modify the program to draw two squares?
43. How do you modify the program to draw one rectangle and one square?
44. What happens if you call `g.draw(box)` instead of `g2.draw(box)`?

Practice It Now you can try these exercises at the end of the chapter: R2.22, R2.26, E2.18.

2.10 Ellipses, Lines, Text, and Color

In Section 2.9 you learned how to write a program that draws rectangles. In the following sections, you will learn how to draw other shapes: ellipses and lines. With these graphical elements, you can draw quite a few interesting pictures.

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You can make simple drawings out of lines, rectangles, and circles.

2.10.1 Ellipses and Circles

To draw an ellipse, you specify its bounding box (see Figure 22) in the same way that you would specify a rectangle, namely by the x- and y-coordinates of the top-left corner and the width and height of the box.

The `Ellipse2D.Double` and `Line2D.Double` classes describe graphical shapes.

However, there is no simple `Ellipse` class that you can use. Instead, you must use one of the two classes `Ellipse2D.Float` and `Ellipse2D.Double`, depending on whether you want to store the ellipse coordinates as single- or double-precision floating-point values. Because the latter are more convenient to use in Java, we will always use the `Ellipse2D.Double` class.

Here is how you construct an ellipse:

```
Ellipse2D.Double ellipse = new Ellipse2D.Double(x, y, width, height);
```

The class name `Ellipse2D.Double` looks different from the class names that you have encountered up to now. It consists of two class names `Ellipse2D` and `Double` separated

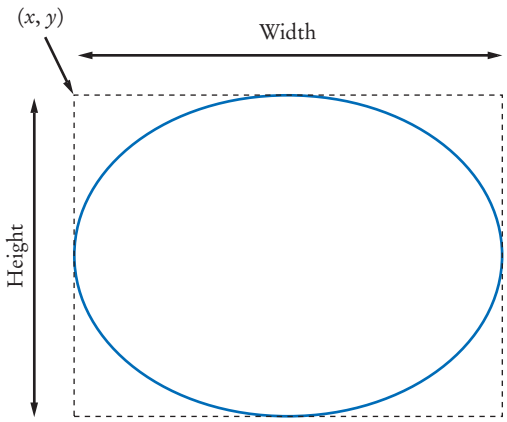


Figure 22 An Ellipse and Its Bounding Box

by a period (.). This indicates that `Ellipse2D.Double` is a so-called **inner class** inside `Ellipse2D`. When constructing and using ellipses, you don't actually need to worry about the fact that `Ellipse2D.Double` is an inner class—just think of it as a class with a long name. However, in the `import` statement at the top of your program, you must be careful that you import only the outer class:

```
import java.awt.geom.Ellipse2D;
```

Drawing an ellipse is easy: Use exactly the same `draw` method of the `Graphics2D` class that you used for drawing rectangles.

```
g2.draw(ellipse);
```

To draw a circle, simply set the width and height to the same values:

```
Ellipse2D.Double circle = new Ellipse2D.Double(x, y, diameter, diameter);
g2.draw(circle);
```

Notice that (*x*, *y*) is the top-left corner of the bounding box, not the center of the circle.

2.10.2 Lines

To draw a line, use an object of the `Line2D.Double` class. A line is constructed by specifying its two end points. You can do this in two ways. Give the *x*- and *y*-coordinates of both end points:

```
Line2D.Double segment = new Line2D.Double(x1, y1, x2, y2);
```

Or specify each end point as an object of the `Point2D.Double` class:

```
Point2D.Double from = new Point2D.Double(x1, y1);
Point2D.Double to = new Point2D.Double(x2, y2);

Line2D.Double segment = new Line2D.Double(from, to);
```

The second option is more object-oriented and is often more useful, particularly if the point objects can be reused elsewhere in the same drawing.

2.10.3 Drawing Text

The `drawString` method draws a string, starting at its basepoint.

You often want to put text inside a drawing, for example, to label some of the parts. Use the `drawString` method of the `Graphics2D` class to draw a string anywhere in a window. You must specify the string and the *x*- and *y*-coordinates of the basepoint of the first character in the string (see Figure 23). For example,

```
g2.drawString("Message", 50, 100);
```

Figure 23 Basepoint and Baseline

2.10.4 Colors

When you first start drawing, all shapes and strings are drawn with a black pen. To change the color, you need to supply an object of type `Color`. Java uses the RGB color model. That is, you specify a color by the amounts of the primary colors—red, green, and blue—that make up the color. The amounts are given as integers between 0 (primary color not present) and 255 (maximum amount present). For example,

```
Color magenta = new Color(255, 0, 255);
```

constructs a `Color` object with maximum red, no green, and maximum blue, yielding a bright purple color called magenta.

For your convenience, a variety of colors have been declared in the `Color` class. Table 4 shows those colors and their RGB values. For example, `Color.PINK` has been declared to be the same color as `new Color(255, 175, 175)`.

When you set a new color in the graphics context, it is used for subsequent drawing operations.

To draw a shape in a different color, first set the color of the `Graphics2D` object, then call the `draw` method:

```
g2.setColor(Color.RED);
g2.draw(circle); // Draws the shape in red
```

If you want to color the inside of the shape, use the `fill` method instead of the `draw` method. For example,

```
g2.fill(circle);
```

fills the inside of the circle with the current color.

Table 4 Predefined Colors

Color	RGB Values
`Color.BLACK`	0, 0, 0
`Color.BLUE`	0, 0, 255
`Color.CYAN`	0, 255, 255
`Color.GRAY`	128, 128, 128
`Color.DARK_GRAY`	64, 64, 64
`Color.LIGHT_GRAY`	192, 192, 192
`Color.GREEN`	0, 255, 0
`Color.MAGENTA`	255, 0, 255
`Color.ORANGE`	255, 200, 0
`Color.PINK`	255, 175, 175
`Color.RED`	255, 0, 0
`Color.WHITE`	255, 255, 255
`Color.YELLOW`	255, 255, 0

Figure 24 An Alien Face

The following program puts all these shapes to work, creating a simple drawing (see Figure 24).

section_10/FaceComponent.java

```
1  import java.awt.Color;
2  import java.awt.Graphics;
3  import java.awt.Graphics2D;
4  import java.awt.Rectangle;
5  import java.awt.geom.Ellipse2D;
6  import java.awt.geom.Line2D;
7  import javax.swing.JComponent;
8
9  /**
10    A component that draws an alien face.
11 */
12 public class FaceComponent extends JComponent
13 {
14    public void paintComponent(Graphics g)
15    {
16       // Recover Graphics2D
17       Graphics2D g2 = (Graphics2D) g;
18
19       // Draw the head
20       Ellipse2D.Double head = new Ellipse2D.Double(5, 10, 100, 150);
21       g2.draw(head);
22
23       // Draw the eyes
24       g2.setColor(Color.GREEN);
25       Rectangle eye = new Rectangle(25, 70, 15, 15);
26       g2.fill(eye);
27       eye.translate(50, 0);
28       g2.fill(eye);
29
30       // Draw the mouth
31       Line2D.Double mouth = new Line2D.Double(30, 110, 80, 110);
32       g2.setColor(Color.RED);
33       g2.draw(mouth);
34
35       // Draw the greeting
36       g2.setColor(Color.BLUE);
37       g2.drawString("Hello, World!", 5, 175);
38    }
39 }
```

section_10/FaceViewer.java

```
1  import javax.swing.JFrame;
2
3  public class FaceViewer
4  {
5     public static void main(String[] args)
6     {
7        JFrame frame = new JFrame();
8        frame.setSize(150, 250);
9        frame.setTitle("An Alien Face");
10       frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
11
12       FaceComponent component = new FaceComponent();
13       frame.add(component);
14
15       frame.setVisible(true);
16    }
17 }
```

45. Give instructions to draw a circle with center (100, 100) and radius 25.
46. Give instructions to draw a letter "V" by drawing two line segments.
47. Give instructions to draw a string consisting of the letter "V".
48. What are the RGB color values of `Color.BLUE`?
49. How do you draw a yellow square on a red background?

Practice It Now you can try these exercises at the end of the chapter: R2.27, E2.19, E2.20.

CHAPTER SUMMARY

Identify objects, methods, and classes.

- Objects are entities in your program that you manipulate by calling methods.
- A method is a sequence of instructions that accesses the data of an object.
- A class describes a set of objects with the same behavior.

Write variable declarations and assignments.

- A variable is a storage location with a name.
- When declaring a variable, you usually specify an initial value.
- When declaring a variable, you also specify the type of its values.
- Use the `int` type for numbers that cannot have a fractional part.
- Use the `double` type for floating-point numbers.
- Numbers can be combined by arithmetic operators such as +, -, and *.
- By convention, variable names should start with a lowercase letter.
- Use comments to add explanations for humans who read your code. The compiler ignores comments.

- Use the assignment operator (=) to change the value of a variable.
- All variables must be initialized before you access them.
- The assignment operator = does *not* denote mathematical equality.

Recognize arguments and return values of methods.

- The public interface of a class specifies what you can do with its objects. The hidden implementation describes how these actions are carried out.
- An argument is a value that is supplied in a method call.
- The return value of a method is a result that the method has computed.

Use constructors to construct new objects.

- Use the `new` operator, followed by a class name and arguments, to construct new objects.

Classify methods as accessor and mutator methods.

- An accessor method does not change the internal data of the object on which it is invoked. A mutator method changes the data.

Use the API documentation for finding method descriptions and packages.

- The API (Application Programming Interface) documentation lists the classes and methods of the Java library.
- Java classes are grouped into packages. Use the `import` statement to use classes that are declared in other packages.

Write programs that test the behavior of methods.

- A test program verifies that methods behave as expected.
- Determining the expected result in advance is an important part of testing.

Describe how multiple object references can refer to the same object.

- An object reference describes the location of an object.
- Multiple object variables can contain references to the same object.
- Number variables store numbers. Object variables store references.

Write programs that display frame windows.

- To show a frame, construct a `JFrame` object, set its size, and make it visible.
- In order to display a drawing in a frame, declare a class that extends the `JComponent` class.

- Place drawing instructions inside the `paintComponent` method. That method is called whenever the component needs to be repainted.
- Use a cast to recover the `Graphics2D` object from the `Graphics` argument of the `paintComponent` method.

Use the Java API for drawing simple figures.

- The `Ellipse2D.Double` and `Line2D.Double` classes describe graphical shapes.
- The `drawString` method draws a string, starting at its basepoint.
- When you set a new color in the graphics context, it is used for subsequent drawing operations.

STANDARD LIBRARY ITEMS INTRODUCED IN THIS CHAPTER

```
java.awt.Color
java.awt.Component
   getHeight
   getWidth
   setSize
   setVisible
java.awt.Frame
   setTitle
java.awt.geom.Ellipse2D.Double
java.awt.geom.Line2D.Double
java.awt.geom.Point2D.Double
java.awt.Graphics
   setColor
java.awt.Graphics2D
   draw
   drawString
   fill
java.awt.Rectangle
   getX
   getY
   getHeight
   getWidth
   setSize
   translate
java.lang.String
   length
   replace
   toLowerCase
   toUpperCase
javax.swing.JComponent
   paintComponent
javax.swing.JFrame
   setDefaultCloseOperation
```

REVIEW EXERCISES

- **R2.1** Explain the difference between an object and a class.
- **R2.2** Give three examples of objects that belong to the `String` class. Give an example of an object that belongs to the `PrintStream` class. Name two methods that belong to the `String` class but not the `PrintStream` class. Name a method of the `PrintStream` class that does not belong to the `String` class.
- **R2.3** What is the *public interface* of a class? How does it differ from the *implementation* of a class?
- **R2.4** Declare and initialize variables for holding the price and the description of an article that is available for sale.
- **R2.5** What is the value of `mystery` after this sequence of statements?

```
int mystery = 1;
mystery = 1 - 2 * mystery;
mystery = mystery + 1;
```

- **R2.6** What is wrong with the following sequence of statements?

```
int mystery = 1;
mystery = mystery + 1;
int mystery = 1 - 2 * mystery;
```

■■ **R2.7** Explain the difference between the = symbol in Java and in mathematics.

■■ **R2.8** Give an example of a method that has an argument of type `int`. Give an example of a method that has a return value of type `int`. Repeat for the type `String`.

■■ **R2.9** Write Java statements that initialize a string `message` with `"Hello"` and then change it to `"HELLO"`. Use the `toUpperCase` method.

■■ **R2.10** Write Java statements that initialize a string `message` with `"Hello"` and then change it to `"hello"`. Use the `replace` method.

■■ **R2.11** Write Java statements that initialize a string `message` with a message such as `"Hello, World"` and then remove punctuation characters from the message, using repeated calls to the `replace` method.

■ **R2.12** Explain the difference between an object and an object variable.

■■ **R2.13** Give the Java code for constructing an *object* of class `Rectangle`, and for declaring an *object variable* of class `Rectangle`.

■■ **R2.14** Give Java code for objects with the following descriptions:

a. A rectangle with center (100, 100) and all side lengths equal to 50

b. A string with the contents "Hello, Dave"

Create objects, not object variables.

■■ **R2.15** Repeat Exercise R2.14, but now declare object variables that are initialized with the required objects.

■■ **R2.16** Write a Java statement to initialize a variable `square` with a rectangle object whose top-left corner is (10, 20) and whose sides all have length 40. Then write a statement that replaces `square` with a rectangle of the same size and top-left corner (20, 20).

■■ **R2.17** Write Java statements that initialize two variables `square1` and `square2` to refer to the same square with center (20, 20) and side length 40.

■■ **R2.18** Find the errors in the following statements:

a.
```
Rectangle r = (5, 10, 15, 20);
```

b.
```
double width = Rectangle(5, 10, 15, 20).getWidth();
```

c.
```
Rectangle r;
r.translate(15, 25);
```

d.
```
r = new Rectangle();
r.translate("far, far away!");
```

■ **R2.19** Name two accessor methods and two mutator methods of the `Rectangle` class.

■■ **R2.20** Consult the API documentation to find methods for

- Concatenating two strings, that is, making a string consisting of the first string, followed by the second string.
- Removing leading and trailing white space of a string.
- Converting a rectangle to a string.
- Computing the smallest rectangle that contains two given rectangles.
- Returning a random floating-point number.

For each method, list the class in which it is defined, the return type, the method name, and the types of the arguments.

■ **R2.21** Explain the difference between an object and an object reference.

■ **Graphics R2.22** What is the difference between a console application and a graphical application?

■■ **Graphics R2.23** Who calls the `paintComponent` method of a component? When does the call to the `paintComponent` method occur?

■■ **Graphics R2.24** Why does the argument of the `paintComponent` method have type `Graphics` and not `Graphics2D`?

■■ **Graphics R2.25** What is the purpose of a graphics context?

■■ **Graphics R2.26** Why are separate viewer and component classes used for graphical programs?

■ **Graphics R2.27** How do you specify a text color?

PRACTICE EXERCISES

■ **Testing E2.1** Write an `AreaTester` program that constructs a `Rectangle` object and then computes and prints its area. Use the `getWidth` and `getHeight` methods. Also print the expected answer.

■ **Testing E2.2** Write a `PerimeterTester` program that constructs a `Rectangle` object and then computes and prints its perimeter. Use the `getWidth` and `getHeight` methods. Also print the expected answer.

■■ **E2.3** Write a program that initializes a string with `"Mississippi"`. Then replace all `"i"` with `"ii"` and print the length of the resulting string. In that string, replace all `"ss"` with `"s"` and print the length of the resulting string.

■ **E2.4** Write a program that constructs a rectangle with area 42 and a rectangle with perimeter 42. Print the widths and heights of both rectangles.

■■ **Testing E2.5** Look into the API documentation of the `Rectangle` class and locate the method

```
void add(int newx, int newy)
```

Read through the method documentation. Then determine the result of the following statements:

```
Rectangle box = new Rectangle(5, 10, 20, 30);
box.add(0, 0);
```

Write a program `AddTester` that prints the expected and actual location, width, and height of `box` after the call to `add`.

■■ **Testing E2.6** Write a program `ReplaceTester` that encodes a string by replacing all letters `"i"` with `"!"` and all letters `"s"` with `"$"`. Use the `replace` method. Demonstrate that you can correctly encode the string `"Mississippi"`. Print both the actual and expected result.

■■■ **E2.7** Write a program `HollePrinter` that switches the letters `"e"` and `"o"` in a string. Use the `replace` method repeatedly. Demonstrate that the string `"Hello, World!"` turns into `"Holle, Werld!"`

■ **Testing E2.8** The `StringBuilder` class has a method for reversing a string. In a `ReverseTester` class, construct a `StringBuilder` from a given string (such as `"desserts"`), call the `reverse` method followed by the `toString` method, and print the result. Also print the expected value.

■■ **E2.9** In the Java library, a color is specified by its red, green, and blue components between 0 and 255 (see Table 4 on page 66). Write a program `BrighterDemo` that constructs a `Color` object with red, green, and blue values of 50, 100, and 150. Then apply the `brighter` method of the `Color` class and print the red, green, and blue values of the resulting color. (You won't actually see the color—see Exercise E2.10 on how to display the color.)

■■ **Graphics E2.10** Repeat Exercise E2.9, but place your code into the following class. Then the color will be displayed.

```
import java.awt.Color;
import javax.swing.JFrame;

public class BrighterDemo
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();
      frame.setSize(200, 200);
      Color myColor = . . .;
      frame.getContentPane().setBackground(myColor);
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

■■ **E2.11** Repeat Exercise E2.9, but apply the `darker` method of the `Color` class twice to the object `Color.RED`. Call your class `DarkerDemo`.

■■ **E2.12** The `Random` class implements a *random number generator*, which produces sequences of numbers that appear to be random. To generate random integers, you construct an object of the `Random` class, and then apply the `nextInt` method. For example, the call `generator.nextInt(6)` gives you a random number between 0 and 5.

Write a program `DieSimulator` that uses the `Random` class to simulate the cast of a die, printing a random number between 1 and 6 every time that the program is run.

■■ **E2.13** Write a program `RandomPrice` that prints a random price between $10.00 and $19.95 every time the program is run.

■■ **Testing E2.14** Look at the API of the `Point` class and find out how to construct a `Point` object. In a `PointTester` program, construct two points with coordinates (3, 4) and (–3, –4). Find the distance between them, using the `distance` method. Print the distance, as well as the expected value. (Draw a sketch on graph paper to find the value you will expect.)

■ **E2.15** Using the `Day` class of Worked Example 2.1, write a `DayTester` program that constructs a `Day` object representing today, adds ten days to it, and then computes the difference between that day and today. Print the difference and the expected value.

■■ **E2.16** Using the `Picture` class of Worked Example 2.2, write a `HalfSizePicture` program that loads a picture and shows it at half the original size, centered in the window.

■■ **E2.17** Using the `Picture` class of Worked Example 2.2, write a `DoubleSizePicture` program that loads a picture, doubles its size, and shows the center of the picture in the window.

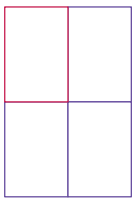
■■ **Graphics E2.18** Write a graphics program that draws two squares, both with the same center. Provide a class `TwoSquareViewer` and a class `TwoSquareComponent`.

■■ **Graphics E2.19** Write a program that draws two solid squares: one in pink and one in purple. Use a standard color for one of them and a custom color for the other. Provide a class `TwoSquareViewer` and a class `TwoSquareComponent`.

■■ **Graphics E2.20** Write a graphics program that draws your name in red, contained inside a blue rectangle. Provide a class `NameViewer` and a class `NameComponent`.

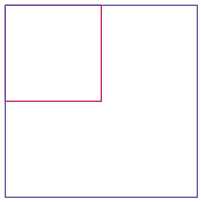
PROGRAMMING PROJECTS

■■ **P2.1** Write a program called `FourRectanglePrinter` that constructs a `Rectangle` object, prints its location by calling `System.out.println(box)`, and then translates and prints it three more times, so that, if the rectangles were drawn, they would form one large rectangle, as shown at right.



Your program will not produce a drawing. It will simply print the locations of the four rectangles.

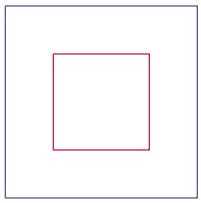
■■ **P2.2** Write a `GrowSquarePrinter` program that constructs a `Rectangle` object `square` representing a square with top-left corner (100, 100) and side length 50, prints its location by calling `System.out.println(square)`, applies the `translate` and `grow` methods, and calls `System.out.println(square)` again. The calls to `translate` and `grow` should modify the square so that it has twice the size and the same top-left corner as the original. If the squares were drawn, they would look like the figure at right.



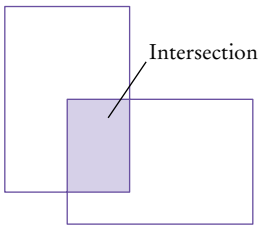
Your program will not produce a drawing. It will simply print the locations of `square` before and after calling the mutator methods.

Look up the description of the `grow` method in the API documentation.

■■■ **P2.3** Write a `CenteredSquaresPrinter` program that constructs a `Rectangle` object `square` representing a square with top-left corner (100, 100) and side length 200, prints its location by calling `System.out.println(square)`, applies the `grow` and `translate` methods, and calls `System.out.println(square)` again. The calls to `grow` and `translate` should modify the square so that it has half the width and is centered in the original square. If the squares were drawn, they would look like the figure at right. Your program will not produce a drawing. It will simply print the locations of square before and after calling the mutator methods. Look up the description of the `grow` method in the API documentation.



■■■ **P2.4** The `intersection` method computes the *intersection* of two rectangles—that is, the rectangle that would be formed by two overlapping rectangles if they were drawn, as shown at right.



You call this method as follows:

```
Rectangle r3 = r1.intersection(r2);
```

Write a program `IntersectionPrinter` that constructs two rectangle objects, prints them as described in Exercise P2.1, and then prints the rectangle object that describes the intersection. Then the program should print the result of the `intersection` method when the rectangles do not overlap. Add a comment to your program that explains how you can tell whether the resulting rectangle is empty.

■■■ **Graphics P2.5** In this exercise, you will explore a simple way of visualizing a `Rectangle` object. The `setBounds` method of the `JFrame` class moves a frame window to a given rectangle. Complete the following program to visually show the `translate` method of the `Rectangle` class:

```
import java.awt.Rectangle;
import javax.swing.JFrame;
import javax.swing.JOptionPane;

public class TranslateDemo
{
   public static void main(String[] args)
   {
      // Construct a frame and show it
      JFrame frame = new JFrame();
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);

      // Your work goes here: Construct a rectangle and set the frame bounds

      JOptionPane.showMessageDialog(frame, "Click OK to continue");

      // Your work goes here: Move the rectangle and set the frame bounds again
   }
}
```

■■■ **P2.6** Write a program `LotteryPrinter` that picks a combination in a lottery. In this lottery, players can choose 6 numbers (possibly repeated) between 1 and 49. Construct an object of the `Random` class (see Exercise E2.12) and invoke an appropriate method to generate each number. (In a real lottery, repetitions aren't allowed, but we haven't yet discussed the programming constructs that would be required to deal with that problem.) Your program should print out a sentence such as "Play this combination—it'll make you rich!", followed by a lottery combination.

■■ **P2.7** Using the `Day` class of Worked Example 2.1, write a program that generates a `Day` object representing February 28 of this year, and three more such objects that represent February 28 of the next three years. Advance each object by one day, and print each object. Also print the expected values:

```
2016-02-29
Expected: 2016-02-29
2017-03-01
Expected: 2017-03-01
. . .
```

■■■ **P2.8** The `GregorianCalendar` class describes a point in time, as measured by the Gregorian calendar, the standard calendar that is commonly used throughout the world today. You construct a `GregorianCalendar` object from a year, month, and day of the month, like this:

```
GregorianCalendar cal = new GregorianCalendar(); // Today's date
GregorianCalendar eckertsBirthday = new GregorianCalendar(1919,
      Calendar.APRIL, 9);
```

Use the values `Calendar.JANUARY . . . Calendar.DECEMBER` to specify the month.

The `add` method can be used to add a number of days to a `GregorianCalendar` object:

```
cal.add(Calendar.DAY_OF_MONTH, 10); // Now cal is ten days from today
```

This is a mutator method—it changes the `cal` object.

The `get` method can be used to query a given `GregorianCalendar` object:

```
int dayOfMonth = cal.get(Calendar.DAY_OF_MONTH);
int month = cal.get(Calendar.MONTH);
int year = cal.get(Calendar.YEAR);
int weekday = cal.get(Calendar.DAY_OF_WEEK);
   // 1 is Sunday, 2 is Monday, . . . , 7 is Saturday
```

Your task is to write a program that prints:

- The date and weekday that is 100 days from today.
- The weekday of your birthday.
- The date that is 10,000 days from your birthday.

Use the birthday of a computer scientist if you don't want to reveal your own.

Hint: The `GregorianCalendar` class is complex, and it is a really good idea to write a few test programs to explore the API before tackling the whole problem. Start with a program that constructs today's date, adds ten days, and prints out the day of the month and the weekday.

■■ P2.9 In Java 8, the `LocalDate` class describes a calendar date that does not depend on a location or time zone. You construct a date like this:

```
LocalDate today = LocalDate.now(); // Today's date
LocalDate eckertsBirthday = LocalDate(1919, 4, 9);
```

The `plusDays` method can be used to add a number of days to a `LocalDate` object:

```
LocalDate later = today.plusDays(10); // Ten days from today
```

This method does not mutate the `today` object, but it returns a new object that is a given number of days away from `today`.

To get the year of a day, call

```
int year = today.getYear();
```

To get the weekday of a `LocalDate`, call

```
String weekday = today.getDayOfWeek().toString();
```

Your task is to write a program that prints

- The weekday of "Pi day", that is, March 14, of the current year.
- The date and weekday of "Programmer's day" in the current year; that is, the 256th day of the year. (The number 256, or 2^8, is useful for some programming tasks.)
- The date and weekday of the date that is 10,000 days earlier than today.

■■■ Testing P2.10 Write a program `LineDistanceTester` that constructs a line joining the points (100, 100) and (200, 200), then constructs points (100, 200), (150, 150), and (250, 50). Print the distance from the line to each of the three points, using the `ptSegDist` method of the `Line2D` class. Also print the expected values. (Draw a sketch on graph paper to find what values you expect.)

■■ Graphics P2.11 Repeat Exercise P2.10, but now write a graphical application that shows the line and the points. Draw each point as a tiny circle. Use the `drawString` method to draw each distance next to the point, using calls

```
g2.drawString("Distance: " + distance, p.getX(), p.getY());
```

■■ Graphics P2.12 Write a graphics program that draws 12 strings, one each for the 12 standard colors (except `Color.WHITE`), each in its own color. Provide a class `ColorNameViewer` and a class `ColorNameComponent`.

■■ **Graphics P2.13** Write a program to plot the face at right. Provide a class `FaceViewer` and a class `FaceComponent`.

■■ **Graphics P2.14** Write a graphical program that draws a traffic light.

■■ **Graphics P2.15** Run the following program:

```
import java.awt.Color;
import javax.swing.JFrame;
import javax.swing.JLabel;

public class FrameViewer
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();
      frame.setSize(200, 200);
      JLabel label = new JLabel("Hello, World!");
      label.setOpaque(true);
      label.setBackground(Color.PINK);
      frame.add(label);
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

Modify the program as follows:

- Double the frame size.
- Change the greeting to "Hello, *your name*!".
- Change the background color to pale green (see Exercise E2.10).
- For extra credit, add an image of yourself. (*Hint:* Construct an `ImageIcon`.)

ANSWERS TO SELF-CHECK QUESTIONS

1. Objects with the same behavior belong to the same class. A window lets in light while protecting a room from the outside wind and heat or cold. A water heater has completely different behavior. It heats water. They belong to different classes.
2. When one calls a method, one is not concerned with how it does its job. As long as a light bulb illuminates a room, it doesn't matter to the occupant how the photons are produced.
3. When you compile the program, you get an error message that the `String` class doesn't have a `println` method.
4. There are three errors:
   - You cannot have spaces in variable names.
   - The variable type should be `double` because it holds a fractional value.
   - There is a semicolon missing at the end of the statement.
5. `double unitPrice = 1.95;`
   `int quantity = 2;`
6. `System.out.print("Total price: ");`
   `System.out.println(unitPrice * quantity);`
7. `int` and `String`
8. `double`
9. Only the first two are legal identifiers.
10. `String myName = "John Q. Public";`
11. No, the left-hand side of the = operator must be a variable.
12. `greeting = "Hello, Nina!";`

    Note that

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

    is not the right answer—that statement declares a new variable.
13. Assignment would occur when one car is replaced by another in the parking space.
14. `river.length()` or `"Mississippi".length()`

15. `System.out.println(greeting.toUpperCase());`
or
```
System.out.println(
   "Hello, World!".toUpperCase());
```

16. It is not legal. The variable `river` has type `String`. The `println` method is not a method of the `String` class.

17. The arguments are the strings "p" and "s".

18. `"Missississi"`

19. 12

20. As `public String toUpperCase()`, with no argument and return type `String`.

21. `new Rectangle(90, 90, 20, 20)`

22.
```
Rectangle box = new Rectangle(5, 10, 20, 30);
Rectangle box2 = new Rectangle(25, 10, 20, 30);
```

23. 0

24. `new PrintStream("output.txt");`

25. `PrintStream out = new PrintStream("output.txt");`

26.
```
Before: 5
After: 30
```

27.
```
Before: 20
After: 20
```
Moving the rectangle does not affect its width or height. You can change the width and height with the `setSize` method.

28.
```
HELLO
hello
```
Note that calling `toUpperCase` doesn't modify the string.

29. An accessor—it doesn't modify the original string but returns a new string with uppercase letters.

30. `box.translate(-5, -10)`, provided the method is called immediately after storing the new rectangle into `box`.

31. `toLowerCase`

32. `"Hello, Space !"`—only the leading and trailing spaces are trimmed.

33. The arguments of the `translate` method tell how far to move the rectangle in the *x*- and *y*-directions. The arguments of the `setLocation` method indicate the new *x*- and *y*-values for the top-left corner.
For example, `box.translate(1, 1)` moves the `box` one pixel down and to the right. `box.setLocation(1, 1)` moves `box` to the top-left corner of the screen.

34. Add the statement `import java.util.Random;` at the top of your program.

35. In the `java.math` package.

36. `x: 30, y: 25`

37. Because the `translate` method doesn't modify the shape of the rectangle.

38. Now `greeting` and `greeting2` both refer to the same `String` object.

39. Both variables still refer to the same string, and the string has not been modified. Recall that the `toUpperCase` method constructs a new string that contains uppercase characters, leaving the original string unchanged.

40. Modify the `EmptyFrameViewer` program as follows:
```
frame.setSize(300, 300);
frame.setTitle("Hello, World!");
```

41. Construct two `JFrame` objects, set each of their sizes, and call `setVisible(true)` on each of them.

42. Change line 17 of `RectangleComponent` to
```
Rectangle box = new Rectangle(5, 10, 20, 20);
```

43. Replace the call to `box.translate(15, 25)` with
```
box = new Rectangle(20, 35, 20, 20);
```

44. The compiler complains that `g` doesn't have a `draw` method.

45. `g2.draw(new Ellipse2D.Double(75, 75, 50, 50));`

46.
```
Line2D.Double segment1
   = new Line2D.Double(0, 0, 10, 30);
g2.draw(segment1);
Line2D.Double segment2
   = new Line2D.Double(10, 30, 20, 0);
g2.draw(segment2);
```

47. `g2.drawString("V", 0, 30);`

48. `0, 0, 255`

49. First fill a big red square, then fill a small yellow square inside:
```
g2.setColor(Color.RED);
g2.fill(new Rectangle(0, 0, 200, 200));
g2.setColor(Color.YELLOW);
g2.fill(new Rectangle(50, 50, 100, 100));
```

WORKED EXAMPLE 2.1 How Many Days Have You Been Alive?

Many programs need to process dates such as "February 15, 2010". The `worked_example_1` directory of this chapter's companion code contains a `Day` class that was designed to work with calendar days.

The `Day` class knows about the intricacies of our calendar, such as the fact that January has 31 days and February has 28 or sometimes 29. The Julian calendar, instituted by Julius Caesar in the first century BCE, introduced the rule that every fourth year is a leap year. In 1582, Pope Gregory XIII ordered the implementation of the calendar that is in common use throughout the world today, called the Gregorian calendar. It refines the leap year rule by specifying that years divisible by 100 are not leap years, unless they are divisible by 400. Thus, the year 1900 was not a leap year but the year 2000 was. All of these details are handled by the internals of the `Day` class.

The `Day` class lets you answer questions such as

- How many days are there between now and the end of the year?
- What day is 100 days from now?

Problem Statement Your task is to write a program that determines how many days you have been alive. You should *not* look inside the internal implementation of the `Day` class. Use the API documentation by pointing your browser to the file `index.html` in the `ch02/worked_example_1/api` subdirectory.

As you can see from the API documentation (see figure on next page), you construct a `Day` object from a given year, month, and day, like this:

```
Day jamesGoslingsBirthday = new Day(1955, 5, 19);
```

There is a method for adding days to a given day, for example:

```
Day later = jamesGoslingsBirthday.addDays(100);
```

You can then find out what the result is, by applying the `getYear/getMonth/getDate` methods:

```
System.out.println(later.getYear());
System.out.println(later.getMonth());
System.out.println(later.getDate());
```

However, that approach does not solve our problem (unless you are willing to replace 100 with other values until, by trial and error, you obtain today's date). Instead, use the `daysFrom` method. According to the API documentation, we need to supply another day. That is, the method is called like this:

```
int daysAlive = day1.daysFrom(day2);
```

In our situation, one of the `Day` objects is `jamesGoslingsBirthday`, and the other is today's date. This can be obtained with the constructor that has no arguments:

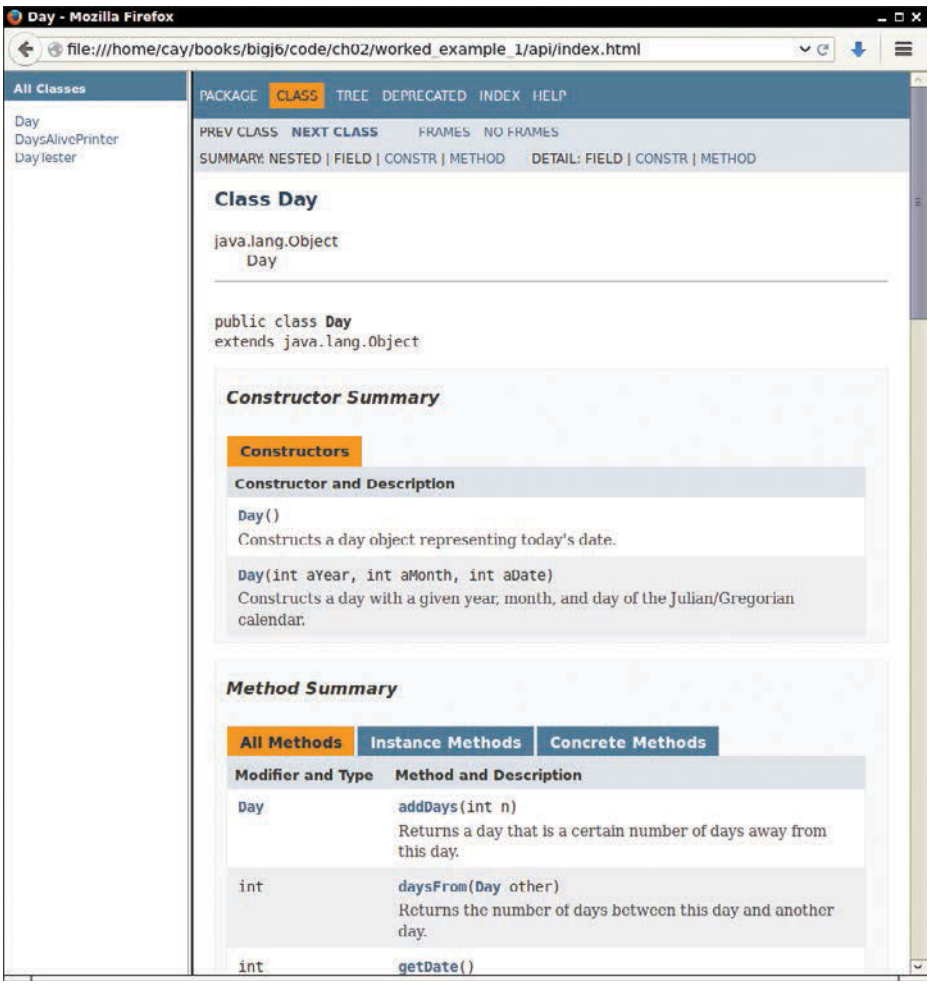
```
Day today = new Day();
```

We have two candidates on which the `daysFrom` method could be invoked, yielding the call

```
int daysAlive = jamesGoslingsBirthday.daysFrom(today);
```

or

```
int daysAlive = today.daysFrom(jamesGoslingsBirthday);
```



Which is the right choice? Fortunately, the author of the `Day` class has anticipated this question. The detail comment of the `daysFrom` method contains this statement:

> `Returns:` the number of days that this day is away from the other
> (larger than `0` if this day comes later than `other`)

We want a positive result. Therefore, the second form is the correct one.

Here is the program that solves our problem (see `ch02/worked_example_1` in your source code):

worked_example_1/DaysAlivePrinter.java

```
1  public class DaysAlivePrinter
2  {
3     public static void main(String[] args)
4     {
5        Day jamesGoslingsBirthday = new Day(1955, 5, 19);
6        Day today = new Day();
7        System.out.print("Today: ");
8        System.out.println(today.toString());
9        int daysAlive = today.daysFrom(jamesGoslingsBirthday);
```

```
10         System.out.print("Days alive: ");
11         System.out.println(daysAlive);
12      }
13   }
```

Program Run

```
Today: 2015-02-09
Days alive: 21826
```

WORKED EXAMPLE 2.2 Working with Pictures

Problem Statement Edit and display image files in the `Picture` class found in the `ch02/worked_example_2` directory of this chapter's companion code.

For example, the following program simply shows the image given below:

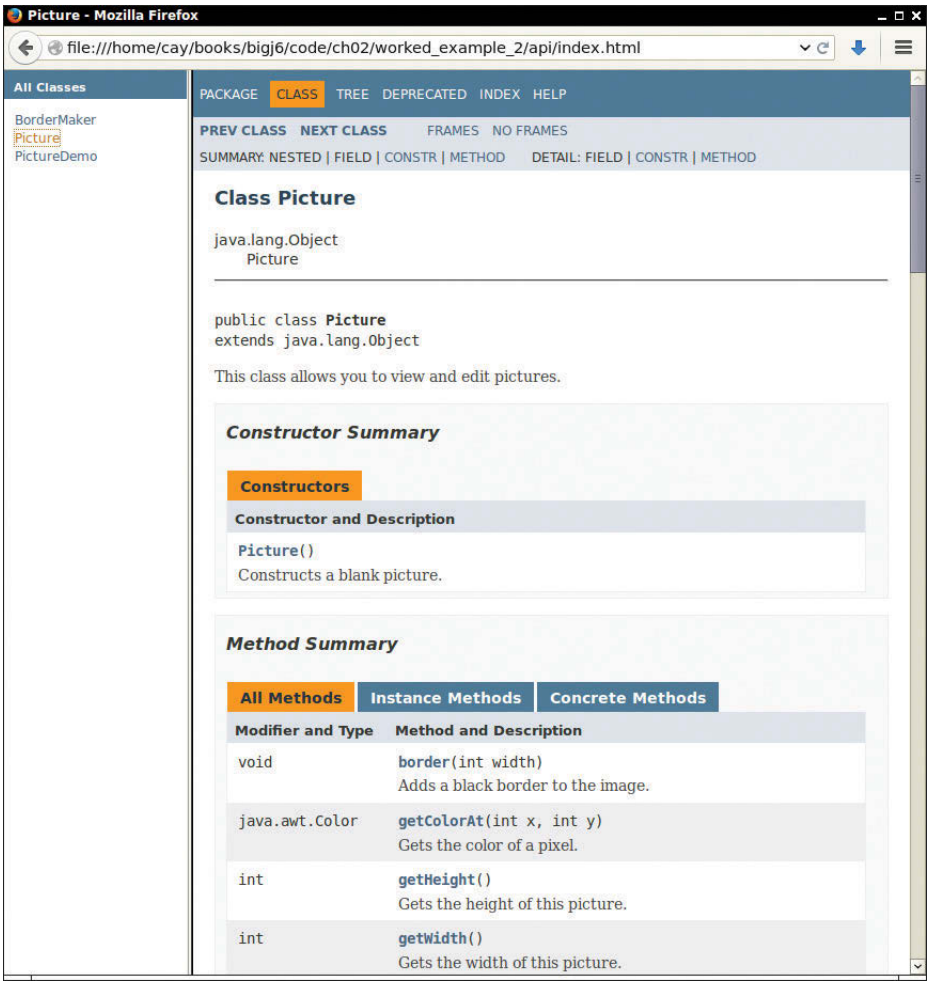
```
public class PictureDemo
{
   public static void main(String[] args)
   {
      Picture pic = new Picture();
      pic.load("queen-mary.png");
   }
}
```

Cay Horstmann.

Your task is to write a program that reads in an image, shrinks it, and adds a border. Shrink it sufficiently so that there is a transparent border inside the black border, as in the figure below.

Cay Horstmann.

You should *not* look inside the internal implementation of the `Picture` class. Instead, use the API documentation by pointing your browser to the file `index.html` in the `worked_example_2/picture/api` subdirectory.



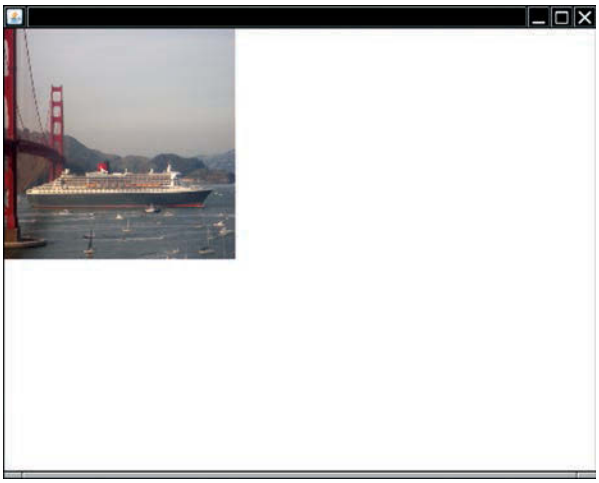
The API contains a number of methods that are unrelated to the task, but two of the methods are clearly useful:

```
public void scale(int newWidth, int newHeight)
public void border(int width)
```

If the method comments are not clear, it is a good idea to write a couple of simple test programs to see their effect. For example, this program demonstrates the `scale` method:

```
public class PictureScaleDemo
{
   public static void main(String[] args)
   {
      Picture pic = new Picture();
      pic.load("queen-mary.png");
      pic.scale(200, 200);
   }
}
```

Here is the result:



Cay Horstmann.

As you can see, the picture has been resized to a 200 × 200 pixel square.

That's not quite what we want. We want the picture to be a bit smaller than the original. Let's say that the black border is 10 pixels thick, and we want another transparent border of 10 pixels. Then the target width and height are 40 pixels less than the original, leaving 20 pixels on each side for the borders.

Looking at the API, we find methods for obtaining the original width and height. Therefore, we will call

```
int newWidth = pic.getWidth() - 40;
int newHeight = pic.getHeight() - 40;
pic.scale(newWidth, newHeight);
```

Then we add the border:

```
pic.border(10);
```

The result is

Cay Horstmann.

If we can move the picture a bit before applying the border, we are done. Another look at the API reveals a method

```
public void move(int dx, int dy)
```

That's just what we need. The picture needs to be moved 20 pixels down and to the right. Our final program is

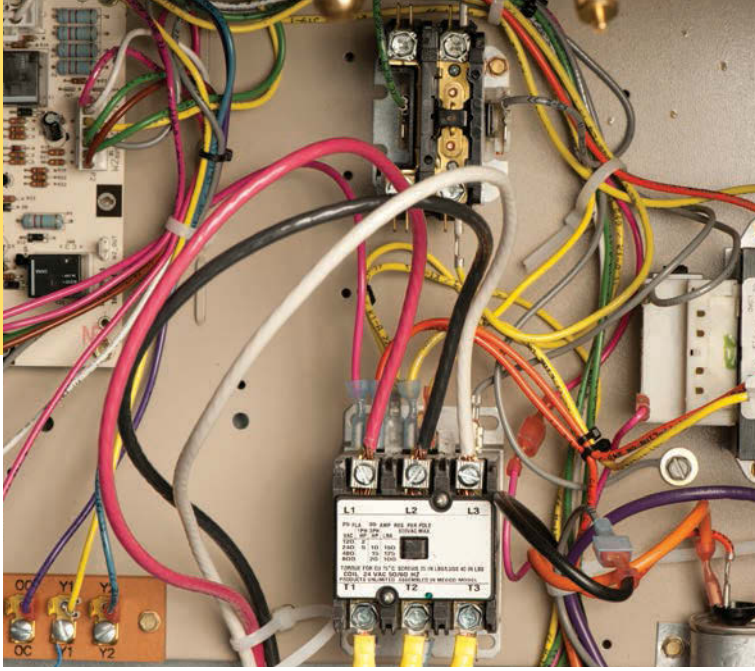
worked_example_2/BorderMaker.java

```
1  public class BorderMaker
2  {
3     public static void main(String[] args)
4     {
5        Picture pic = new Picture();
6        pic.load("queen-mary.png");
7        int newWidth = pic.getWidth() - 40;
8        int newHeight = pic.getHeight() - 40;
9        pic.scale(newWidth, newHeight);
10       pic.move(20, 20);
11       pic.border(10);
12    }
13 }
```

Couldn't we have achieved the same result with an image editing program such as Photoshop or GIMP? Yes, but it is an easy matter to extend this program so that it can automatically apply a border to any number of images.

CHAPTER 3

IMPLEMENTING CLASSES



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CHAPTER GOALS

To become familiar with the process of implementing classes

To be able to implement and test simple methods

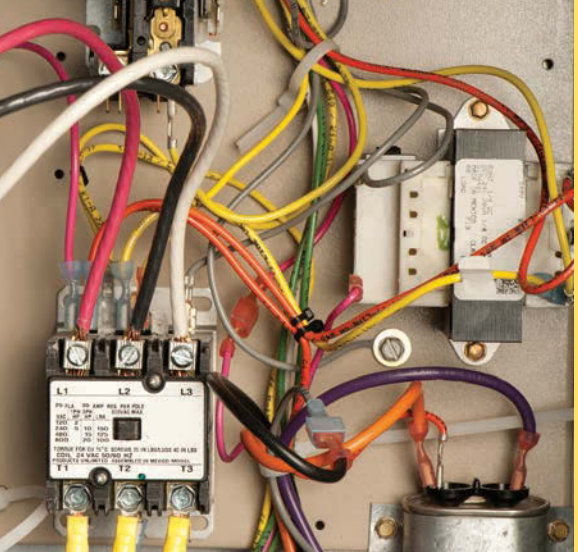
To understand the purpose and use of constructors

To understand how to access instance variables and local variables

To be able to write javadoc comments

To implement classes for drawing graphical shapes

CHAPTER CONTENTS



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In this chapter, you will learn how to implement your own classes. You will start with a given design that specifies the public interface of the class—that is, the methods through which programmers can manipulate the objects of the class. Then you will learn the steps to completing the class—creating the internal "workings" like the inside of an air conditioner shown here. You need to implement the methods, which entails finding a data representation for the objects and supplying the instructions for each method. You need to document your efforts so that other programmers can understand and use your creation. And you need to provide a tester to validate that your class works correctly.

3.1 Instance Variables and Encapsulation

In Chapter 1, you learned how to use objects from existing classes. In this chapter, you will start implementing your own classes. We begin with a very simple example that shows you how objects store their data, and how methods access the data of an object. Our first example is a class that models a *tally counter*, a mechanical device that is used to count people—for example, to find out how many people attend a concert or board a bus (see Figure 1).

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Figure 1 A Tally Counter

3.1.1 Instance Variables

Whenever the operator clicks the button of a tally counter, the counter value advances by one. We model this operation with a `click` method of a `Counter` class. A physical counter has a display to show the current value. In our simulation, we use a `getValue` method to get the current value. For example,

```
Counter tally = new Counter();
tally.click();
tally.click();
int result = tally.getValue(); // Sets result to 2
```

When implementing the `Counter` class, you need to determine the data that each counter object contains. In this simple example, that is very straightforward. Each counter needs a variable that keeps track of the number of simulated button clicks.

An object's instance variables store the data required for executing its methods.

An object stores its data in **instance variables**. An *instance* of a class is an object of the class. Thus, an instance variable is a storage location that is present in each object of the class.

You specify instance variables in the class declaration:

```
public class Counter
{
   private int value;
   . . .
}
```

Syntax 3.1 Instance Variable Declaration

Syntax

```
public class ClassName
{
   private typeName variableName;
   . . .
}
```

```
public class Counter
{
   private int value;
   . . .
}
```

Instance variables should always be private.

Each object of this class has a separate copy of this instance variable.

Type of the variable

An instance variable declaration consists of the following parts:

- An **access specifier** (`private`)
- The **type** of the instance variable (such as `int`)
- The name of the instance variable (such as `value`)

Each object of a class has its own set of instance variables.

Each object of a class has its own set of instance variables. For example, if `concertCounter` and `boardingCounter` are two objects of the `Counter` class, then each object has its own `value` variable (see Figure 2). As you will see in Section 3.3, the instance variable `value` is set to 0 when a `Counter` object is constructed.

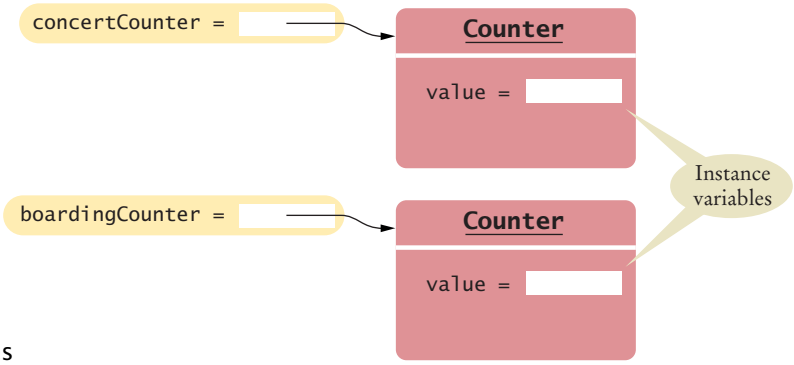

Figure 2
Instance Variables

These clocks have common behavior, but each of them has a different state. Similarly, objects of a class can have their instance variables set to different values.

3.1.2 The Methods of the Counter Class

In this section, we will look at the implementation of the methods of the `Counter` class.

The `click` method advances the counter value by 1. You have seen the method header syntax in Chapter 2. Now, focus on the body of the method inside the braces.

```
public void click()
{
   value = value + 1;
}
```

Note how the `click` method accesses the instance variable `value`. *Which* instance variable? The one belonging to the object on which the method is invoked. For example, consider the call

```
concertCounter.click();
```

This call advances the `value` variable of the `concertCounter` object.

The `getValue` method returns the current value:

```
public int getValue()
{
   return value;
}
```

The `return` statement is a special statement that terminates the method call and returns a result (the **return value**) to the method's caller.

Private instance variables can only be accessed by methods of the same class.

Instance variables are generally declared with the access specifier `private`. That specifier means that they can be accessed only by the methods of the *same class*, not by any other method. For example, the `value` variable can be accessed by the `click` and `getValue` methods of the `Counter` class but not by a method of another class. Those other methods need to use the `Counter` class methods if they want to manipulate a counter's internal data.

3.1.3 Encapsulation

In the preceding section, you learned that you should hide instance variables by making them private. Why would a programmer want to hide something?

The strategy of information hiding is not unique to computer programming—it is used in many engineering disciplines. Consider the thermostat that you find in your home. It is a device that allows a user to set temperature preferences and that controls the furnace and the air conditioner. If you ask your contractor what is inside the thermostat, you will likely get a shrug.

The thermostat is a *black box*, something that magically does its thing. A contractor would never open the control module—it contains electronic parts that can only be serviced at the factory. In general, engineers use the term "black box" to describe any device whose inner workings are hidden. Note that a black box is not totally mysterious. Its interface with the outside world is well-defined. For example, the contractor understands how the thermostat must be connected with the furnace and air conditioner.

Encapsulation is the process of hiding implementation details and providing methods for data access.

The process of hiding implementation details while publishing an interface is called **encapsulation**. In Java, the `class` construct provides encapsulation. The public methods of a class are the interface through which the private implementation is manipulated.

Why do contractors use prefabricated components such as thermostats and furnaces? These "black boxes" greatly simplify the work of the contractor. In ancient times, builders had to know how to construct furnaces from brick and mortar, and how to produce some rudimentary temperature controls. Nowadays, a contractor just makes a trip to the hardware store, without needing to know what goes on inside the components.

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A thermostat functions as a "black box" whose inner workings are hidden.

Similarly, a programmer using a class is not burdened by unnecessary detail, as you know from your own experience. In Chapter 2, you used classes for strings, streams, and windows without worrying how these classes are implemented.

Encapsulation allows a programmer to use a class without having to know its implementation.

Encapsulation also helps with diagnosing errors. A large program may consist of hundreds of classes and thousands of methods, but if there is an error with the internal data of an object, you only need to look at the methods of one class. Finally, encapsulation makes it possible to change the implementation of a class without having to tell the programmers who use the class.

Information hiding makes it simpler for the implementor of a class to locate errors and change implementations.

In Chapter 2, you learned to be an object user. You saw how to obtain objects, how to manipulate them, and how to assemble them into a program. In that chapter, you treated objects as black boxes. Your role was roughly analogous to the contractor who installs a new thermostat.

In this chapter, you will move on to implementing classes. In these sections, your role is analogous to the hardware manufacturer who puts together a thermostat from buttons, sensors, and other electronic parts. You will learn the necessary Java programming techniques that enable your objects to carry out the desired behavior.

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a demonstration of the `Counter` class.

section_1/Counter.java

```
1  /**
2     This class models a tally counter.
3  */
4  public class Counter
5  {
6     private int value;
7
8     /**
9        Gets the current value of this counter.
10       @return the current value
11    */
12    public int getValue()
13    {
14       return value;
15    }
16
17    /**
18       Advances the value of this counter by 1.
19    */
20    public void click()
21    {
22       value = value + 1;
23    }
24
```

```
25    /**
26       Resets the value of this counter to 0.
27    */
28    public void reset()
29    {
30       value = 0;
31    }
32 }
```

1. Supply the body of a method `public void unclick()` that undoes an unwanted button click.
2. Suppose you use a class `Clock` with private instance variables `hours` and `minutes`. How can you access these variables in your program?
3. Consider the `Counter` class. A counter's value starts at `0` and is advanced by the `click` method, so it should never be negative. Suppose you found a negative `value` variable during testing. Where would you look for the error?
4. In Chapters 1 and 2, you used `System.out` as a black box to cause output to appear on the screen. Who designed and implemented `System.out`?
5. Suppose you are working in a company that produces personal finance software. You are asked to design and implement a class for representing bank accounts. Who will be the users of your class?

Practice It Now you can try these exercises at the end of the chapter: R3.1, R3.3, E3.1.

3.2 Specifying the Public Interface of a Class

In the following sections, we will discuss the process of specifying the public interface of a class. Imagine that you are a member of a team that works on banking software. A fundamental concept in banking is a *bank account*. Your task is to design a `BankAccount` class that can be used by other programmers to manipulate bank accounts. What methods should you provide? What information should you give the programmers who use this class? You will want to settle these questions before you implement the class.

3.2.1 Specifying Methods

In order to implement a class, you first need to know which methods are required.

You need to know exactly what operations of a bank account need to be implemented. Some operations are essential (such as taking deposits), whereas others are not important (such as giving a gift to a customer who opens a bank account). Deciding which operations are essential is not always an easy task. We will revisit that issue in Chapters 8 and 12. For now, we will assume that a competent designer has decided that the following are considered the essential operations of a bank account:

- Deposit money
- Withdraw money
- Get the current balance

In Java, you call a method when you want to apply an operation to an object. To figure out the exact specification of the method calls, imagine how a programmer would carry out the bank account operations. We'll assume that the variable `harrysChecking` contains a reference to an object of type `BankAccount`. We want to support method calls such as the following:

```
harrysChecking.deposit(2240.59);
harrysChecking.withdraw(500);
double currentBalance = harrysChecking.getBalance();
```

The first two methods are mutators. They modify the balance of the bank account and don't return a value. The third method is an accessor. It returns a value that you store in a variable or pass to a method.

From the sample calls, we decide the `BankAccount` class should declare three methods:

- `public void deposit(double amount)`
- `public void withdraw(double amount)`
- `public double getBalance()`

Recall from Chapter 12 that `double` denotes the double-precision floating-point type, and `void` indicates that a method does not return a value.

Here we only give the method *headers*. When you declare a method, you also need to provide the method **body**, which consists of statements that are executed when the method is called.

```
public void deposit(double amount)
{
   method body—implementation filled in later
}
```

We will supply the method bodies in Section 3.3.

Note that the methods have been declared as `public`, indicating that all other methods in a program can call them. Occasionally, it can be useful to have `private` methods. They can only be called from other methods of the same class.

Some people like to fill in the bodies so that they compile, like this:

```
public double getBalance()
{
   // TODO: fill in implementation
   return 0;
}
```

That is a good idea if you compose your method specification in your development environment—you won't get warnings about incorrect code.

3.2.2 Specifying Constructors

Constructors set the initial data for objects.

As you know from Chapter 2, constructors are used to initialize objects. In Java, a **constructor** is very similar to a method, with two important differences:

- The name of the constructor is always the same as the name of the class (e.g., `BankAccount`).
- Constructors have no return type (not even `void`).

We want to be able to construct bank accounts that initially have a zero balance, as well as accounts that have a given initial balance.

For this purpose, we specify two constructors:

- `public BankAccount()`
- `public BankAccount(double initialBalance)`

They are used as follows:

```
BankAccount harrysChecking = new BankAccount();
BankAccount momsSavings = new BankAccount(5000);
```

The constructor name is always the same as the class name.

Don't worry about the fact that there are two constructors with the same name—*all* constructors of a class have the same name, that is, the name of the class. The compiler can tell them apart because they take different arguments. The first constructor takes no arguments at all. Such a constructor is called a **no-argument constructor**. The second constructor takes an argument of type `double`.

Just like a method, a constructor also has a body—a sequence of statements that is executed when a new object is constructed.

```
public BankAccount()
{
   constructor body—implementation filled in later
}
```

The statements in the constructor body will set the instance variables of the object that is being constructed—see Section 3.3.

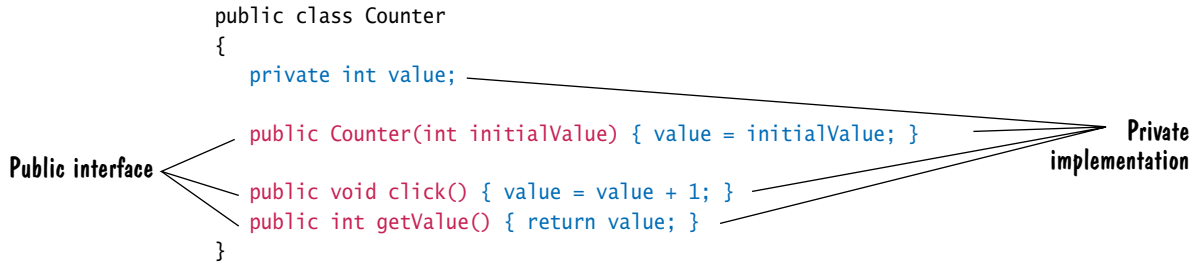
When declaring a class, you place all constructor and method declarations inside, like this:

```
public class BankAccount
{
   private instance variables—filled in later

   // Constructors
   public BankAccount()
   {
      implementation—filled in later
   }

   public BankAccount(double initialBalance)
   {
      implementation—filled in later
   }

   // Methods
   public void deposit(double amount)
   {
      implementation—filled in later
   }

   public void withdraw(double amount)
   {
      implementation—filled in later
   }

   public double getBalance()
   {
      implementation—filled in later
   }
}
```

Syntax 3.2 Class Declaration

Syntax

```
accessSpecifier class ClassName
{
   instance variables
   constructors
   methods
}
```



The public constructors and methods of a class form the **public interface** of the class. These are the operations that any programmer can use to create and manipulate `BankAccount` objects.

3.2.3 Using the Public Interface

Our `BankAccount` class is simple, but it allows programmers to carry out all of the important operations that commonly occur with bank accounts. For example, consider this program segment, authored by a programmer who uses the `BankAccount` class. These statements transfer an amount of money from one bank account to another:

```
// Transfer from one account to another
double transferAmount = 500;
momsSavings.withdraw(transferAmount);
harrysChecking.deposit(transferAmount);
```

And here is a program segment that adds interest to a savings account:

```
double interestRate = 5; // 5 percent interest
double interestAmount = momsSavings.getBalance() * interestRate / 100;
momsSavings.deposit(interestAmount);
```

As you can see, programmers can use objects of the `BankAccount` class to carry out meaningful tasks, without knowing how the `BankAccount` objects store their data or how the `BankAccount` methods do their work.

Of course, as implementors of the `BankAccount` class, we will need to supply the private implementation. We will do so in Section 3.3. First, however, an important step remains: *documenting* the public interface. That is the topic of the next section.

3.2.4 Commenting the Public Interface

When you implement classes and methods, you should get into the habit of thoroughly *commenting* their behaviors. In Java there is a very useful standard form for

documentation comments. If you use this form in your classes, a program called **javadoc** can automatically generate a neat set of HTML pages that describe them. (See Programming Tip 3.1 on page 90 for a description of this utility.)

Use documentation comments to describe the classes and public methods of your programs.

A documentation comment is placed before the class or method declaration that is being documented. It starts with a `/**`, a special comment delimiter used by the `javadoc` utility. Then you describe the method's *purpose*. Then, for each argument, you supply a line that starts with `@param`, followed by the name of the variable that holds the argument (which is called a **parameter variable**). Supply a short explanation for each argument after the variable name. Finally, you supply a line that starts with `@return`, describing the return value. You omit the `@param` tag for methods that have no arguments, and you omit the `@return` tag for methods whose return type is `void`.

The `javadoc` utility copies the *first* sentence of each comment to a summary table in the HTML documentation. Therefore, it is best to write that first sentence with some care. It should start with an uppercase letter and end with a period. It does not have to be a grammatically complete sentence, but it should be meaningful when it is pulled out of the comment and displayed in a summary.

Here are two typical examples:

```
/**
   Withdraws money from the bank account.
   @param amount the amount to withdraw
*/
public void withdraw(double amount)
{
   implementation—filled in later
}

/**
   Gets the current balance of the bank account.
   @return the current balance
*/
public double getBalance()
{
   implementation—filled in later
}
```

The comments you have just seen explain individual *methods*. Supply a brief comment for each *class*, too, explaining its purpose. Place the documentation comment above the class declaration:

```
/**
   A bank account has a balance that can be changed by
   deposits and withdrawals.
*/
public class BankAccount
{
   . . .
}
```

Your first reaction may well be "Whoa! Am I supposed to write all this stuff?" Sometimes, documentation comments seem pretty repetitive, but in most cases, they are informative. Even with seemingly repetitive comments, you should take the time to write them.

It is always a good idea to write the method comment *first*, before writing the code in the method body. This is an excellent test to see that you firmly understand what

you need to program. If you can't explain what a class or method does, you aren't ready to implement it.

Provide documentation comments for every class, every method, every parameter variable, and every return value.

What about very simple methods? You can easily spend more time pondering whether a comment is too trivial to write than it takes to write it. In practical programming, very simple methods are rare. It is harmless to have a trivial method overcommented, whereas a complicated method without any comment can cause real grief to future maintenance programmers. According to the standard Java documentation style, *every* class, *every* method, *every* parameter variable, and *every* return value should have a comment.

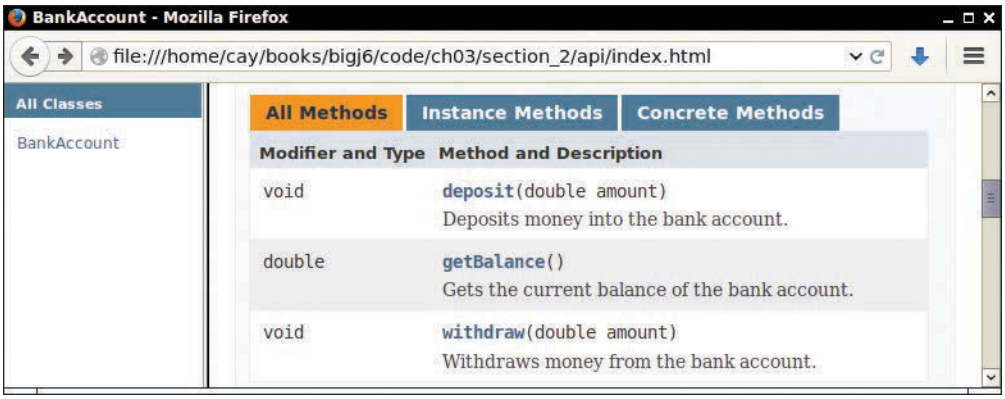


Figure 3 A Method Summary Generated by `javadoc`

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download the `BankAccount` class with documentation but without implementation.

The `javadoc` utility formats your comments into a neat set of documents that you can view in a web browser. It makes good use of the seemingly repetitive phrases. The first sentence of the comment is used for a *summary table* of all methods of your class (see Figure 3). The `@param` and `@return` comments are neatly formatted in the detail description of each method (see Figure 4). If you omit any of the comments, then `javadoc` generates documents that look strangely empty.

Figure 4 Method Detail Generated by `javadoc`

This documentation format should look familiar. The programmers who implement the Java library use `javadoc` themselves. They too document every class, every method, every parameter variable, and every return value, and then use `javadoc` to extract the documentation in HTML format.

6. How can you use the methods of the public interface to *empty* the `harrysChecking` bank account?
7. What is wrong with this sequence of statements?

```
BankAccount harrysChecking = new BankAccount(10000);
System.out.println(harrysChecking.withdraw(500));
```

8. Suppose you want a more powerful bank account abstraction that keeps track of an *account number* in addition to the balance. How would you change the public interface to accommodate this enhancement?
9. Suppose we enhance the `BankAccount` class so that each account has an account number. Supply a documentation comment for the constructor

```
public BankAccount(int accountNumber, double initialBalance)
```

10. Why is the following documentation comment questionable?

```
/**
   Each account has an account number.
   @return the account number of this account
*/
public int getAccountNumber()
```

Practice It Now you can try these exercises at the end of the chapter: R3.7, R3.8, R3.9.

Common Error 3.1

Declaring a Constructor as `void`

Do not use the `void` reserved word when you declare a constructor:

```
public void BankAccount()  // Error—don't use void!
```

This would declare a method with return type `void` and *not* a constructor. Unfortunately, the Java compiler does not consider this a syntax error.

Programming Tip 3.1

The `javadoc` Utility

Always insert documentation comments in your code, whether or not you use `javadoc` to produce HTML documentation. Most people find the HTML documentation convenient, so it is worth learning how to run `javadoc`. Some programming environments (such as BlueJ) can execute `javadoc` for you. Alternatively, you can invoke the `javadoc` utility from a shell window, by issuing the command

```
javadoc MyClass.java
```

or, if you want to document multiple Java files,

```
javadoc *.java
```

The `javadoc` utility produces files such as `MyClass.html` in HTML format, which you can inspect in a browser. If you know HTML (see Appendix H), you can embed HTML tags into the

comments to specify fonts or add images. Perhaps most importantly, `javadoc` automatically provides *hyperlinks* to other classes and methods.

You can run `javadoc` before implementing any methods. Just leave all the method bodies empty. Don't run the compiler—it would complain about missing return values. Simply run `javadoc` on your file to generate the documentation for the public interface that you are about to implement.

The `javadoc` tool is wonderful because it does one thing right: It allows you to put the documentation *together with your code*. That way, when you update your programs, you can see right away which documentation needs to be updated. Hopefully, you will update it right then and there. Afterward, run `javadoc` again and get updated information that is timely and nicely formatted.

3.3 Providing the Class Implementation

Now that you understand the specification of the public interface of the `BankAccount` class, let's provide the implementation.

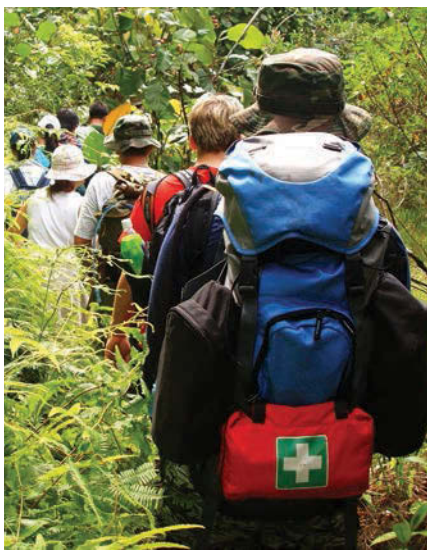
3.3.1 Providing Instance Variables

The private implementation of a class consists of instance variables, and the bodies of constructors and methods.

First, we need to determine the data that each bank account object contains. In the case of our simple bank account class, each object needs to store a single value, the current balance. (A more complex bank account class might store additional data—perhaps an account number, the interest rate paid, the date for mailing out the next statement, and so on.)

```
public class BankAccount
{
   private double balance;
   // Methods and constructors below
   . . .
}
```

In general, it can be challenging to find a good set of instance variables. Ask yourself what an object needs to remember so that it can carry out any of its methods.



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Like a wilderness explorer who needs to carry all items that may be needed, an object needs to store the data required for its method calls.

3.3.2 Providing Constructors

A **constructor** has a simple job: to initialize the instance variables of an object.

Recall that we designed the `BankAccount` class to have two constructors. The first constructor simply sets the balance to zero:

```
public BankAccount()
{
   balance = 0;
}
```

The second constructor sets the balance to the value supplied as the construction argument:

```
public BankAccount(double initialBalance)
{
   balance = initialBalance;
}
```

To see how these constructors work, let us trace the statement

```
BankAccount harrysChecking = new BankAccount(1000);
```

one step at a time.

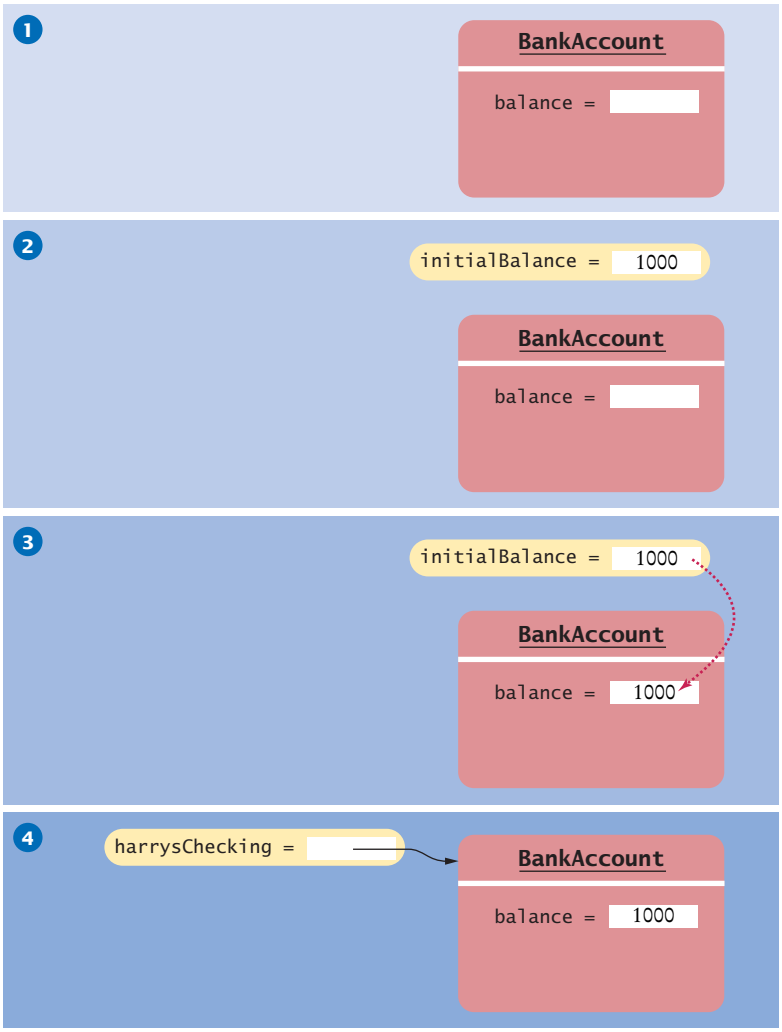
Here are the steps that are carried out when the statement executes (see Figure 5):

- Create a new object of type `BankAccount`. 1
- Call the second constructor (because an argument is supplied in the constructor call).
- Set the parameter variable `initialBalance` to 1000. 2
- Set the `balance` instance variable of the newly created object to `initialBalance`. 3
- Return an object reference, that is, the memory location of the object, as the value of the `new` expression.
- Store that object reference in the `harrysChecking` variable. 4

In general, when you implement constructors, be sure that each constructor initializes all instance variables, and that you make use of all parameter variables (see Common Error 3.2 on page 96).

A constructor is like a set of assembly instructions for an object.

Figure 5
How a Constructor Works



3.3.3 Providing Methods

In this section, we finish implementing the methods of the `BankAccount` class.

When you implement a method, ask yourself whether it is an accessor or mutator method. A mutator method needs to update the instance variables in some way. An accessor method retrieves or computes a result.

Here is the `deposit` method. It is a mutator method, updating the balance:

```
public void deposit(double amount)
{
   balance = balance + amount;
}
```

The `withdraw` method is very similar to the `deposit` method:

```
public void withdraw(double amount)
{
   balance = balance - amount;
}
```

Table 1 Implementing Classes

Example	Comments
`public class BankAccount { . . . }`	This is the start of a class declaration. Instance variables, methods, and constructors are placed inside the braces.
`private double balance;`	This is an instance variable of type `double`. Instance variables should be declared as `private`.
`public double getBalance() { . . . }`	This is a method declaration. The body of the method must be placed inside the braces.
`. . . { return balance; }`	This is the body of the `getBalance` method. The `return` statement returns a value to the caller of the method.
`public void deposit(double amount) { . . . }`	This is a method with a parameter variable (`amount`). Because the method is declared as `void`, it has no return value.
`. . . { balance = balance + amount; }`	This is the body of the `deposit` method. It does not have a `return` statement.
`public BankAccount() { . . . }`	This is a constructor declaration. A constructor has the same name as the class and no return type.
`. . . { balance = 0; }`	This is the body of the constructor. A constructor should initialize the instance variables.

There is one method left, `getBalance`. Unlike the `deposit` and `withdraw` methods, which modify the instance variable of the object on which they are invoked, the `getBalance` method returns a value:

```
public double getBalance()
{
   return balance;
}
```

We have now completed the implementation of the `BankAccount` class—see the code listing below. There is only one step remaining: testing that the class works correctly. That is the topic of the next section.

section_3/BankAccount.java

```
1  /**
2     A bank account has a balance that can be changed by
3     deposits and withdrawals.
4  */
5  public class BankAccount
6  {
7     private double balance;
8
9     /**
10       Constructs a bank account with a zero balance.
11    */
12    public BankAccount()
13    {
14       balance = 0;
15    }
```

```
16
17    /**
18       Constructs a bank account with a given balance.
19       @param initialBalance the initial balance
20    */
21    public BankAccount(double initialBalance)
22    {
23       balance = initialBalance;
24    }
25
26    /**
27       Deposits money into the bank account.
28       @param amount the amount to deposit
29    */
30    public void deposit(double amount)
31    {
32       balance = balance + amount;
33    }
34
35    /**
36       Withdraws money from the bank account.
37       @param amount the amount to withdraw
38    */
39    public void withdraw(double amount)
40    {
41       balance = balance - amount;
42    }
43
44    /**
45       Gets the current balance of the bank account.
46       @return the current balance
47    */
48    public double getBalance()
49    {
50       return balance;
51    }
52 }
```

11. Suppose we modify the `BankAccount` class so that each bank account has an account number. How does this change affect the instance variables?

12. Why does the following code not succeed in robbing mom's bank account?

```
public class BankRobber
{
   public static void main(String[] args)
   {
      BankAccount momsSavings = new BankAccount(1000);
      momsSavings.balance = 0;
   }
}
```

13. The `Rectangle` class has four instance variables: `x`, `y`, `width`, and `height`. Give a possible implementation of the `getWidth` method.

14. Give a possible implementation of the `translate` method of the `Rectangle` class.

Practice It Now you can try these exercises at the end of the chapter: R3.4, R3.10, E3.7.

Common Error 3.2

Ignoring Parameter Variables

A surprisingly common beginner's error is to ignore parameter variables of methods or constructors. This usually happens when an assignment gives an example with specific values. For example, suppose you are asked to provide a class `Letter` with a recipient and a sender, and you are given a sample letter like this:

```
Dear John:

I am sorry we must part.
I wish you all the best.

Sincerely,

Mary
```

Now look at this incorrect attempt:

```
public class Letter
{
   private String recipient;
   private String sender;

   public Letter(String aRecipient, String aSender)
   {
      recipient = "John"; // Error—should use parameter variable
      sender = "Mary"; // Same error
   }
   . . .
}
```

The constructor ignores the names of the recipient and sender arguments that were provided to the constructor. If a user constructs a

```
new Letter("John", "Yoko")
```

the sender is still set to `"Mary"`, which is bound to be embarrassing.

The constructor should use the parameter variables, like this:

```
public Letter(String aRecipient, String aSender)
{
   recipient = aRecipient;
   sender = aSender;
}
```

HOW TO 3.1

Implementing a Class

This "How To" section tells you how you implement a class from a given specification.

Problem Statement Implement a class that models a self-service cash register. The customer scans the price tags and deposits money in the machine. The machine dispenses the change.

Step 1 Find out which methods you are asked to supply.

In a simulation, you won't have to provide every feature that occurs in the real world—there are too many. In the cash register example, we don't deal with sales tax or credit card payments. The assignment tells you *which aspects* of the self-service cash register your class should simulate. Make a list of them:

- **Process the price of each purchased item.**
- **Receive payment.**
- **Calculate the amount of change due to the customer.**

Step 2 Specify the public interface.

Turn the list in Step 1 into a set of methods, with specific types for the parameter variables and the return values. Many programmers find this step simpler if they write out method calls that are applied to a sample object, like this:

```
CashRegister register = new CashRegister();
register.recordPurchase(29.95);
register.recordPurchase(9.95);
register.receivePayment(50);
double change = register.giveChange();
```

Now we have a specific list of methods:

- `public void recordPurchase(double amount)`
- `public void receivePayment(double amount)`
- `public double giveChange()`

To complete the public interface, you need to specify the constructors. Ask yourself what information you need in order to construct an object of your class. Sometimes you will want two constructors: one that sets all instance variables to a default and one that sets them to user-supplied values.

In the case of the cash register example, we can get by with a single constructor that creates an empty register. A more realistic cash register might start out with some coins and bills so that we can give exact change, but that is well beyond the scope of our assignment.

Thus, we add a single constructor:

- `public CashRegister()`

Step 3 Document the public interface.

Here is the documentation, with comments, that describes the class and its methods:

```
/**
   A cash register totals up sales and computes change due.
*/
public class CashRegister
{
   /**
      Constructs a cash register with no money in it.
   */
   public CashRegister()
   {
   }

   /**
      Records the sale of an item.
      @param amount the price of the item
   */
   public void recordPurchase(double amount)
   {
```

```
   }

   /**
      Processes a payment received from the customer.
      @param amount the amount of the payment
   */
   public void receivePayment(double amount)
   {
   }

   /**
      Computes the change due and resets the machine for the next customer.
      @return the change due to the customer
   */
   public double giveChange()
   {
   }
}
```

Step 4 Determine instance variables.

Ask yourself what information an object needs to store to do its job. Remember, the methods can be called in any order. The object needs to have enough internal memory to be able to process every method using just its instance variables and the parameter variables. Go through each method, perhaps starting with a simple one or an interesting one, and ask yourself what you need to carry out the method's task. Make instance variables to store the information that the method needs.

Just as importantly, don't introduce unnecessary instance variables (see Common Error 3.3 on page 106). If a value can be computed from other instance variables, it is generally better to compute it on demand than to store it.

In the cash register example, you need to keep track of the total purchase amount and the payment. You can compute the change due from these two amounts.

```
public class CashRegister
{
   private double purchase;
   private double payment;
   . . .
}
```

Step 5 Implement constructors and methods.

Implement the constructors and methods in your class, one at a time, starting with the easiest ones. Here is the implementation of the `recordPurchase` method:

```
public void recordPurchase(double amount)
{
   purchase = purchase + amount;
}
```

The `receivePayment` method looks almost the same,

```
public void receivePayment(double amount)
{
   payment = payment + amount;
}
```

but why does the method add the amount, instead of simply setting `payment = amount`? A customer might provide two separate payments, such as two $10 bills, and the machine must process them both. Remember, methods can be called more than once, and they can be called in any order.

Finally, here is the `giveChange` method. This method is a bit more sophisticated—it computes the change due, and it also resets the cash register for the next sale.

```
public double giveChange()
{
   double change = payment - purchase;
   purchase = 0;
   payment = 0;
   return change;
}
```

If you find that you have trouble with the implementation, you may need to rethink your choice of instance variables. It is common for a beginner to start out with a set of instance variables that cannot accurately reflect the state of an object. Don't hesitate to go back and add or modify instance variables.

You can find the complete implementation in the `how_to_1` directory of the book's companion code.

Step 6 Test your class.

Write a short tester program and execute it. The tester program should carry out the method calls that you found in Step 2.

```
public class CashRegisterTester
{
   public static void main(String[] args)
   {
      CashRegister register = new CashRegister();

      register.recordPurchase(29.50);
      register.recordPurchase(9.25);
      register.receivePayment(50);

      double change = register.giveChange();

      System.out.println(change);
      System.out.println("Expected: 11.25");
   }
}
```

The output of this test program is:

```
11.25
Expected: 11.25
```

WORKED EXAMPLE 3.1 **Making a Simple Menu**

Learn how to implement a class that constructs simple text-based menus. Go to `wiley.com/go/bjeo6examples` and download Worked Example 3.1.

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3.4 Unit Testing

In the preceding section, we completed the implementation of the `BankAccount` class. What can you do with it? Of course, you can compile the file `BankAccount.java`. However, you can't *execute* the resulting `BankAccount.class` file. It doesn't contain a `main` method. That is normal—most classes don't contain a `main` method.

© Chris Fertnig/iStockphoto.

An engineer tests a part in isolation. This is an example of unit testing.

A unit test verifies that a class works correctly in isolation, outside a complete program.

In the long run, your class may become a part of a larger program that interacts with users, stores data in files, and so on. However, before integrating a class into a program, it is always a good idea to test it in isolation. Testing in isolation, outside a complete program, is called **unit testing**.

To test your class, you have two choices. Some interactive development environments have commands for constructing objects and invoking methods (see Special Topic 2.1). Then you can test a class simply by constructing an object, calling methods, and verifying that you get the expected return values. Figure 6 shows the result of calling the `getBalance` method on a `BankAccount` object in BlueJ.

To test a class, use an environment for interactive testing, or write a tester class to execute test instructions.

Alternatively, you can write a *tester class*. A tester class is a class with a `main` method that contains statements to run methods of another class. As discussed in Section 2.7, a tester class typically carries out the following steps:

1. Construct one or more objects of the class that is being tested.
2. Invoke one or more methods.
3. Print out one or more results.
4. Print the expected results.

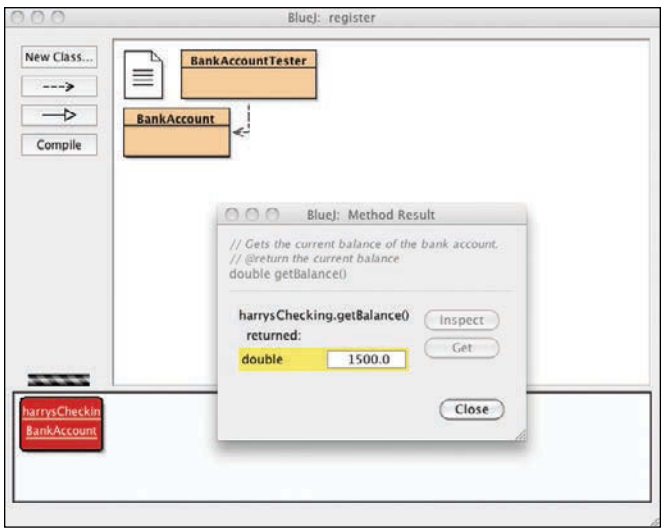


Figure 6 The Return Value of the `getBalance` Method in BlueJ

The `MoveTester` class in Section 2.7 is a good example of a tester class. That class runs methods of the `Rectangle` class—a class in the Java library.

Following is a class to run methods of the `BankAccount` class. The `main` method constructs an object of type `BankAccount`, invokes the `deposit` and `withdraw` methods, and then displays the remaining balance on the console.

We also print the value that we expect to see. In our sample program, we deposit $2,000 and withdraw $500. We therefore expect a balance of $1,500.

section_4/BankAccountTester.java

```
1  /**
2     A class to test the BankAccount class.
3  */
4  public class BankAccountTester
5  {
6     /**
7        Tests the methods of the BankAccount class.
8        @param args not used
9     */
10    public static void main(String[] args)
11    {
12       BankAccount harrysChecking = new BankAccount();
13       harrysChecking.deposit(2000);
14       harrysChecking.withdraw(500);
15       System.out.println(harrysChecking.getBalance());
16       System.out.println("Expected: 1500");
17    }
18 }
```

Program Run

```
1500
Expected: 1500
```

To produce a program, you need to combine the `BankAccount` and the `BankAccountTester` classes. The details for building the program depend on your compiler and development environment. In most environments, you need to carry out these steps:

1. Make a new subfolder for your program.
2. Make two files, one for each class.
3. Compile both files.
4. Run the test program.

Many students are surprised that such a simple program contains two classes. However, this is normal. The two classes have entirely different purposes. The `BankAccount` class describes objects that compute bank balances. The `BankAccountTester` class runs a test that puts a `BankAccount` object through its paces.

15. When you run the `BankAccountTester` program, how many objects of class `BankAccount` are constructed? How many objects of type `BankAccountTester`?

16. Why is the `BankAccountTester` class unnecessary in development environments that allow interactive testing, such as BlueJ?

Practice It Now you can try these exercises at the end of the chapter: E3.6, E3.13.

Computing & Society 3.1 Electronic Voting Machines

In the 2000 presidential elections in the United States, votes were tallied by a variety of machines. Some machines processed cardboard ballots into which voters punched holes to indicate their choices (see below). When voters were not careful, remains of paper—the now infamous "chads"—were partially stuck in the punch cards, causing votes to be miscounted. A manual recount was necessary, but it was not carried out everywhere due to time constraints and procedural wrangling. The election was very close, and there remain doubts in the minds of many people whether the election outcome would have been different if the voting machines had accurately counted the intent of the voters.

Punch Card Ballot

Subsequently, voting machine manufacturers have argued that electronic voting machines would avoid the problems caused by punch cards or optically scanned forms. In an electronic voting machine, voters indicate their preferences by pressing buttons or touching icons on a computer screen. Typically, each voter is presented with a summary screen for review before casting the ballot. The process is very similar to using a bank's automated teller machine.

It seems plausible that these machines make it more likely that a vote is counted in the same way that the voter intends. However, there has been significant controversy surrounding some types of electronic voting machines. If a machine simply records the votes and prints out the totals after the election has been completed, then how do you know that the machine worked correctly? Inside the machine is a computer that executes a program, and, as you may know from your own experience, programs can have bugs.

In fact, some electronic voting machines do have bugs. There have been isolated cases where machines reported tallies that were impossible. When a machine reports far more or far fewer votes than voters, then it is clear that it malfunctioned. Unfortunately, it is then impossible to find out the actual votes. Over time, one would expect these bugs to be fixed in the software. More insidiously, if the results are plausible, nobody may ever investigate.

Many computer scientists have spoken out on this issue and confirmed that it is impossible, with today's technology, to tell that software is error free and has not been tampered with. Many of them recommend that electronic voting machines should employ a *voter-verifiable audit trail*. (A good source of information is `http://verifiedvoting.org`.) Typically, a voter-verifiable machine prints out a ballot. Each voter has a chance to review the printout, and then deposits it in an old-fashioned ballot box. If there is a problem with the electronic equipment, the printouts can be scanned or counted by hand.

As this book is written, this concept is strongly resisted both by manufacturers of electronic voting machines and by their customers, the cities and counties that run elections. Manufacturers are reluctant to increase the cost of the machines because they may not be able to pass the cost increase on to their customers, who tend to have tight budgets. Election officials fear problems with malfunctioning printers, and some of them have publicly stated that they actually prefer equipment that eliminates bothersome recounts.

What do you think? You probably use an automated bank teller machine to get cash from your bank account. Do you review the paper record that the machine issues? Do you check your bank statement? Even if you don't, do you put your faith in other people who double-check their balances, so that the bank won't get away with widespread cheating?

Is the integrity of banking equipment more important or less important than that of voting machines? Won't every voting process have some room for error and fraud anyway? Is the added cost for equipment, paper, and staff time reasonable to combat a potentially slight risk of malfunction and fraud? Computer scientists cannot answer these questions—an informed society must make these tradeoffs. But, like all professionals, they have an obligation to speak out and give accurate testimony about the capabilities and limitations of computing equipment.

Touch Screen Voting Machine

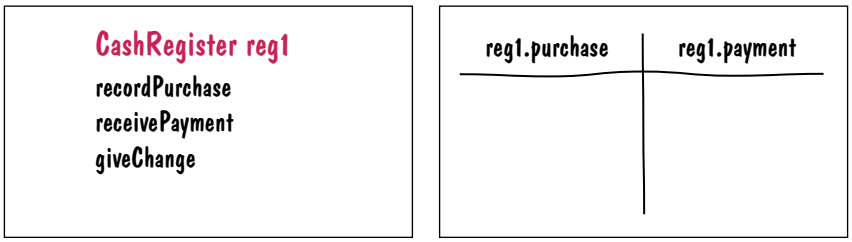
3.5 Problem Solving: Tracing Objects

Researchers have studied why some students have an easier time learning how to program than others. One important skill of successful programmers is the ability to simulate the actions of a program with pencil and paper. In this section, you will see how to develop this skill by tracing method calls on objects.

Write the methods on the front of a card and the instance variables on the back.

Use an index card or a sticky note for each object. On the front, write the methods that the object can execute. On the back, make a table for the values of the instance variables.

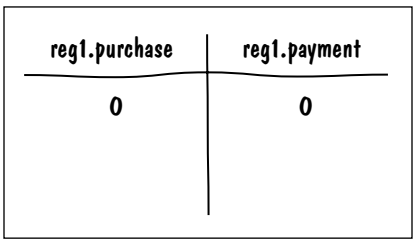
Here is a card for a `CashRegister` object:



front *back*

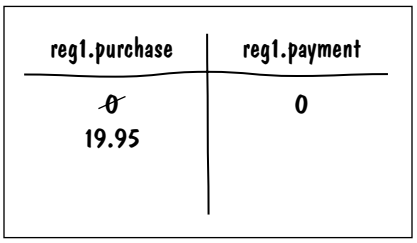
In a small way, this gives you a feel for encapsulation. An object is manipulated through its public interface (on the front of the card), and the instance variables are hidden on the back.

When an object is constructed, fill in the initial values of the instance variables:



Update the values of the instance variables when a mutator method is called.

Whenever a mutator method is executed, cross out the old values and write the new ones below. Here is what happens after a call to the `recordPurchase` method:



If you have more than one object in your program, you will have multiple cards, one for each object:

reg1.purchase	reg1.payment
~~0~~ 19.95	~~0~~ 19.95

reg2.purchase	reg2.payment
~~0~~ ~~29.50~~ 9.25	~~0~~ 50.00

These diagrams are also useful when you design a class. Suppose you are asked to enhance the `CashRegister` class to compute the sales tax. Add methods `recordTaxablePurchase` and `getSalesTax` to the front of the card. Now turn the card over, look over the instance variables, and ask yourself whether the object has sufficient information to compute the answer. Remember that each object is an autonomous unit. Any value that can be used in a computation must be

- An instance variable.
- A method argument.
- A static variable (uncommon; see Section 8.4).

To compute the sales tax, we need to know the tax rate and the total of the taxable items. (Food items are usually not subject to sales tax.) We don't have that information available. Let us introduce additional instance variables for the tax rate and the taxable total. The tax rate can be set in the constructor (assuming it stays fixed for the lifetime of the object). When adding an item, we need to be told whether the item is taxable. If so, we add its price to the taxable total.

For example, consider the following statements.

```
CashRegister reg3 = new CashRegister(7.5);  // 7.5 percent sales tax
reg3.recordPurchase(3.95); // Not taxable
reg3.recordTaxablePurchase(19.95); // Taxable
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download an enhanced `CashRegister` class that computes the sales tax.

When you record the effect on a card, it looks like this:

reg3.purchase	reg3.taxablePurchase	reg3.payment	reg3.taxRate
~~0~~ 3.95	~~0~~ 19.95	0	7.5

With this information, we can compute the tax. It is **taxablePurchase x taxRate / 100**. Tracing the object helped us understand the need for additional instance variables.

SELF CHECK

17. Consider a `Car` class that simulates fuel consumption in a car. We will assume a fixed efficiency (in miles per gallon) that is supplied in the constructor. There are methods for adding gas, driving a given distance, and checking the amount of gas left in the tank. Make a card for a `Car` object, choosing suitable instance variables and showing their values after the object was constructed.

18. Trace the following method calls:

```
Car myCar = new Car(25);
myCar.addGas(20);
myCar.drive(100);
myCar.drive(200);
myCar.addGas(5);
```

19. Suppose you are asked to simulate the odometer of the car, by adding a method `getMilesDriven`. Add an instance variable to the object's card that is suitable for computing this method's result.

20. Trace the methods of Self Check 18, updating the instance variable that you added in Self Check 19.

Practice It Now you can try these exercises at the end of the chapter: R3.19, R3.20, R3.21.

3.6 Local Variables

Local variables are declared in the body of a method.

In this section, we discuss the behavior of *local* variables. A **local variable** is a variable that is declared in the body of a method. For example, the `giveChange` method in How To 3.1 declares a local variable `change`:

```
public double giveChange()
{
   double change = payment - purchase;
   purchase = 0;
   payment = 0;
   return change;
}
```

Parameter variables are similar to local variables, but they are declared in method headers. For example, the following method declares a parameter variable `amount`:

```
public void receivePayment(double amount)
```

When a method exits, its local variables are removed.

Local and parameter variables belong to methods. When a method runs, its local and parameter variables come to life. When the method exits, they are removed immediately. For example, if you call `register.giveChange()`, then a variable `change` is created. When the method exits, that variable is removed.

In contrast, instance variables belong to objects, not methods. When an object is constructed, its instance variables are created. The instance variables stay alive until no method uses the object any longer. (The Java virtual machine contains an agent called a **garbage collector** that periodically reclaims objects when they are no longer used.)

Instance variables are initialized to a default value, but you must initialize local variables.

An important difference between instance variables and local variables is initialization. You must **initialize** all local variables. If you don't initialize a local variable, the compiler complains when you try to use it. (Note that parameter variables are initialized when the method is called.)

Instance variables are initialized with a default value before a constructor is invoked. Instance variables that are numbers are initialized to 0. Object references are set to a special value called `null`. If an object reference is `null`, then it refers to no object at all. We will discuss the `null` value in greater detail in Section 5.2.5.

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a demonstration of local variables.

21. What do local variables and parameter variables have in common? In which essential aspect do they differ?
22. Why was it necessary to introduce the local variable `change` in the `giveChange` method? That is, why didn't the method simply end with the statement
    ```
    return payment - purchase;
    ```
23. Consider a `CashRegister` object `reg1` whose `payment` instance variable has the value 20 and whose `purchase` instance variable has the value 19.5. Trace the call `reg1.giveChange()`. Include the local variable `change`. Draw an X in its column when the variable ceases to exist.

Practice It Now you can try these exercises at the end of the chapter: R3.15, R3.16.

Common Error 3.3

Duplicating Instance Variables in Local Variables

Beginning programmers commonly add types to assignment statements, thereby changing them into local variable declarations. For example,

```
public double giveChange()
{
   double change = payment - purchase;
   double purchase = 0; // ERROR! This declares a local variable.
   double payment = 0;  // ERROR! The instance variable is not updated.
   return change;
}
```

Another common error is to declare a parameter variable with the same name as an instance variable. For example, consider this `BankAccount` constructor:

```
public BankAccount(double balance)
{
   balance = balance; // ERROR! Does not set the instance variable
}
```

This constructor simply sets the parameter variable to itself, leaving it unchanged. A simple remedy is to come up with a different name for the parameter variable:

```
public BankAccount(double initialBalance)
{
   balance = initialBalance; // OK
}
```

Common Error 3.4

Providing Unnecessary Instance Variables

A common beginner's mistake is to use instance variables when local variables would be more appropriate. For example, consider the `change` variable of the `giveChange` method. It is not needed anywhere else—that's why it is local to the method. But what if it had been declared as an instance variable?

```
public class CashRegister
{
   private double purchase;
   private double payment;
   private double change; // Not appropriate
```

```
   public double giveChange()
   {
      change = payment - purchase;
      purchase = 0;
      payment = 0;
      return change;
   }
   . . .
}
```

This class will work, but there is a hidden danger. Other methods can read and write to the `change` instance variable, which can be a source of confusion.

Use instance variables for values that an object needs to remember between method calls. Use local variables for values that don't need to be retained when a method has completed.

Common Error 3.5

Forgetting to Initialize Object References in a Constructor

Just as it is a common error to forget to initialize a local variable, it is easy to forget about instance variables. Every constructor needs to ensure that all instance variables are set to appropriate values.

If you do not initialize an instance variable, the Java compiler will initialize it for you. Numbers are initialized with `0`, but object references—such as string variables—are set to the `null` reference.

Of course, `0` is often a convenient default for numbers. However, `null` is hardly ever a convenient default for objects. Consider this "lazy" constructor for a modified version of the `BankAccount` class:

```
public class BankAccount
{
   private double balance;
   private String owner;
   . . .
   public BankAccount(double initialBalance)
   {
      balance = initialBalance;
   }
}
```

Then `balance` is initialized, but the `owner` variable is set to a `null` reference. This can be a problem—it is illegal to call methods on the `null` reference.

To avoid this problem, it is a good idea to initialize every instance variable:

```
public BankAccount(double initialBalance)
{
   balance = initialBalance;
   owner = "None";
}
```

3.7 The this Reference

When you call a method, you pass two kinds of inputs to the method:

- The object on which you invoke the method
- The method arguments

For example, when you call

```
momsSavings.deposit(500);
```

the `deposit` method needs to know the account object (`momsSavings`) as well as the amount that is being deposited (500).

When you implement the method, you provide a parameter variable for each argument. But you don't need to provide a parameter variable for the object on which the method is being invoked. That object is called the **implicit parameter**. All other parameter variables (such as the amount to be deposited in our example) are called **explicit parameters**.

Look again at the code of the `deposit` method:

```
public void deposit(double amount)
{
   balance = balance + amount;
}
```

Here, `amount` is an explicit parameter. You don't see the implicit parameter—that is why it is called "implicit". But consider what `balance` means exactly. After all, our program may have multiple `BankAccount` objects, and *each of them* has its own balance.

Use of an instance variable name in a method denotes the instance variable of the implicit parameter.

Because we are depositing the money into `momsSavings`, `balance` must mean `momsSavings.balance`. In general, when you refer to an instance variable inside a method, it means the instance variable of the implicit parameter.

In any method, you can access the implicit parameter—the object on which the method is called—with the reserved word `this`. For example, in the preceding method invocation, `this` refers to the same object as `momsSavings` (see Figure 7).

The statement

```
balance = balance + amount;
```

actually means

```
this.balance = this.balance + amount;
```

The `this` reference denotes the implicit parameter.

When you refer to an instance variable in a method, the compiler automatically applies it to the `this` reference. Some programmers actually prefer to manually insert the `this` reference before every instance variable because they find it makes the code clearer. Here is an example:

```
public BankAccount(double initialBalance)
{
   this.balance = initialBalance;
}
```

You may want to try it out and see if you like that style.

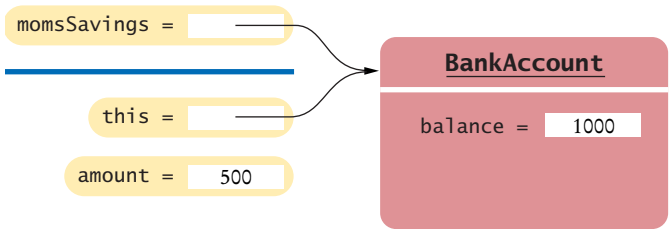


Figure 7 The Implicit Parameter of a Method Call

The this reference can also be used to distinguish between instance variables and local or parameter variables. Consider the constructor

```
public BankAccount(double balance)
{
   this.balance = balance;
}
```

A local variable shadows an instance variable with the same name. You can access the instance variable name through the this reference.

The expression this.balance clearly refers to the balance instance variable. However, the expression balance by itself seems ambiguous. It could denote either the parameter variable or the instance variable. The Java language specifies that in this situation the local variable wins out. It "shadows" the instance variable. Therefore,

```
this.balance = balance;
```

means: "Set the instance variable balance to the parameter variable balance".

There is another situation in which it is important to understand implicit parameters. Consider the following modification to the BankAccount class. We add a method to apply the monthly account fee:

```
public class BankAccount
{
   . . .
   public void monthlyFee()
   {
      withdraw(10); // Withdraw $10 from this account
   }
}
```

A method call without an implicit parameter is applied to the same object.

That means to withdraw from the *same* bank account object that is carrying out the monthlyFee operation. In other words, the implicit parameter of the withdraw method is the (invisible) implicit parameter of the monthlyFee method.

If you find it confusing to have an invisible parameter, you can use the this reference to make the method easier to read:

```
public class BankAccount
{
   . . .
   public void monthlyFee()
   {
      this.withdraw(10); // Withdraw $10 from this account
   }
}
```

FULL CODE EXAMPLE

Go to wiley.com/go/bjeo6code to download a a program that demonstrates the this reference.

You have now seen how to use objects and implement classes, and you have learned some important technical details about variables and method parameters. The remainder of this chapter continues the optional graphics track. In the next chapter, you will learn more about the most fundamental data types of the Java language.

24. How many implicit and explicit parameters does the withdraw method of the BankAccount class have, and what are their names and types?
25. In the deposit method, what is the meaning of this.amount? Or, if the expression has no meaning, why not?
26. How many implicit and explicit parameters does the main method of the BankAccountTester class have, and what are they called?

Practice It Now you can try these exercises at the end of the chapter: R3.11, R3.13.

Special Topic 3.1

Calling One Constructor from Another

Consider the `BankAccount` class. It has two constructors: a no-argument constructor to initialize the balance with zero, and another constructor to supply an initial balance. Rather than explicitly setting the balance to zero, one constructor can call another constructor of the same class instead. There is a shorthand notation to achieve this result:

```
public class BankAccount
{
   public BankAccount(double initialBalance)
   {
      balance = initialBalance;
   }

   public BankAccount()
   {
      this(0);
   }
   . . .
}
```

The command `this(0);` means "Call another constructor of this class and supply the value `0`". Such a call to another constructor can occur only as the *first line in a constructor*.

This syntax is a minor convenience. We will not use it in this book. Actually, the use of the reserved word `this` is a little confusing. Normally, `this` denotes a reference to the implicit parameter, but if `this` is followed by parentheses, it denotes a call to another constructor of the same class.

3.8 Shape Classes

It is a good idea to make a class for any part of a drawing that can occur more than once.

In this section, we continue the optional graphics track by discussing how to organize complex drawings in a more object-oriented fashion.

When you produce a drawing that has multiple shapes, or parts made of multiple shapes, such as the car in Figure 8, it is a good idea to make a separate class for each part. The class should have a `draw` method that draws the shape, and a constructor to set the position of the shape. For example, here is the outline of the `Car` class:

```
public class Car
{
   public Car(int x, int y)
   {
      Remember position.
      . . .
   }

   public void draw(Graphics2D g2)
   {
      Drawing instructions.
      . . .
   }
}
```

You will find the complete class declaration at the end of this section. The `draw` method contains a rather long sequence of instructions for drawing the body, roof, and tires.

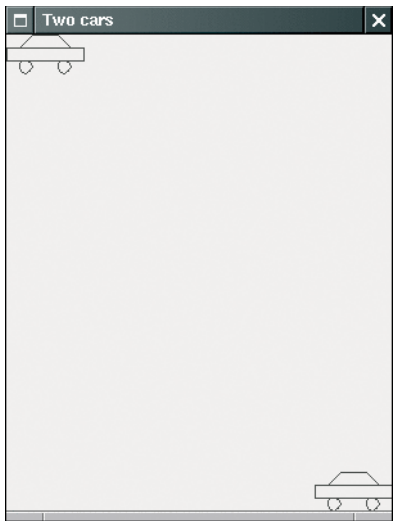


Figure 8
The Car Component Draws Two Car Shapes

To figure out how to draw a complex shape, make a sketch on graph paper.

The coordinates of the car parts seem a bit arbitrary. To come up with suitable values, draw the image on graph paper and read off the coordinates (Figure 9).

The program that produces Figure 8 is composed of three classes.

- The `Car` class is responsible for drawing a single car. Two objects of this class are constructed, one for each car.
- The `CarComponent` class displays the drawing.
- The `CarViewer` class shows a frame that contains a `CarComponent`.

Let us look more closely at the `CarComponent` class. The `paintComponent` method draws two cars. We place one car in the top-left corner of the window, and the other car in the bottom-right corner. To compute the bottom-right position, we call the `getWidth` and `getHeight` methods of the `JComponent` class. These methods return the dimensions of the component. We subtract the dimensions of the car to determine the position of `car2`:

```
Car car1 = new Car(0, 0);
int x = getWidth() - 60;
int y = getHeight() - 30;
Car car2 = new Car(x, y);
```

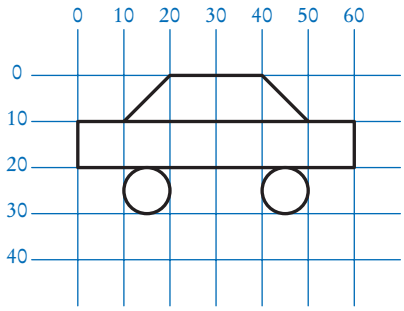


Figure 9
Using Graph Paper to Find Shape Coordinates

Pay close attention to the call to `getWidth` inside the `paintComponent` method of `CarComponent`. The method call has no implicit parameter, which means that the method is applied to the same object that executes the `paintComponent` method. The component simply obtains *its own* width.

Run the program and resize the window. Note that the second car always ends up at the bottom-right corner of the window. Whenever the window is resized, the `paintComponent` method is called and the car position is recomputed, taking the current component dimensions into account.

section_8/CarComponent.java

```
1  import java.awt.Graphics;
2  import java.awt.Graphics2D;
3  import javax.swing.JComponent;
4
5  /**
6     This component draws two car shapes.
7  */
8  public class CarComponent extends JComponent
9  {
10    public void paintComponent(Graphics g)
11    {
12       Graphics2D g2 = (Graphics2D) g;
13
14       Car car1 = new Car(0, 0);
15
16       int x = getWidth() - 60;
17       int y = getHeight() - 30;
18
19       Car car2 = new Car(x, y);
20
21       car1.draw(g2);
22       car2.draw(g2);
23    }
24 }
```

section_8/Car.java

```
1  import java.awt.Graphics2D;
2  import java.awt.Rectangle;
3  import java.awt.geom.Ellipse2D;
4  import java.awt.geom.Line2D;
5  import java.awt.geom.Point2D;
6
7  /**
8     A car shape that can be positioned anywhere on the screen.
9  */
10 public class Car
11 {
12    private int xLeft;
13    private int yTop;
14
15    /**
16       Constructs a car with a given top left corner.
17       @param x the x-coordinate of the top-left corner
18       @param y the y-coordinate of the top-left corner
19    */
20    public Car(int x, int y)
21    {
```

```
22          xLeft = x;
23          yTop = y;
24       }
25
26       /**
27          Draws the car.
28          @param g2 the graphics context
29       */
30       public void draw(Graphics2D g2)
31       {
32          Rectangle body = new Rectangle(xLeft, yTop + 10, 60, 10);
33          Ellipse2D.Double frontTire
34                = new Ellipse2D.Double(xLeft + 10, yTop + 20, 10, 10);
35          Ellipse2D.Double rearTire
36                = new Ellipse2D.Double(xLeft + 40, yTop + 20, 10, 10);
37
38          // The bottom of the front windshield
39          Point2D.Double r1 = new Point2D.Double(xLeft + 10, yTop + 10);
40          // The front of the roof
41          Point2D.Double r2 = new Point2D.Double(xLeft + 20, yTop);
42          // The rear of the roof
43          Point2D.Double r3 = new Point2D.Double(xLeft + 40, yTop);
44          // The bottom of the rear windshield
45          Point2D.Double r4 = new Point2D.Double(xLeft + 50, yTop + 10);
46
47          Line2D.Double frontWindshield = new Line2D.Double(r1, r2);
48          Line2D.Double roofTop = new Line2D.Double(r2, r3);
49          Line2D.Double rearWindshield = new Line2D.Double(r3, r4);
50
51          g2.draw(body);
52          g2.draw(frontTire);
53          g2.draw(rearTire);
54          g2.draw(frontWindshield);
55          g2.draw(roofTop);
56          g2.draw(rearWindshield);
57       }
58    }
```

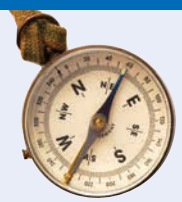
section_8/CarViewer.java

```
1  import javax.swing.JFrame;
2
3  public class CarViewer
4  {
5     public static void main(String[] args)
6     {
7        JFrame frame = new JFrame();
8
9        frame.setSize(300, 400);
10       frame.setTitle("Two cars");
11       frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
12
13       CarComponent component = new CarComponent();
14       frame.add(component);
15
16       frame.setVisible(true);
17    }
18 }
```

27. Which class needs to be modified to have the two cars positioned next to each other?
28. Which class needs to be modified to have the car tires painted in black, and what modification do you need to make?
29. How do you make the cars twice as big?

Practice It Now you can try these exercises at the end of the chapter: E3.19, E3.24.

HOW TO 3.2 Drawing Graphical Shapes



Suppose you want to write a program that displays graphical shapes such as cars, aliens, charts, or any other images that can be obtained from rectangles, lines, and ellipses. These instructions give you a step-by-step procedure for decomposing a drawing into parts and implementing a program that produces the drawing.

Problem Statement Create a program that draws a national flag.

Step 1 Determine the shapes that you need for the drawing.

You can use the following shapes:

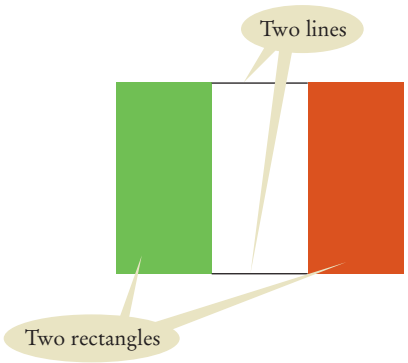
- Squares and rectangles
- Circles and ellipses
- Lines

The outlines of these shapes can be drawn in any color, and you can fill the insides of these shapes with any color. You can also use text to label parts of your drawing.

Some national flags consist of three equally wide sections of different colors, side by side.

© Punchstock.

You could draw such a flag using three rectangles. But if the middle rectangle is white, as it is, for example, in the flag of Italy (green, white, red), it is easier and looks better to draw a line on the top and bottom of the middle portion:



Step 2 Find the coordinates for the shapes.

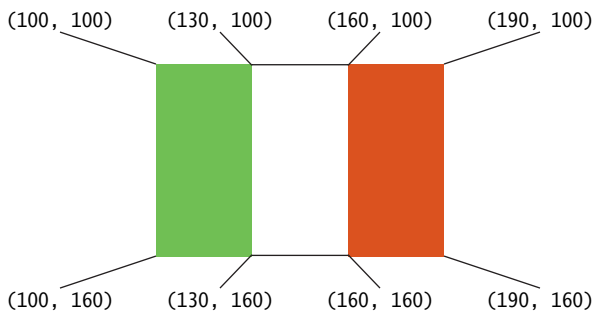
You now need to find the exact positions for the geometric shapes.

- For rectangles, you need the x- and y-position of the top-left corner, the width, and the height.
- For ellipses, you need the top-left corner, width, and height of the bounding rectangle.
- For lines, you need the x- and y-positions of the start and end points.
- For text, you need the x- and y-position of the basepoint.

A commonly-used size for a window is 300 by 300 pixels. You may not want the flag crammed all the way to the top, so perhaps the upper-left corner of the flag should be at point (100, 100).

Many flags, such as the flag of Italy, have a width : height ratio of 3 : 2. (You can often find exact proportions for a particular flag by doing a bit of Internet research on one of several Flags of the World sites.) For example, if you make the flag 90 pixels wide, then it should be 60 pixels tall. (Why not make it 100 pixels wide? Then the height would be $100 \cdot 2 / 3 \approx 67$, which seems more awkward.)

Now you can compute the coordinates of all the important points of the shape:



Step 3 Write Java statements to draw the shapes.

In our example, there are two rectangles and two lines:

```
Rectangle leftRectangle = new Rectangle(100, 100, 30, 60);
Rectangle rightRectangle = new Rectangle(160, 100, 30, 60);
Line2D.Double topLine = new Line2D.Double(130, 100, 160, 100);
Line2D.Double bottomLine = new Line2D.Double(130, 160, 160, 160);
```

If you are more ambitious, then you can express the coordinates in terms of a few variables. In the case of the flag, we have arbitrarily chosen the top-left corner and the width. All other coordinates follow from those choices. If you decide to follow the ambitious approach, then the rectangles and lines are determined as follows:

```
Rectangle leftRectangle = new Rectangle(
      xLeft, yTop,
      width / 3, width * 2 / 3);
Rectangle rightRectangle = new Rectangle(
      xLeft + 2 * width / 3, yTop,
      width / 3, width * 2 / 3);
Line2D.Double topLine = new Line2D.Double(
      xLeft + width / 3, yTop,
      xLeft + width * 2 / 3, yTop);
Line2D.Double bottomLine = new Line2D.Double(
      xLeft + width / 3, yTop + width * 2 / 3,
      xLeft + width * 2 / 3, yTop + width * 2 / 3);
```

Now you need to fill the rectangles and draw the lines. For the flag of Italy, the left rectangle is green and the right rectangle is red. Remember to switch colors before the filling and drawing operations:

```
g2.setColor(Color.GREEN);
g2.fill(leftRectangle);
g2.setColor(Color.RED);
g2.fill(rightRectangle);
g2.setColor(Color.BLACK);
g2.draw(topLine);
g2.draw(bottomLine);
```

Step 4 Combine the drawing statements with the component "plumbing".

```
public class MyComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Graphics2D g2 = (Graphics2D) g;
      Drawing instructions.
      . . .
   }
}
```

In our simple example, you could add all shapes and drawing instructions inside the `paintComponent` method:

```
public class ItalianFlagComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Graphics2D g2 = (Graphics2D) g;
      Rectangle leftRectangle = new Rectangle(100, 100, 30, 60);
      . . .
      g2.setColor(Color.GREEN);
      g2.fill(leftRectangle);
      . . .
   }
}
```

That approach is acceptable for simple drawings, but it is not very object-oriented. After all, a flag is an object. It is better to make a separate class for the flag. Then you can draw different flags at different positions. Specify the sizes in a constructor and supply a `draw` method:

```
public class ItalianFlag
{
   private int xLeft;
   private int yTop;
   private int width;

   public ItalianFlag(int x, int y, int aWidth)
   {
      xLeft = x;
      yTop = y;
      width = aWidth;
   }

   public void draw(Graphics2D g2)
   {
      Rectangle leftRectangle = new Rectangle(
            xLeft, yTop,
            width / 3, width * 2 / 3);
```

```
         . . .
         g2.setColor(Color.GREEN);
         g2.fill(leftRectangle);
         . . .
      }
   }
```

You still need a separate class for the component, but it is very simple:

```
public class ItalianFlagComponent extends JComponent
{
   public void paintComponent(Graphics g)
   {
      Graphics2D g2 = (Graphics2D) g;
      ItalianFlag flag = new ItalianFlag(100, 100, 90);
      flag.draw(g2);
   }
}
```

Step 5 Write the viewer class.

Provide a viewer class, with a `main` method in which you construct a frame, add your component, and make your frame visible. The viewer class is completely routine; you only need to change a single line to show a different component.

```
public class ItalianFlagViewer
{
   public static void main(String[] args)
   {
      JFrame frame = new JFrame();

      frame.setSize(300, 400);
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

      ItalianFlagComponent component = new ItalianFlagComponent();
      frame.add(component);

      frame.setVisible(true);
   }
}
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download the complete flag drawing program.

CHAPTER SUMMARY

Understand instance variables and the methods that access them.

- An object's instance variables store the data required for executing its methods.
- Each object of a class has its own set of instance variables.
- Private instance variables can only be accessed by methods of the same class.
- Encapsulation is the process of hiding implementation details and providing methods for data access.

- Encapsulation allows a programmer to use a class without having to know its implementation.
- Information hiding makes it simpler for the implementor of a class to locate errors and change implementations.

Write method and constructor headers that describe the public interface of a class.

- In order to implement a class, you first need to know which methods are required.
- Constructors set the initial data for objects.
- The constructor name is always the same as the class name.
- Use documentation comments to describe the classes and public methods of your programs.
- Provide documentation comments for every class, every method, every parameter variable, and every return value.

Implement a class.

- The private implementation of a class consists of instance variables, and the bodies of constructors and methods.

Write tests that verify that a class works correctly.

- A unit test verifies that a class works correctly in isolation, outside a complete program.
- To test a class, use an environment for interactive testing, or write a tester class to execute test instructions.

Use the technique of object tracing for visualizing object behavior.

- Write the methods on the front of a card and the instance variables on the back.
- Update the values of the instance variables when a mutator method is called.

Compare initialization and lifetime of instance, local, and parameter variables.

- Local variables are declared in the body of a method.
- When a method exits, its local variables are removed.
- Instance variables are initialized to a default value, but you must initialize local variables.

Recognize the use of the implicit parameter in method declarations.

- Use of an instance variable name in a method denotes the instance variable of the implicit parameter.
- The `this` reference denotes the implicit parameter.
- A local variable shadows an instance variable with the same name. You can access the instance variable name through the `this` reference.
- A method call without an implicit parameter is applied to the same object.

Implement classes that draw graphical shapes.

- It is a good idea to make a class for any part of a drawing that can occur more than once.
- To figure out how to draw a complex shape, make a sketch on graph paper.

REVIEW EXERCISES

■ **R3.1** What is the public interface of the `Counter` class in Section 3.1? How does it differ from the implementation of the class?

■ **R3.2** What is encapsulation? Why is it useful?

■ **R3.3** Instance variables are a part of the hidden implementation of a class, but they aren't actually hidden from programmers who have the source code of the class. Explain to what extent the `private` reserved word provides information hiding.

■ **R3.4** Consider a class `Grade` that represents a letter grade, such as A+ or B. Give two choices of instance variables that can be used for implementing the `Grade` class.

■■ **R3.5** Consider a class `Time` that represents a point in time, such as 9 A.M. or 3:30 P.M. Give two different sets of instance variables that can be used for implementing the `Time` class.

■ **R3.6** Suppose the implementor of the `Time` class of Exercise R3.5 changes from one implementation strategy to another, keeping the public interface unchanged. What do the programmers who use the `Time` class need to do?

■■ **R3.7** You can read the `value` instance variable of the `Counter` class with the `getValue` accessor method. Should there be a `setValue` mutator method to change it? Explain why or why not.

■■ **R3.8**

a. Show that the `BankAccount(double initialBalance)` constructor is not strictly necessary. That is, if we removed that constructor from the public interface, how could a programmer still obtain `BankAccount` objects with an arbitrary balance?

b. Conversely, could we keep only the `BankAccount(double initialBalance)` constructor and remove the `BankAccount()` constructor?

■■ **R3.9** Why does the `BankAccount` class not have a `reset` method?

■ **R3.10** What happens in our implementation of the `BankAccount` class when more money is withdrawn from the account than the current balance?

■■ **R3.11** What is the `this` reference? Why would you use it?

■■ **R3.12** Which of the methods in the `CashRegister` class of Worked Example 3.1 are accessor methods? Which are mutator methods?

■■ **R3.13** What does the following method do? Give an example of how you can call the method.

```
public class BankAccount
{
   public void mystery(BankAccount that, double amount)
   {
      this.balance = this.balance - amount;
      that.balance = that.balance + amount;
   }
   . . . // Other bank account methods
}
```

■■ **R3.14** Suppose you want to implement a class `TimeDepositAccount`. A time deposit account has a fixed interest rate that should be set in the constructor, together with the initial

balance. Provide a method to get the current balance. Provide a method to add the earned interest to the account. This method should have no arguments because the interest rate is already known. It should have no return value because you already provided a method for obtaining the current balance. It is not possible to deposit additional funds into this account. Provide a `withdraw` method that removes the entire balance. Partial withdrawals are not allowed.

■ **R3.15** Consider the following implementation of a class `Square`:

```
public class Square
{
   private int sideLength;
   private int area; // Not a good idea

   public Square(int length)
   {
      sideLength = length;
   }

   public int getArea()
   {
      area = sideLength * sideLength;
      return area;
   }
}
```

Why is it not a good idea to introduce an instance variable for the area? Rewrite the class so that `area` is a local variable.

■■ **R3.16** Consider the following implementation of a class `Square`:

```
public class Square
{
   private int sideLength;
   private int area;

   public Square(int initialLength)
   {
      sideLength = initialLength;
      area = sideLength * sideLength;
   }

   public int getArea() { return area; }
   public void grow() { sideLength = 2 * sideLength; }
}
```

What error does this class have? How would you fix it?

■■ **Testing R3.17** Provide a unit test class for the `Counter` class in Section 3.1.

■■ **Testing R3.18** Read Exercise E3.12, but do not implement the `Car` class yet. Write a tester class that tests a scenario in which gas is added to the car, the car is driven, more gas is added, and the car is driven again. Print the actual and expected amount of gas in the tank.

■ **R3.19** Using the object tracing technique described in Section 3.5, trace the program at the end of Section 3.4.

■■ **R3.20** Using the object tracing technique described in Section 3.5, trace the program in How To 3.1.

■■ **R3.21** Using the object tracing technique described in Section 3.5, trace the program in Worked Example 3.1.

■■■ **R3.22** Design a modification of the `BankAccount` class in which the first five transactions per month are free and a $1 fee is charged for every additional transaction. Provide a method that deducts the fee at the end of a month. What additional instance variables do you need? Using the object tracing technique described in Section 3.5, trace a scenario that shows how the fees are computed over two months.

■■ **Graphics R3.23** Suppose you want to extend the car viewer program in Section 3.8 to show a suburban scene, with several cars and houses. Which classes do you need?

■■■ **Graphics R3.24** Explain why the calls to the `getWidth` and `getHeight` methods in the `CarComponent` class have no explicit parameter.

■■ **Graphics R3.25** How would you modify the `Car` class in order to show cars of varying sizes?

PRACTICE EXERCISES

■ **E3.1** We want to add a button to the tally counter in Section 3.1 that allows an operator to undo an accidental button click. Provide a method

```
public void undo()
```

that simulates such a button. As an added precaution, make sure that clicking the undo button more often than the click button has no effect. (*Hint:* The call `Math.max(n, 0)` returns `n` if `n` is greater than zero, zero otherwise.)

■ **E3.2** Simulate a tally counter that can be used to admit a limited number of people. First, the limit is set with a call

```
public void setLimit(int maximum)
```

If the click button is clicked more often than the limit, it has no effect. (*Hint:* The call `Math.min(n, limit)` returns `n` if `n` is less than `limit`, and `limit` otherwise.)

■■ **E3.3** Simulate a circuit for controlling a hallway light that has switches at both ends of the hallway. Each switch can be up or down, and the light can be on or off. Toggling either switch turns the lamp on or off. Provide methods

```
public int getFirstSwitchState() // 0 for down, 1 for up
public int getSecondSwitchState()
public int getLampState() // 0 for off, 1 for on
public void toggleFirstSwitch()
public void toggleSecondSwitch()
```

■ **Testing E3.4** Write a `CircuitTester` class that tests all switch combinations in Exercise E3.3, printing out actual and expected states for the switches and lamps.

■■■ **E3.5** Change the public interface of the circuit class of Exercise E3.3 so that it has the following methods:

```
public int getSwitchState(int switch)
public int getLampState()
public void toggleSwitch(int switch)
```

Provide an implementation using only language features that have been introduced. The challenge is to find a data representation from which to recover the switch states.

■ **Testing E3.6** Write a `BankAccountTester` class whose `main` method constructs a bank account, deposits $1,000, withdraws $500, withdraws another $400, and then prints the remaining balance. Also print the expected result.

■ **E3.7** Add a method

```
public void addInterest(double rate)
```

to the `BankAccount` class that adds interest at the given rate. For example, after the statements

```
BankAccount momsSavings = new BankAccount(1000);
momsSavings.addInterest(10); // 10 percent interest
```

the balance in `momsSavings` is $1,100. Also supply a `BankAccountTester` class that prints the actual and expected balance.

■ **E3.8** Write a class `SavingsAccount` that is similar to the `BankAccount` class, except that it has an added instance variable `interest`. Supply a constructor that sets both the initial balance and the interest rate. Supply a method `addInterest` (with no explicit parameter) that adds interest to the account. Write a `SavingsAccountTester` class that constructs a savings account with an initial balance of $1,000 and an interest rate of 10 percent. Then apply the `addInterest` method and print the resulting balance. Also compute the expected result by hand and print it.

■■■ **E3.9** Add a method `printReceipt` to the `CashRegister` class. The method should print the prices of all purchased items and the total amount due. *Hint:* You will need to form a string of all prices. Use the `concat` method of the `String` class to add additional items to that string. To turn a price into a string, use the call `String.valueOf(price)`.

■ **E3.10** After closing time, the store manager would like to know how much business was transacted during the day. Modify the `CashRegister` class to enable this functionality. Supply methods `getSalesTotal` and `getSalesCount` to get the total amount of all sales and the number of sales. Supply a method `reset` that resets any counters and totals so that the next day's sales start from zero.

■■ **E3.11** Implement a class `Employee`. An employee has a name (a string) and a salary (a `double`). Provide a constructor with two arguments

```
public Employee(String employeeName, double currentSalary)
```

and methods

```
public String getName()
public double getSalary()
public void raiseSalary(double byPercent)
```

These methods return the name and salary, and raise the employee's salary by a certain percentage. Sample usage:

```
Employee harry = new Employee("Hacker, Harry", 50000);
harry.raiseSalary(10); // Harry gets a 10 percent raise
```

Supply an `EmployeeTester` class that tests all methods.

■■ **E3.12** Implement a class `Car` with the following properties. A car has a certain fuel efficiency (measured in miles/gallon or liters/km—pick one) and a certain amount of fuel in the gas tank. The efficiency is specified in the constructor, and the initial fuel level is 0. Supply a method `drive` that simulates driving the car for a certain distance, reducing the amount of gasoline in the fuel tank. Also supply methods `getGasInTank`, returning the current amount of gasoline in the fuel tank, and `addGas`, to add gasoline to the fuel tank. Sample usage:

```
Car myHybrid = new Car(50); // 50 miles per gallon
myHybrid.addGas(20); // Tank 20 gallons
```

```
myHybrid.drive(100); // Drive 100 miles
double gasLeft = myHybrid.getGasInTank(); // Get gas remaining in tank
```

You may assume that the `drive` method is never called with a distance that consumes more than the available gas. Supply a `CarTester` class that tests all methods.

■ **E3.13** Implement a class `Product`. A product has a name and a price, for example `new Product("Toaster", 29.95)`. Supply methods `getName`, `getPrice`, and `reducePrice`. Supply a program `ProductPrinter` that makes two products, prints each name and price, reduces their prices by $5.00, and then prints the prices again.

■■ **E3.14** Provide a class for authoring a simple letter. In the constructor, supply the names of the sender and the recipient:

```
public Letter(String from, String to)
```

Supply a method

```
public void addLine(String line)
```

to add a line of text to the body of the letter.

Supply a method

```
public String getText()
```

that returns the entire text of the letter. The text has the form:

```
Dear recipient name:
blank line
first line of the body
second line of the body
. . .
last line of the body
blank line
Sincerely,
blank line
sender name
```

Also supply a class `LetterPrinter` that prints this letter.

```
Dear John:

I am sorry we must part.
I wish you all the best.

Sincerely,

Mary
```

Construct an object of the `Letter` class and call `addLine` twice.

Hints: (1) Use the `concat` method to form a longer string from two shorter strings. (2) The special string `"\n"` represents a new line. For example, the statement

```
body = body.concat("Sincerely,").concat("\n");
```

adds a line containing the string `"Sincerely,"` to the body.

■■ **E3.15** Write a class `Bug` that models a bug moving along a horizontal line. The bug moves either to the right or left. Initially, the bug moves to the right, but it can turn to change its direction. In each move, its position changes by one unit in the current direction. Provide a constructor

```
public Bug(int initialPosition)
```

and methods

```
public void turn()
public void move()
public int getPosition()
```

Sample usage:

```
Bug bugsy = new Bug(10);
bugsy.move(); // Now the position is 11
bugsy.turn();
bugsy.move(); // Now the position is 10
```

Your `BugTester` should construct a bug, make it move and turn a few times, and print the actual and expected position.

■■ **E3.16** Implement a class `Moth` that models a moth flying along a straight line. The moth has a position, which is the distance from a fixed origin. When the moth moves toward a point of light, its new position is halfway between its old position and the position of the light source. Supply a constructor

```
public Moth(double initialPosition)
```

and methods

```
public void moveToLight(double lightPosition)
public double getPosition()
```

Your `MothTester` should construct a moth, move it toward a couple of light sources, and check that the moth's position is as expected.

■■■ **Graphics E3.17** Write a program that fills the window with a large ellipse, with a black outline and filled with your favorite color. The ellipse should touch the window boundaries, even if the window is resized. Call the `getWidth` and `getHeight` methods of the `JComponent` class in the `paintComponent` method.

■■ **Graphics E3.18** Draw a shooting target—a set of concentric rings in alternating black and white colors. *Hint:* Fill a black circle, then fill a smaller white circle on top, and so on. Your program should be composed of classes `Target`, `TargetComponent`, and `TargetViewer`.

■■ **Graphics E3.19** Write a program that draws a picture of a house. It could be as simple as the accompanying figure, or if you like, more elaborate (3-D, skyscraper, marble columns in the entryway, whatever). Implement a class `House` and supply a method `draw(Graphics2D g2)` that draws the house.

■■ **Graphics E3.20** Extend Exercise E3.19 by supplying a `House` constructor for specifying the position and size. Then populate your screen with a few houses of different sizes.

■■ **Graphics E3.21** Change the car viewer program in Section 3.8 to make the cars appear in different colors. Each `Car` object should store its own color. Supply modified `Car` and `CarComponent` classes.

■■ **Graphics E3.22** Change the `Car` class so that the size of a car can be specified in the constructor. Change the `CarComponent` class to make one of the cars appear twice the size of the original example.

■■ **Graphics E3.23** Write a program to plot the string "HELLO", using only lines and circles. Do not call `drawString`, and do not use `System.out`. Make classes `LetterH`, `LetterE`, `LetterL`, and `LetterO`.

■■ **Graphics E3.24** Write a program that displays the Olympic rings. Color the rings in the Olympic colors. Provide classes `OlympicRing`, `OlympicRingViewer`, and `OlympicRingComponent`.

■■ **Graphics E3.25** Make a bar chart to plot the following data set. Label each bar. Make the bars horizontal for easier labeling. Provide a class `BarChartViewer` and a class `BarChartComponent`.

Bridge Name	Longest Span (ft)
Golden Gate	4,200
Brooklyn	1,595
Delaware Memorial	2,150
Mackinac	3,800

PROGRAMMING PROJECTS

■ **P3.1** Enhance the `CashRegister` class so that it counts the purchased items. Provide a `getItemCount` method that returns the count.

■■■ **P3.2** Support computing sales tax in the `CashRegister` class. The tax rate should be supplied when constructing a `CashRegister` object. Add `recordTaxablePurchase` and `getTotalTax` methods. (Amounts added with `recordPurchase` are not taxable.) The `giveChange` method should correctly reflect the sales tax that is charged on taxable items.

■■ **P3.3** Implement a class `Balloon`. A balloon starts out with radius 0. Supply a method

```
public void inflate(double amount)
```

that increases the radius by the given amount. Supply a method

```
public double getVolume()
```

that returns the current volume of the balloon. Use `Math.PI` for the value of π. To compute the cube of a value `r`, just use `r * r * r`.

■■ **P3.4** A microwave control panel has four buttons: one for increasing the time by 30 seconds, one for switching between power levels 1 and 2, a reset button, and a start button. Implement a class that simulates the microwave, with a method for each button. The method for the start button should print a message "Cooking for ... seconds at level ...".

■■ **P3.5** A `Person` has a name (just a first name for simplicity) and friends. Store the names of the friends in a string, separated by spaces. Provide a constructor that constructs a person with a given name and no friends. Provide methods

```
public void befriend(Person p)
public void unfriend(Person p)
public String getFriendNames()
```

■ **P3.6** Add a method

```
public int getFriendCount()
```

to the `Person` class of Exercise P3.5.

■■■ **P3.7** Implement a class `Student`. For the purpose of this exercise, a student has a name and a total quiz score. Supply an appropriate constructor and methods `getName()`, `addQuiz(int score)`, `getTotalScore()`, and `getAverageScore()`. To compute the average, you also need to store the *number of quizzes* that the student took.

Supply a `StudentTester` class that tests all methods.

■ **P3.8** Write a class `Battery` that models a rechargeable battery. A battery has a constructor

```
public Battery(double capacity)
```

where capacity is a value measured in milliampere hours. A typical AA battery has a capacity of 2000 to 3000 mAh. The method

```
public void drain(double amount)
```

drains the capacity of the battery by the given amount. The method

```
public void charge()
```

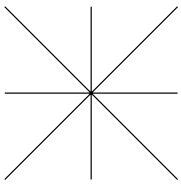
charges the battery to its original capacity.

The method

```
public double getRemainingCapacity()
```

gets the remaining capacity of the battery.

■■ **Graphics P3.9** Write a program that draws three stars like the one at right. Use classes `Star`, `StarComponent`, and `StarViewer`.



■■ **P3.10** Implement a class `RoachPopulation` that simulates the growth of a roach population. The constructor takes the size of the initial roach population. The `breed` method simulates a period in which the roaches breed, which doubles their population. The `spray(double percent)` method simulates spraying with insecticide, which reduces the population by the given percentage. The `getRoaches` method returns the current number of roaches. A program called `RoachSimulation` simulates a population that starts out with 10 roaches. Breed, spray to reduce the population by 10 percent, and print the roach count. Repeat three more times.

■■ **P3.11** Implement a `VotingMachine` class that can be used for a simple election. Have methods to clear the machine state, to vote for a Democrat, to vote for a Republican, and to get the tallies for both parties.

■■■ **P3.12** In this project, you will enhance the `BankAccount` class and see how abstraction and encapsulation enable evolutionary changes to software.

Begin with a simple enhancement: charging a fee for every deposit and withdrawal. Supply a mechanism for setting the fee and modify the `deposit` and `withdraw` methods so that the fee is levied. Test your class and check that the fee is computed correctly.

Now make a more complex change. The bank will allow a fixed number of free transactions (deposits or withdrawals) every month, and charge for transactions exceeding the free allotment. The charge is not levied immediately but at the end of the month.

Supply a new method `deductMonthlyCharge` to the `BankAccount` class that deducts the monthly charge and resets the transaction count. (*Hint:* Use `Math.max(actual transaction count, free transaction count)` in your computation.)

Produce a test program that verifies that the fees are calculated correctly over several months.

■■■ **P3.13** In this project, you will explore an object-oriented alternative to the "Hello, World" program in Chapter 1.

Begin with a simple `Greeter` class that has a single method, `sayHello`. That method should *return* a string, not print it. Create two objects of this class and invoke their `sayHello` methods. Of course, both objects return the same answer.

Enhance the `Greeter` class so that each object produces a customized greeting. For example, the object constructed as `new Greeter("Dave")` should say `"Hello, Dave"`. (Use the `concat` method to combine strings to form a longer string, or peek ahead at Section 4.5 to see how you can use the `+` operator for the same purpose.)

Add a method `sayGoodbye` to the `Greeter` class.

Finally, add a method `refuseHelp` to the `Greeter` class. It should return a string such as `"I am sorry, Dave. I am afraid I can't do that."`

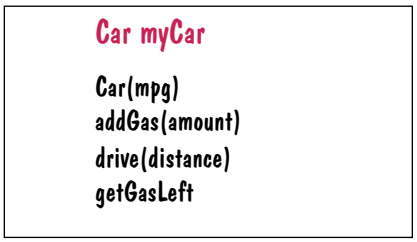
If you use BlueJ, place two `Greeter` objects on the workbench (one that greets the world and one that greets Dave) and invoke methods on them. Otherwise, write a tester program that constructs these objects, invokes methods, and prints the results.

ANSWERS TO SELF-CHECK QUESTIONS

1.
```
public void unclick()
{
   value = value - 1;
}
```
2. You can only access them by invoking the methods of the `Clock` class.
3. In one of the methods of the `Counter` class.
4. The programmers who designed and implemented the Java library.
5. Other programmers who work on the personal finance application.
6.
```
harrysChecking.withdraw(
   harrysChecking.getBalance());
```
7. The `withdraw` method has return type `void`. It doesn't return a value. Use the `getBalance` method to obtain the balance after the withdrawal.
8. Add an `accountNumber` parameter variable to the constructors, and add a `getAccountNumber` method. There is no need for a `setAccountNumber` method—the account number never changes after construction.
9.
```
/**
   Constructs a new bank account with a given
   initial balance.
   @param accountNumber the account number for
   this account
   @param initialBalance the initial balance for
   this account
*/
```
10. The first sentence of the method description should describe the method—it is displayed in isolation in the summary table.
11. An instance variable needs to be added to the class:
```
private int accountNumber;
```
12. Because the `balance` instance variable is accessed from the `main` method of `BankRobber`. The compiler will report an error because `main` is not a method of the `BankAccount` class and has no access to `BankAccount` instance variables.
13.
```
public int getWidth()
{
   return width;
}
```
14. There is more than one correct answer. One possible implementation is as follows:
```
public void translate(int dx, int dy)
{
   int newx = x + dx;
   x = newx;
   int newy = y + dy;
   y = newy;
}
```
15. One `BankAccount` object, no `BankAccountTester` object. The purpose of the `BankAccountTester` class is merely to hold the `main` method.
16. In those environments, you can issue interactive commands to construct `BankAccount`

objects, invoke methods, and display their return values.

17.



front

gasLeft	milesPerGallon
0	25

back

18.

gasLeft	milesPerGallon
~~0~~ ~~20~~ ~~16~~ ~~8~~ 13	25

19.

gasLeft	milesPerGallon	totalMiles
0	25	0

20.

gasLeft	milesPerGallon	totalMiles
~~0~~ ~~20~~ ~~16~~ ~~8~~ 13	25	0 100 300

21. Variables of both categories belong to methods—they come alive when the method is called, and they die when the method exits. They differ in their initialization. Parameter variables are initialized with the values supplied as arguments in the call; local variables must be explicitly initialized.

22. After computing the change due, `payment` and `purchase` were set to zero. If the method returned `payment - purchase`, it would always return zero.

23.

reg1.purchase	reg1.payment	change
~~19.5~~	~~20~~	
		0.5
0	0	
		X

24. One implicit parameter, called `this`, of type `BankAccount`, and one explicit parameter, called `amount`, of type `double`.

25. It is not a legal expression. `this` is of type `BankAccount` and the `BankAccount` class has no instance variable named `amount`.

26. No implicit parameter—the `main` method is not invoked on any object—and one explicit parameter, called `args`.

27. `CarComponent`

28. In the `draw` method of the `Car` class, call

```
g2.fill(frontTire);
g2.fill(rearTire);
```

29. Double all measurements in the `draw` method of the `Car` class.

WORKED EXAMPLE 3.1 Making a Simple Menu

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Problem Statement Your task is to design a class `Menu`. An object of this class can display a menu such as

```
1) Open new account
2) Log into existing account
3) Help
4) Quit
```

The numbers should be supplied automatically when options are added to the menu.

Step 1 Find out which methods you are asked to supply.

The problem description lists two tasks:

Display the menu.
Add an option to the menu.

Step 2 Specify the public interface.

Here we turn the list in Step 1 into a set of methods, with specific types for the parameter variables and the return values. As recommended in How To 3.1, we start by writing out sample code:

```
mainMenu.addOption("Open new account");
mainMenu.addOption("Log into existing account");
mainMenu.display();
```

Now we have a specific list of methods:

```
public void addOption(String option)
public void display()
```

To complete the public interface, we need to specify the constructors. We have two choices:

- Supply a constructor `Menu(String firstOption)` that makes a menu with one option.
- Supply a constructor `Menu()` that makes a menu with no options.

Either choice will work fine. If we decide in favor of the second choice, the user of the class needs to call `addOption` to add the first option—after all, there is no sense in having a menu with no options. At first glance, that seems like a burden for the programmer using the class. But actually, it is usually conceptually simpler if an API has no special cases (such as having to supply the first option in the constructor). Therefore, we decide that "simplest is best" and specify the constructor

```
public Menu()
```

Step 3 Document the public interface.

Here is the documentation, with comments, that describes the class and its methods:

```
/**
   A menu that is displayed on a console.
*/
public class Menu
{
   /**
      Constructs a menu with no options.
   */
   public Menu()
   {
   }
```

```
   /**
      Adds an option to the end of this menu.
      @param option the option to add
   */
   public void addOption(String option)
   {
   }

   /**
      Displays the menu on the console.
   */
   public void display()
   {
   }
}
```

Step 4 Determine instance variables.

What data does a `Menu` option need to keep in order to fulfill its responsibilities? Of course, in order to display the menu, it needs to store the menu text. Now consider the `addOption` method. That method adds a number and the option to the menu text. Where does the number come from? The menu object needs to store it too, so that it can increment whenever `addOption` is called.

Therefore, our instance variables are

```
public class Menu
{
   private String menuText;
   private int optionCount;
   . . .
}
```

Step 5 Implement constructors and methods.

We now implement the constructors and methods in the class, one at a time, in the order that is most convenient. The constructor seems pretty easy:

```
public Menu()
{
   menuText = "";
   optionCount = 0;
}
```

The `display` method is easy as well:

```
public void display()
{
   System.out.println(menuText);
}
```

The `addOption` method requires a bit more thought. Here is the pseudocode:

```
Increment the option count.
Add the following to the menu text:
   The option count
   A ) symbol
   The option to be added
   A "newline" character that causes the next option to appear on a new line
```

How do you add something to a string? If you look at the API of the `String` class, you will find a method `concat`. For example, the call

```
menuText.concat(option)
```

creates a string consisting of the strings `menuText` and `option`. You can then store that string back into the `menuText` variable:

```
menuText = menuText.concat(option);
```

As you will learn in Chapter 4, you can achieve the same effect with the `+` operator:

```
menuText = menuText + option;
```

We use the `+` operator in our solution because it is so convenient. Our method then becomes

```
public void addOption(String option)
{
   optionCount = optionCount + 1;
   menuText = menuText + optionCount + ") " + option + "\n";
}
```

Step 6 Test your class.

Here is a short program that demonstrates all methods in the public interface of the `Menu` class:

```
public class MenuDemo
{
   public static void main(String[] args)
   {
      Menu mainMenu = new Menu();
      mainMenu.addOption("Open new account");
      mainMenu.addOption("Log into existing account");
      mainMenu.addOption("Help");
      mainMenu.addOption("Quit");
      mainMenu.display();
   }
}
```

Program Run

```
1) Open new account
2) Log into existing account
3) Help
4) Quit
```

CHAPTER 4

FUNDAMENTAL DATA TYPES

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CHAPTER GOALS

To understand integer and floating-point numbers

To recognize the limitations of the numeric types

To become aware of causes for overflow and roundoff errors

To understand the proper use of constants

To write arithmetic expressions in Java

To use the `String` type to manipulate character strings

To write programs that read input and produce formatted output

CHAPTER CONTENTS

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Numbers and character strings (such as the ones on this display board) are important data types in any Java program. In this chapter, you will learn how to work with numbers and text, and how to write simple programs that perform useful tasks with them. We also cover the important topic of input and output, which enables you to implement interactive programs.

4.1 Numbers

We start this chapter with information about numbers. The following sections tell you how to choose the most appropriate number types for your numeric values, and how to work with constants—numeric values that do not change.

4.1.1 Number Types

Java has eight primitive types, including four integer types and two floating-point types.

In Java, every value is either a reference to an object, or it belongs to one of the eight **primitive types** shown in Table 1.

Six of the primitive types are number types; four of them for integers and two for floating-point numbers.

Each of the number types has a different range. Appendix G explains why the range limits are related to powers of two. The largest number that can be represented in an `int` is denoted by `Integer.MAX_VALUE`. Its value is about 2.14 billion. Similarly, the smallest integer is `Integer.MIN_VALUE`, about –2.14 billion.

Table 1 Primitive Types

Type	Description	Size
`int`	The integer type, with range –2,147,483,648 (`Integer.MIN_VALUE`) . . . 2,147,483,647 (`Integer.MAX_VALUE`, about 2.14 billion)	4 bytes
`byte`	The type describing a single byte, with range –128 . . . 127	1 byte
`short`	The short integer type, with range –32,768 . . . 32,767	2 bytes
`long`	The long integer type, with range –9,223,372,036,854,775,808 . . . 9,223,372,036,854,775,807	8 bytes
`double`	The double-precision floating-point type, with a range of about $\pm 10^{308}$ and about 15 significant decimal digits	8 bytes
`float`	The single-precision floating-point type, with a range of about $\pm 10^{38}$ and about 7 significant decimal digits	4 bytes
`char`	The character type, representing code units in the Unicode encoding scheme (see Computing & Society 4.2 on page 161)	2 bytes
`boolean`	The type with the two truth values `false` and `true` (see Chapter 5)	1 bit

Table 2 Number Literals in Java

Number	Type	Comment
`6`	`int`	An integer has no fractional part.
`-6`	`int`	Integers can be negative.
`0`	`int`	Zero is an integer.
`0.5`	`double`	A number with a fractional part has type `double`.
`1.0`	`double`	An integer with a fractional part .0 has type `double`.
`1E6`	`double`	A number in exponential notation: 1×10^6 or 1000000. Numbers in exponential notation always have type `double`.
`2.96E-2`	`double`	Negative exponent: $2.96 \times 10^{-2} = 2.96 / 100 = 0.0296$
`100000L`	`long`	The `L` suffix indicates a long literal.
`100,000`		**Error:** Do not use a comma as a decimal separator.
`100_000`	`int`	You can use underscores in number literals.
`3 1/2`		**Error:** Do not use fractions; use decimal notation: 3.5

When a value such as `6` or `0.335` occurs in a Java program, it is called a **number literal**. If a number literal has a decimal point, it is a floating-point number; otherwise, it is an integer. Table 2 shows how to write integer and floating-point literals in Java.

A numeric computation overflows if the result falls outside the range for the number type.

Generally, you will use the `int` type for integer quantities. Occasionally, however, calculations involving integers can *overflow*. This happens if the result of a computation exceeds the range for the number type. For example,

```
int n = 1000000;
System.out.println(n * n);  // Prints –727379968, which is clearly wrong
```

The product `n * n` is 10^{12}, which is larger than the largest integer (about $2 \cdot 10^9$). The result is truncated to fit into an `int`, yielding a value that is completely wrong. Unfortunately, there is no warning when an integer overflow occurs.

If you run into this problem, the simplest remedy is to use the `long` type. Special Topic 4.1 on page 136 shows you how to use the `BigInteger` type in the unlikely event that even the `long` type overflows.

Overflow is not usually a problem for double-precision floating-point numbers. The `double` type has a range of about $\pm 10^{308}$. Floating-point numbers have a different problem—limited precision. The `double` type has about 15 significant digits, and there are many numbers that cannot be accurately represented as `double` values.

Rounding errors occur when an exact representation of a floating-point number is not possible.

When a value cannot be represented exactly, it is rounded to the nearest match. Consider this example:

```
double f = 4.35;
System.out.println(100 * f); // Prints 434.99999999999994
```

If a computation yields an integer that is larger than the largest `int` value (about 2.14 billion), it overflows.

Floating-point numbers have limited precision. Not every value can be represented precisely, and roundoff errors can occur.

The problem arises because computers represent numbers in the binary number system. In the binary number system, there is no exact representation of the fraction 1/10, just as there is no exact representation of the fraction 1/3 = 0.33333 in the decimal number system. (See Appendix G for more information.)

For this reason, the `double` type is not appropriate for financial calculations. In this book, we will continue to use `double` values for bank balances and other financial quantities so that we keep our programs as simple as possible. However, professional programs need to use the `BigDecimal` type for this purpose—see Special Topic 4.1.

In Java, it is legal to assign an integer value to a floating-point variable:

```
int dollars = 100;
double balance = dollars; // OK
```

But the opposite assignment is an error: You cannot assign a floating-point expression to an integer variable.

```
double balance = 13.75;
int dollars = balance; // Error
```

You will see in Section 4.2.5 how to convert a value of type `double` into an integer.

In this book, we do not use the `float` type. It has less than 7 significant digits, which greatly increases the risk of **roundoff errors**. Some programmers use `float` to save on memory if they need to store a huge set of numbers that do not require much precision.

4.1.2 Constants

In many programs, you need to use numerical **constants**—values that do not change and that have a special significance for a computation.

A typical example for the use of constants is a computation that involves coin values, such as the following:

```
payment = dollars + quarters * 0.25 + dimes * 0.1
      + nickels * 0.05 + pennies * 0.01;
```

Most of the code is self-documenting. However, the four numeric quantities, 0.25, 0.1, 0.05, and 0.01 are included in the arithmetic expression without any explanation. Of course, in this case, you know that the value of a nickel is five cents, which explains the 0.05, and so on. However, the next person who needs to maintain this code may live in another country and may not know that a nickel is worth five cents.

Thus, it is a good idea to use symbolic names for all values, even those that appear obvious. Here is a clearer version of the computation of the total:

```
double quarterValue = 0.25;
double dimeValue = 0.1;
double nickelValue = 0.05;
double pennyValue = 0.01;
```

```
payment = dollars + quarters * quarterValue + dimes * dimeValue
      + nickels * nickelValue + pennies * pennyValue;
```

There is another improvement we can make. There is a difference between the `nickels` and `nickelValue` variables. The `nickels` variable can truly vary over the life of the program, as we calculate different payments. But `nickelValue` is always 0.05.

A `final` variable is a constant. Once its value has been set, it cannot be changed.

In Java, constants are identified with the reserved word `final`. A variable tagged as `final` can never change after it has been set. If you try to change the value of a `final` variable, the compiler will report an error and your program will not compile.

Many programmers use all-uppercase names for constants (`final` variables), such as `NICKEL_VALUE`. That way, it is easy to distinguish between variables (with mostly lowercase letters) and constants. We will follow this convention in this book. However, this rule is a matter of good style, not a requirement of the Java language. The compiler will not complain if you give a `final` variable a name with lowercase letters.

Use named constants to make your programs easier to read and maintain.

Here is an improved version of the code that computes the value of a payment.

```
final double QUARTER_VALUE = 0.25;
final double DIME_VALUE = 0.1;
final double NICKEL_VALUE = 0.05;
final double PENNY_VALUE = 0.01;
payment = dollars + quarters * QUARTER_VALUE + dimes * DIME_VALUE
      + nickels * NICKEL_VALUE + pennies * PENNY_VALUE;
```

Frequently, constant values are needed in several methods. Then you should declare them together with the instance variables of a class and tag them as `static` and `final`. As before, `final` indicates that the value is a constant. The `static` reserved word means that the constant belongs to the class—this is explained in greater detail in Chapter 8.)

```
public class CashRegister
{
   // Constants
   public static final double QUARTER_VALUE = 0.25;
   public static final double DIME_VALUE = 0.1;
   public static final double NICKEL_VALUE = 0.05;
   public static final double PENNY_VALUE = 0.01;

   // Instance variables
   private double purchase;
   private double payment;

   // Methods
   . . .
}
```

We declared the constants as `public`. There is no danger in doing this because constants cannot be modified. Methods of other classes can access a public constant by first specifying the name of the class in which it is declared, then a period, then the name of the constant, such as `CashRegister.NICKEL_VALUE`.

The `Math` class from the standard library declares a couple of useful constants:

```
public class Math
{
   . . .
   public static final double E = 2.7182818284590452354;
   public static final double PI = 3.14159265358979323846;
}
```

You can refer to these constants as `Math.PI` and `Math.E` in any method. For example,

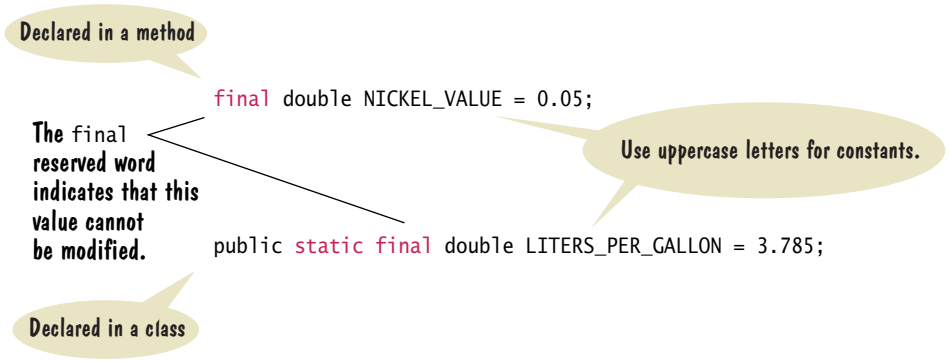
```
double circumference = Math.PI * diameter;
```

Syntax 4.1 Constant Declaration

Syntax

Declared in a method: `final` *typeName variableName* = *expression*;

Declared in a class: *accessSpecifier* `static final` *typeName variableName* = *expression*;



The sample program below puts constants to work. The program shows a refinement of the `CashRegister` class of How To 3.1. The public interface of that class has been modified in order to solve a common business problem.

Busy cashiers sometimes make mistakes totaling up coin values. Our `CashRegister` class features a method whose inputs are the *coin counts*. For example, the call

```
register.receivePayment(1, 2, 1, 1, 4);
```

processes a payment consisting of one dollar, two quarters, one dime, one nickel, and four pennies. The `receivePayment` method figures out the total value of the payment, $1.69. As you can see from the code listing, the method uses named constants for the coin values.

section_1/CashRegister.java

```
1  /**
2     A cash register totals up sales and computes change due.
3  */
4  public class CashRegister
5  {
6     public static final double QUARTER_VALUE = 0.25;
7     public static final double DIME_VALUE = 0.1;
8     public static final double NICKEL_VALUE = 0.05;
9     public static final double PENNY_VALUE = 0.01;
10
11    private double purchase;
12    private double payment;
13
14    /**
15       Constructs a cash register with no money in it.
16    */
17    public CashRegister()
18    {
19       purchase = 0;
20       payment = 0;
```

```
21      }
22
23      /**
24         Records the purchase price of an item.
25         @param amount the price of the purchased item
26      */
27      public void recordPurchase(double amount)
28      {
29         purchase = purchase + amount;
30      }
31
32      /**
33         Processes the payment received from the customer.
34         @param dollars the number of dollars in the payment
35         @param quarters the number of quarters in the payment
36         @param dimes the number of dimes in the payment
37         @param nickels the number of nickels in the payment
38         @param pennies the number of pennies in the payment
39      */
40      public void receivePayment(int dollars, int quarters,
41            int dimes, int nickels, int pennies)
42      {
43         payment = dollars + quarters * QUARTER_VALUE + dimes * DIME_VALUE
44               + nickels * NICKEL_VALUE + pennies * PENNY_VALUE;
45      }
46
47      /**
48         Computes the change due and resets the machine for the next customer.
49         @return the change due to the customer
50      */
51      public double giveChange()
52      {
53         double change = payment - purchase;
54         purchase = 0;
55         payment = 0;
56         return change;
57      }
58   }
```

section_1/CashRegisterTester.java

```
1   /**
2      This class tests the CashRegister class.
3   */
4   public class CashRegisterTester
5   {
6      public static void main(String[] args)
7      {
8         CashRegister register = new CashRegister();
9
10        register.recordPurchase(0.75);
11        register.recordPurchase(1.50);
12        register.receivePayment(2, 0, 5, 0, 0);
13        System.out.print("Change: ");
14        System.out.println(register.giveChange());
15        System.out.println("Expected: 0.25");
16
17        register.recordPurchase(2.25);
18        register.recordPurchase(19.25);
19        register.receivePayment(23, 2, 0, 0, 0);
```

```
20         System.out.print("Change: ");
21         System.out.println(register.giveChange());
22         System.out.println("Expected: 2.0");
23      }
24   }
```

Program Run

```
Change: 0.25
Expected: 0.25
Change: 2.0
Expected: 2.0
```

1. Which are the most commonly used number types in Java?
2. Suppose you want to write a program that works with population data from various countries. Which Java data type should you use?
3. Which of the following initializations are incorrect, and why?
   a. `int dollars = 100.0;`
   b. `double balance = 100;`
4. What is the difference between the following two statements?

   ```
   final double CM_PER_INCH = 2.54;
   ```

   and

   ```
   public static final double CM_PER_INCH = 2.54;
   ```

5. What is wrong with the following statement sequence?

   ```
   double diameter = . . .;
   double circumference = 3.14 * diameter;
   ```

Practice It Now you can try these exercises at the end of the chapter: R4.1, R4.27, E4.21.

Special Topic 4.1

Big Numbers

If you want to compute with really large numbers, you can use big number objects. Big number objects are objects of the `BigInteger` and `BigDecimal` classes in the `java.math` package. Unlike the number types such as `int` or `double`, big number objects have essentially no limits on their size and precision. However, computations with big number objects are much slower than those that involve number types. Perhaps more importantly, you can't use the familiar arithmetic operators such as `(+ - *)` with them. Instead, you have to use methods called `add`, `subtract`, and `multiply`. Here is an example of how to create a `BigInteger` object and how to call the `multiply` method:

```
BigInteger n = new BigInteger("1000000");
BigInteger r = n.multiply(n);
System.out.println(r); // Prints 1000000000000
```

The `BigDecimal` type carries out floating-point computations without roundoff errors. For example,

```
BigDecimal d = new BigDecimal("4.35");
BigDecimal e = new BigDecimal("100");
BigDecimal f = d.multiply(e);
System.out.println(f); // Prints 435.00
```

Programming Tip 4.1

Do Not Use Magic Numbers

A **magic number** is a numeric constant that appears in your code without explanation. For example, consider the following scary example that actually occurs in the Java library source:

```
h = 31 * h + ch;
```

Why 31? The number of days in January? One less than the number of bits in an integer? Actually, this code computes a "hash code" from a string—a number that is derived from the characters in such a way that different strings are likely to yield different hash codes. The value 31 turns out to scramble the character values nicely.

A better solution is to use a named constant:

```
final int HASH_MULTIPLIER = 31;
h = HASH_MULTIPLIER * h + ch;
```

You should never use magic numbers in your code. Any number that is not completely self-explanatory should be declared as a named constant. Even the most reasonable cosmic constant is going to change one day. You think there are 365 days in a year? Your customers on Mars are going to be pretty unhappy about your silly prejudice. Make a constant

```
final int DAYS_PER_YEAR = 365;
```

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We prefer programs that are easy to understand over those that appear to work by magic.

4.2 Arithmetic

In this section, you will learn how to carry out arithmetic calculations in Java.

4.2.1 Arithmetic Operators

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Java supports the same four basic arithmetic operations as a calculator—addition, subtraction, multiplication, and division—but it uses different symbols for the multiplication and division **operators**.

You must write `a * b` to denote multiplication. Unlike in mathematics, you cannot write `a b`, a · `b`, or a × `b`. Similarly, division is always indicated with the `/` operator, never a ÷ or a fraction bar. For example, $\frac{a + b}{2}$ becomes `(a + b) / 2`.

The combination of variables, literals, operators, and/or method calls is called an **expression**. For example, `(a + b) / 2` is an expression.

Parentheses are used just as in algebra: to indicate in which order the parts of the expression should be computed. For example, in the expression `(a + b) / 2`, the sum `a + b` is computed first, and then the sum is divided by 2. In contrast, in the expression

```
a + b / 2
```

only `b` is divided by 2, and then the sum of `a` and `b / 2` is formed. As in regular algebraic notation, multiplication and division have a *higher precedence* than addition and subtraction. For example, in the expression `a + b / 2`, the `/` is carried out first, even though the `+` operation occurs further to the left (see Appendix B).

Mixing integers and floating-point values in an arithmetic expression yields a floating-point value.

If you mix integer and floating-point values in an arithmetic expression, the result is a floating-point value. For example, `7 + 4.0` is the floating-point value `11.0`.

4.2.2 Increment and Decrement

The ++ operator adds 1 to a variable; the -- operator subtracts 1.

Changing a variable by adding or subtracting 1 is so common that there is a special shorthand for it. The ++ operator increments a variable (see Figure 1):

```
counter++; // Adds 1 to the variable counter
```

Similarly, the -- operator decrements a variable:

```
counter--; // Subtracts 1 from counter
```

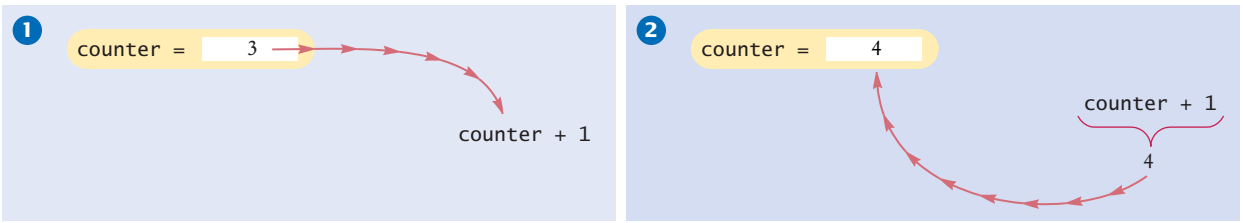


Figure 1 Incrementing a Variable

4.2.3 Integer Division and Remainder

If both arguments of / are integers, the remainder is discarded.

Division works as you would expect, as long as at least one of the numbers involved is a floating-point number. That is,

```
7.0 / 4.0
7 / 4.0
7.0 / 4
```

all yield 1.75. However, if *both* numbers are integers, then the result of the **integer division** is always an integer, with the remainder discarded. That is,

```
7 / 4
```

evaluates to 1 because 7 divided by 4 is 1 with a remainder of 3 (which is discarded). This can be a source of subtle programming errors—see Common Error 4.1.

Integer division and the % operator yield the dollar and cent values of a piggybank full of pennies.

The % operator computes the remainder of an integer division.

If you are interested in the remainder only, use the % operator:

```
7 % 4
```

is 3, the remainder of the integer division of 7 by 4. The % symbol has no analog in algebra. It was chosen because it looks similar to /, and the remainder operation is related to division. The operator is called **modulus**. (Some people call it *modulo* or *mod*.) It has no relationship with the percent operation that you find on some calculators.

Here is a typical use for the integer / and % operations. Suppose you have an amount of pennies in a piggybank:

```
int pennies = 1729;
```

You want to determine the value in dollars and cents. You obtain the dollars through an integer division by 100:

```
int dollars = pennies / 100;  // Sets dollars to 17
```

Table 3 Integer Division and Remainder

Expression (where n = 1729)	Value	Comment
`n % 10`	9	`n % 10` is always the last digit of `n`.
`n / 10`	172	This is always `n` without the last digit.
`n % 100`	29	The last two digits of `n`.
`n / 10.0`	172.9	Because 10.0 is a floating-point number, the fractional part is not discarded.
`-n % 10`	-9	Because the first argument is negative, the remainder is also negative.
`n % 2`	1	`n % 2` is 0 if `n` is even, 1 or –1 if `n` is odd.

The integer division discards the remainder. To obtain the remainder, use the `%` operator:

```
int cents = pennies % 100;  // Sets cents to 29
```

See Table 3 for additional examples.

4.2.4 Powers and Roots

The Java library declares many mathematical functions, such as `Math.sqrt` (square root) and `Math.pow` (raising to a power).

In Java, there are no symbols for powers and roots. To compute them, you must call methods. To take the square root of a number, you use the `Math.sqrt` method. For example, $\sqrt{x}$ is written as `Math.sqrt(x)`. To compute x^n, you write `Math.pow(x, n)`.

In algebra, you use fractions, exponents, and roots to arrange expressions in a compact two-dimensional form. In Java, you have to write all expressions in a linear arrangement. For example, the mathematical expression

$$b \times \left(1 + \frac{r}{100}\right)^n$$

becomes

```
b * Math.pow(1 + r / 100, n)
```

Figure 2 shows how to analyze such an expression. Table 4 shows additional mathematical methods.

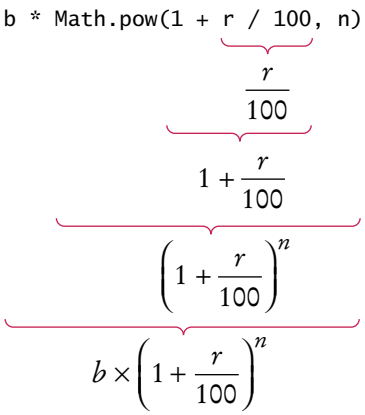


Figure 2
Analyzing an Expression

Table 4 Mathematical Methods

Method	Returns	Method	Returns
`Math.sqrt(x)`	Square root of x (≥ 0)	`Math.abs(x)`	Absolute value $\lvert x \rvert$
`Math.pow(x, y)`	x^y ($x > 0$, or $x = 0$ and $y > 0$, or $x < 0$ and y is an integer)	`Math.max(x, y)`	The larger of x and y
`Math.sin(x)`	Sine of x (x in radians)	`Math.min(x, y)`	The smaller of x and y
`Math.cos(x)`	Cosine of x	`Math.exp(x)`	e^x
`Math.tan(x)`	Tangent of x	`Math.log(x)`	Natural log ($\ln(x)$, $x > 0$)
`Math.round(x)`	Closest integer to x (as a `long`)	`Math.log10(x)`	Decimal log ($\log_{10}(x)$, $x > 0$)
`Math.ceil(x)`	Smallest integer $\geq x$ (as a `double`)	`Math.floor(x)`	Largest integer $\leq x$ (as a `double`)
`Math.toRadians(x)`	Convert x degrees to radians (i.e., returns $x \cdot \pi / 180$)	`Math.toDegrees(x)`	Convert x radians to degrees (i.e., returns $x \cdot 180 / \pi$)

4.2.5 Converting Floating-Point Numbers to Integers

Occasionally, you have a value of type `double` that you need to convert to the type `int`. It is an error to assign a floating-point value to an integer:

```
double balance = total + tax;
int dollars = balance; // Error: Cannot assign double to int
```

The compiler disallows this assignment because it is potentially dangerous:

- The fractional part is lost.
- The magnitude may be too large. (The largest integer is about 2 billion, but a floating-point number can be much larger.)

You use a cast (*typeName*) to convert a value to a different type.

You must use the **cast** operator `(int)` to convert a convert floating-point value to an integer. Write the cast operator before the expression that you want to convert:

```
double balance = total + tax;
int dollars = (int) balance;
```

The cast `(int)` converts the floating-point value `balance` to an integer by discarding the fractional part. For example, if `balance` is 13.75, then `dollars` is set to 13.

When applying the cast operator to an arithmetic expression, you need to place the expression inside parentheses:

```
int dollars = (int) (total + tax);
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that demonstrates casts, rounding, and the `%` operator.

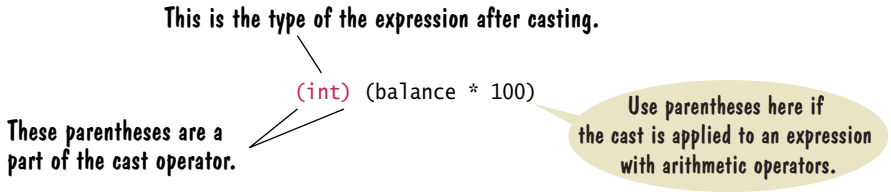
Discarding the fractional part is not always appropriate. If you want to round a floating-point number to the nearest whole number, use the `Math.round` method. This method returns a `long` integer, because large floating-point numbers cannot be stored in an `int`.

```
long rounded = Math.round(balance);
```

If `balance` is 13.75, then `rounded` is set to 14.

Syntax 4.2 Cast

Syntax *(typeName) expression*



If you know that the result can be stored in an `int` and does not require a `long`, you can use a cast:

```
int rounded = (int) Math.round(balance);
```

Table 5 Arithmetic Expressions

Mathematical Expression	Java Expression	Comments
$\frac{x + y}{2}$	`(x + y) / 2`	The parentheses are required; `x + y / 2` computes $x + \frac{y}{2}$.
$\frac{xy}{2}$	`x * y / 2`	Parentheses are not required; operators with the same precedence are evaluated left to right.
$\left(1 + \frac{r}{100}\right)^n$	`Math.pow(1 + r / 100, n)`	Use `Math.pow(x, n)` to compute x^n.
$\sqrt{a^2 + b^2}$	`Math.sqrt(a * a + b * b)`	`a * a` is simpler than `Math.pow(a, 2)`.
$\frac{i + j + k}{3}$	`(i + j + k) / 3.0`	If i, j, and k are integers, using a denominator of 3.0 forces floating-point division.
π	`Math.PI`	`Math.PI` is a constant declared in the `Math` class.

6. A bank account earns interest once per year. In Java, how do you compute the interest earned in the first year? Assume variables `percent` and `balance` of type `double` have already been declared.
7. In Java, how do you compute the side length of a square whose area is stored in the variable `area`?
8. The volume of a sphere is given by the formula at right. If the radius is given by a variable `radius` of type `double`, write a Java expression for the volume. $V = \frac{4}{3}\pi r^3$
9. What is the value of `1729 / 100` and `1729 % 100`?
10. If `n` is a positive number, what is `(n / 10) % 10`?

Practice It Now you can try these exercises at the end of the chapter: R4.4, R4.8, E4.4, E4.24.

Common Error 4.1

Unintended Integer Division

It is unfortunate that Java uses the same symbol, namely /, for both integer and floating-point division. These are really quite different operations. It is a common error to use **integer division** by accident. Consider this segment that computes the average of three integers:

```
int score1 = 10;
int score2 = 4;
int score3 = 9;
double average = (score1 + score2 + score3) / 3; // Error
System.out.println("Average score: " + average); // Prints 7.0, not 7.666666666666667
```

What could be wrong with that? Of course, the average of `score1`, `score2`, and `score3` is

$$\frac{\texttt{score1 + score2 + score3}}{3}$$

Here, however, the / does not mean division in the mathematical sense. It denotes integer division because both 3 and the sum of `score1 + score2 + score3` are integers. Because the scores add up to 23, the average is computed to be 7, the result of the integer division of 23 by 3. That integer 7 is then moved into the floating-point variable `average`. The remedy is to make the numerator or denominator into a floating-point number:

```
double total = score1 + score2 + score3;
double average = total / 3;
```

or

```
double average = (score1 + score2 + score3) / 3.0;
```

Common Error 4.2

Unbalanced Parentheses

Consider the expression

```
((a + b) * t / 2 * (1 - t)
```

© Croko/iStockphoto.

What is wrong with it? Count the parentheses. There are three (and two). The parentheses are *unbalanced*. This kind of typing error is very common with complicated expressions. Now consider this expression.

```
(a + b) * t) / (2 * (1 - t)
```

This expression has three (and three), but it still is not correct. In the middle,

```
(a + b) * t) / (2 * (1 - t)
          ↑
```

there is only one (but two), which is an error. In the middle of an expression, the count of (must be greater than or equal to the count of), and at the end of the expression the two counts must be the same.

Here is a simple trick to make the counting easier without using pencil and paper. It is difficult for the brain to keep two counts simultaneously. Keep only one count when scanning the expression. Start with 1 at the first opening parenthesis, add 1 whenever you see an opening parenthesis, and subtract one whenever you see a closing parenthesis. Say the numbers aloud as you scan the expression. If the count ever drops below zero, or is not zero at the end, the parentheses are unbalanced. For example, when scanning the previous expression, you would mutter

```
(a + b) * t) / (2 * (1 - t)
1     0   -1
```

and you would find the error.

Programming Tip 4.2

Spaces in Expressions

It is easier to read

```
x1 = (-b + Math.sqrt(b * b - 4 * a * c)) / (2 * a);
```

than

```
x1=(-b+Math.sqrt(b*b-4*a*c))/(2*a);
```

Simply put spaces around all operators `+ - * / % =`. However, don't put a space after a *unary* minus: a – used to negate a single quantity, such as `-b`. That way, it can be easily distinguished from a *binary* minus, as in `a - b`.

It is customary not to put a space after a method name. That is, write `Math.sqrt(x)` and not `Math.sqrt (x)`.

Java 8 Note 4.1

Avoiding Negative Remainders

The `%` operator yields negative values when the first operand is negative. This can be an annoyance. For example, suppose a robot keeps track of directions in degrees between `0` and `359`. Now the robot turns by some number of degrees. You can't simply compute the new direction as `(direction + turn) % 360` because you might get a negative result (see Exercise R4.7). In Java 8, you can instead call

```
Math.floorMod(direction + turn, 360)
```

to compute the correct remainder. The result of `Math.floorMod(m, n)` is always positive when `n` is positive.

Special Topic 4.2

Combining Assignment and Arithmetic

In Java, you can combine arithmetic and assignment. For example, the instruction

```
balance += amount;
```

is a shortcut for `balance = balance + amount;`

Similarly,

```
total *= 2;
```

is another way of writing `total = total * 2;`

Many programmers find this a convenient shortcut. If you like it, go ahead and use it in your own code. For simplicity, we won't use it in this book, though.

Special Topic 4.3

Instance Methods and Static Methods

In the preceding section, you encountered the `Math` class, which contains a collection of helpful methods for carrying out mathematical computations. These methods do not operate on an object. That is, you don't call

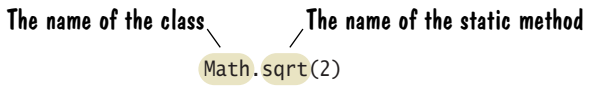
```
double root = 2.sqrt(); // Error
```

In Java, numbers are not objects, so you can never invoke a method on a number. Instead, you pass a number as an argument (explicit parameter) to a method, enclosing the number in parentheses after the method name:

```
double root = Math.sqrt(2);
```

Such methods are called **static methods**. (The term "static" is a historical holdover from the C and C++ programming languages. It has nothing to do with the usual meaning of the word.)

Static methods do not operate on objects, but they are still declared inside classes. When calling the method, you specify the class to which the `sqrt` method belongs:



In contrast, a method that is invoked on an object is called an **instance method**. As a rule of thumb, you use static methods when you manipulate numbers. You will learn more about the distinction between static and instance methods in Chapter 8.

Computing & Society 4.1 The Pentium Floating-Point Bug

In 1994, Intel Corporation released what was then its most powerful processor, the Pentium. Unlike previous generations of its processors, it had a very fast floating-point unit. Intel's goal was to compete aggressively with the makers of higher-end processors for engineering workstations. The Pentium was a huge success immediately.

In the summer of 1994, Dr. Thomas Nicely of Lynchburg College in Virginia ran an extensive set of computations to analyze the sums of reciprocals of certain sequences of prime numbers. The results were not always what his theory predicted, even after he took into account the inevitable roundoff errors. Then Dr. Nicely noted that the same program did produce the correct results when running on the slower 486 processor that preceded the Pentium in Intel's lineup. This should not have happened. The optimal roundoff behavior of floating-point calculations has been standardized by the Institute for Electrical and Electronics Engineers (IEEE) and Intel claimed to adhere to the IEEE standard in both the 486 and the Pentium processors. Upon further checking, Dr. Nicely discovered that indeed there was a very small set of numbers for which the product of two numbers was computed differently on the two processors. For example,

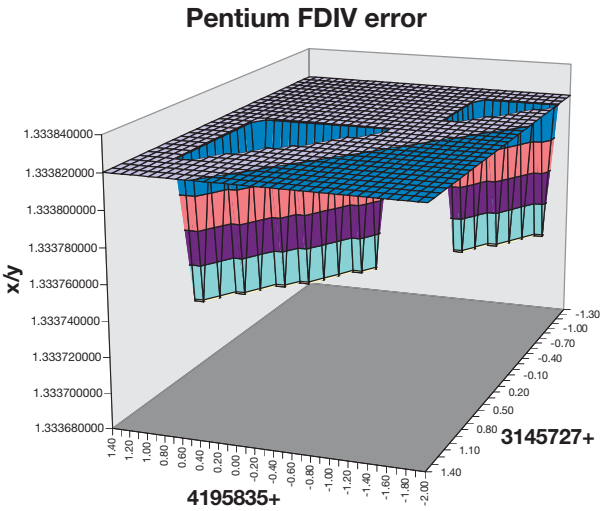
$$4{,}195{,}835 - ((4{,}195{,}835/3{,}145{,}727) \times 3{,}145{,}727)$$

is mathematically equal to 0, and it did compute as 0 on a 486 processor. On his Pentium processor the result was 256.

As it turned out, Intel had independently discovered the bug in its testing and had started to produce chips that fixed it. The bug was caused by an error in a table that was used to speed up the floating-point multiplication algorithm of the processor. Intel determined that the problem was exceedingly rare. They claimed that under normal use, a typical consumer would only notice the problem once every 27,000 years. Unfortunately for Intel, Dr. Nicely had not been a normal user.

Now Intel had a real problem on its hands. It figured that the cost of replacing all Pentium processors that it had sold so far would cost a great deal of money. Intel already had more orders for the chip than it could produce, and it would be particularly galling to have to give out the scarce chips as free replacements instead of selling them. Intel's management decided to punt on the issue and initially offered to replace the processors only for those customers who could prove that their work required absolute precision in mathematical calculations. Naturally, that did not go over well with the hundreds of thousands of customers who had paid retail prices of $700 and more for a Pentium chip and did not want to live with the nagging feeling that perhaps, one day, their income tax program would produce a faulty return.

Ultimately, Intel caved in to public demand and replaced all defective chips, at a cost of about 475 million dollars.

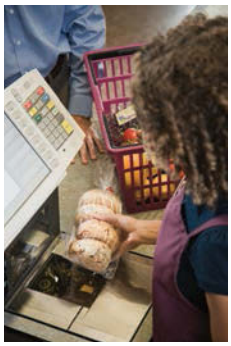


This graph shows a set of numbers for which the original Pentium processor obtained the wrong quotient.

4.3 Input and Output

In the following sections, you will see how to read user input and how to control the appearance of the output that your programs produce.

4.3.1 Reading Input



© Media Bakery.

A supermarket scanner reads bar codes. The Java Scanner *reads numbers and text.*

You can make your programs more flexible if you ask the program user for inputs rather than using fixed values. Consider, for example, a program that processes prices and quantities of soda containers. Prices and quantities are likely to fluctuate. The program user should provide them as inputs.

When a program asks for user input, it should first print a message that tells the user which input is expected. Such a message is called a **prompt**.

```
System.out.print("Please enter the number of bottles: "); // Display prompt
```

Use the `print` method, not `println`, to display the prompt. You want the input to appear after the colon, not on the following line. Also remember to leave a space after the colon.

Because output is sent to `System.out`, you might think that you use `System.in` for input. Unfortunately, it isn't quite that simple. When Java was first designed, not much attention was given to reading keyboard input. It was assumed that all programmers would produce graphical user interfaces with text fields and menus. `System.in` was given a minimal set of features and must be combined with other classes to be useful.

To read keyboard input, you use a class called `Scanner`. You obtain a `Scanner` object by using the following statement:

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

Use the Scanner class to read keyboard input in a console window.

Once you have a scanner, you use its `nextInt` method to read an integer value:

```
System.out.print("Please enter the number of bottles: ");
int bottles = in.nextInt();
```

Syntax 4.3 Input Statement

Include this line so you can use the Scanner class.

```
import java.util.Scanner;
.
.
Scanner in = new Scanner(System.in);
.
.
System.out.print("Please enter the number of bottles: ");
int bottles = in.nextInt();
```

Create a Scanner object to read keyboard input.

Don't use println here.

Display a prompt in the console window.

Define a variable to hold the input value.

The program waits for user input, then places the input into the variable.

When the `nextInt` method is called, the program waits until the user types a number and presses the Enter key. After the user supplies the input, the number is placed into the `bottles` variable, and the program continues.

To read a floating-point number, use the `nextDouble` method instead:

```
System.out.print("Enter price: ");
double price = in.nextDouble();
```

The `Scanner` class belongs to the package `java.util`. When using the `Scanner` class, import it by placing the following declaration at the top of your program file:

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

4.3.2 Formatted Output

When you print the result of a computation, you often want to control its appearance. For example, when you print an amount in dollars and cents, you usually want it to be rounded to two significant digits. That is, you want the output to look like

```
Price per liter: 1.22
```

instead of

```
Price per liter: 1.215962441314554
```

Use the `printf` method to specify how values should be formatted.

The following command displays the price with two digits after the decimal point:

```
System.out.printf("%.2f", price);
```

You can also specify a *field width*:

```
System.out.printf("%10.2f", price);
```

The price is printed using ten characters: six spaces followed by the four characters `1.22`.

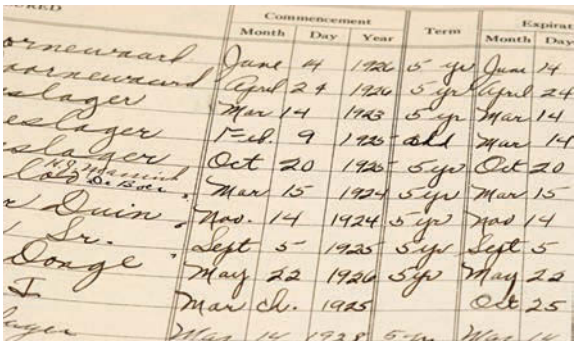
The construct `%10.2f` is called a *format specifier:* it describes how a value should be formatted. The letter `f` at the end of the format specifier indicates that we are displaying a floating-point number. Use `d` for an integer and `s` for a string; see Table 6 for examples.

A format string contains format specifiers and literal characters. Any characters that are not format specifiers are printed verbatim. For example, the command

```
System.out.printf("Price per liter:%10.2f", price);
```

prints

```
Price per liter:      1.22
```



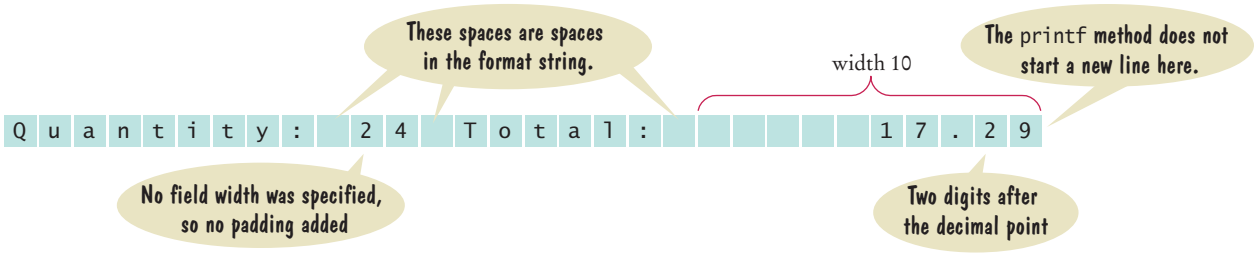
You use the `printf` *method to line up your output in neat columns.*

Table 6 Format Specifier Examples

Format String	Sample Output	Comments
`"%d"`	`24`	Use `d` with an integer.
`"%5d"`	`  24`	Spaces are added so that the field width is 5.
`"Quantity:%5d"`	`Quantity:  24`	Characters inside a format string but outside a format specifier appear in the output.
`"%f"`	`1.21997`	Use `f` with a floating-point number.
`"%.2f"`	`1.22`	Prints two digits after the decimal point.
`"%7.2f"`	`  1.22`	Spaces are added so that the field width is 7.
`"%s"`	`Hello`	Use `s` with a string.
`"%d %.2f"`	`24 1.22`	You can format multiple values at once.

You can print multiple values with a single call to the `printf` method. Here is a typical example:

```
System.out.printf("Quantity: %d Total: %10.2f", quantity, total);
```



The `printf` method, like the `print` method, does not start a new line after the output. If you want the next output to be on a separate line, you can call `System.out.println()`. Alternatively, Section 4.5.4 shows you how to add a newline character to the format string.

Our next example program will prompt for the price of a six-pack of soda and a two-liter bottle, and then print out the price per liter for both. The program puts to work what you just learned about reading input and formatting output.

What is the better deal? A six-pack of 12-ounce cans or a two-liter bottle?

section_3/Volume.java

```
1  import java.util.Scanner;
2
3  /**
4     This program prints the price per liter for a six-pack of cans and
5     a two-liter bottle.
6  */
7  public class Volume
8  {
9     public static void main(String[] args)
10    {
11       // Read price per pack
12
13       Scanner in = new Scanner(System.in);
14
15       System.out.print("Please enter the price for a six-pack: ");
16       double packPrice = in.nextDouble();
17
18       // Read price per bottle
19
20       System.out.print("Please enter the price for a two-liter bottle: ");
21       double bottlePrice = in.nextDouble();
22
23       final double CANS_PER_PACK = 6;
24       final double CAN_VOLUME = 0.355; // 12 oz. = 0.355 l
25       final double BOTTLE_VOLUME = 2;
26
27       // Compute and print price per liter
28
29       double packPricePerLiter = packPrice / (CANS_PER_PACK * CAN_VOLUME);
30       double bottlePricePerLiter = bottlePrice / BOTTLE_VOLUME;
31
32       System.out.printf("Pack price per liter:   %8.2f", packPricePerLiter);
33       System.out.println();
34
35       System.out.printf("Bottle price per liter: %8.2f", bottlePricePerLiter);
36       System.out.println();
37    }
38 }
```

Program Run

```
Please enter the price for a six-pack: 2.95
Please enter the price for a two-liter bottle: 2.85
Pack price per liter:       1.38
Bottle price per liter:     1.43
```

11. Write statements to prompt for and read the user's age using a `Scanner` variable named `in`.
12. What is wrong with the following statement sequence?

```
System.out.print("Please enter the unit price: ");
double unitPrice = in.nextDouble();
int quantity = in.nextInt();
```

13. What is problematic about the following statement sequence?

```
System.out.print("Please enter the unit price: ");
double unitPrice = in.nextInt();
```

14. What is problematic about the following statement sequence?

```
System.out.print("Please enter the number of cans");
int cans = in.nextInt();
```

15. What is the output of the following statement sequence?

```
int volume = 10;
System.out.printf("The volume is %5d", volume);
```

16. Using the `printf` method, print the values of the integer variables `bottles` and `cans` so that the output looks like this:

```
Bottles:        8
Cans:          24
```

The numbers to the right should line up. (You may assume that the numbers have at most 8 digits.)

Practice It Now you can try these exercises at the end of the chapter: R4.13, E4.6, E4.7.

HOW TO 4.1 Carrying Out Computations

Many programming problems require arithmetic computations. This How To shows you how to turn a problem statement into pseudocode and, ultimately, a Java program.

Problem Statement Suppose you are asked to write a program that simulates a vending machine. A customer selects an item for purchase and inserts a bill into the vending machine. The vending machine dispenses the purchased item and gives change. We will assume that all item prices are multiples of 25 cents, and the machine gives all change in dollar coins and quarters. Your task is to compute how many coins of each type to return.

Step 1 Understand the problem: What are the inputs? What are the desired outputs?

In this problem, there are two inputs:

- The denomination of the bill that the customer inserts
- The price of the purchased item

There are two desired outputs:

- The number of dollar coins that the machine returns
- The number of quarters that the machine returns

Step 2 Work out examples by hand.

This is a very important step. If you can't compute a couple of solutions by hand, it's unlikely that you'll be able to write a program that automates the computation.

Let's assume that a customer purchased an item that cost $2.25 and inserted a $5 bill. The customer is due $2.75, or two dollar coins and three quarters, in change.

That is easy for you to see, but how can a Java program come to the same conclusion? The key is to work in pennies, not dollars. The change due the customer is 275 pennies. Dividing by 100 yields 2, the number of dollars. Dividing the remainder (75) by 25 yields 3, the number of quarters.

Step 3 Write pseudocode for computing the answers.

In the previous step, you worked out a specific instance of the problem. You now need to come up with a method that works in general.

Given an arbitrary item price and payment, how can you compute the coins due? First, compute the change due in pennies:

change due = 100 x bill value - item price in pennies

To get the dollars, divide by 100 and discard the remainder:

dollar coins = change due / 100 (without remainder)

The remaining change due can be computed in two ways. If you are familiar with the modulus operator, you can simply compute

change due = change due % 100

Alternatively, subtract the penny value of the dollar coins from the change due:

change due = change due - 100 x dollar coins

To get the quarters due, divide by 25:

quarters = change due / 25

Step 4 Declare the variables and constants that you need, and specify their types.

Here, we have five variables:

- `billValue`
- `itemPrice`
- `changeDue`
- `dollarCoins`
- `quarters`

Should we introduce constants to explain 100 and 25 as `PENNIES_PER_DOLLAR` and `PENNIES_PER_QUARTER`? Doing so will make it easier to convert the program to international markets, so we will take this step.

It is very important that `changeDue` and `PENNIES_PER_DOLLAR` are of type `int` because the computation of `dollarCoins` uses integer division. Similarly, the other variables are integers.

Step 5 Turn the pseudocode into Java statements.

If you did a thorough job with the pseudocode, this step should be easy. Of course, you have to know how to express mathematical operations (such as powers or integer division) in Java.

```
changeDue = PENNIES_PER_DOLLAR * billValue - itemPrice;
dollarCoins = changeDue / PENNIES_PER_DOLLAR;
changeDue = changeDue % PENNIES_PER_DOLLAR;
quarters = changeDue / PENNIES_PER_QUARTER;
```

Step 6 Provide input and output.

Before starting the computation, we prompt the user for the bill value and item price:

```
System.out.print("Enter bill value (1 = $1 bill, 5 = $5 bill, etc.): ");
billValue = in.nextInt();
System.out.print("Enter item price in pennies: ");
itemPrice = in.nextInt();
```

When the computation is finished, we display the result. For extra credit, we use the `printf` method to make sure that the output lines up neatly.

```
System.out.printf("Dollar coins: %6d", dollarCoins);
System.out.printf("Quarters:     %6d", quarters);
```

A vending machine takes bills and gives change in coins.

Photos.com/Jupiter Images.

Step 7 Provide a class with a `main` method.

Your computation needs to be placed into a class. Find an appropriate name for the class that describes the purpose of the computation. In our example, we will choose the name `VendingMachine`.

Inside the class, supply a `main` method.

In the `main` method, you need to declare constants and variables (Step 4), carry out computations (Step 5), and provide input and output (Step 6). Clearly, you will want to first get the input, then do the computations, and finally show the output. Declare the constants at the beginning of the method, and declare each variable just before it is needed.

Here is the complete program, `how_to_1/VendingMachine.java`:

```
import java.util.Scanner;

/**
   This program simulates a vending machine that gives change.
*/
public class VendingMachine
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);

      final int PENNIES_PER_DOLLAR = 100;
      final int PENNIES_PER_QUARTER = 25;

      System.out.print("Enter bill value (1 = $1 bill, 5 = $5 bill, etc.): ");
      int billValue = in.nextInt();
      System.out.print("Enter item price in pennies: ");
      int itemPrice = in.nextInt();

      // Compute change due

      int changeDue = PENNIES_PER_DOLLAR * billValue - itemPrice;
      int dollarCoins = changeDue / PENNIES_PER_DOLLAR;
      changeDue = changeDue % PENNIES_PER_DOLLAR;
      int quarters = changeDue / PENNIES_PER_QUARTER;

      // Print change due

      System.out.printf("Dollar coins: %6d", dollarCoins);
      System.out.println();
```

```
            System.out.printf("Quarters:     %6d", quarters);
            System.out.println();
        }
    }
```

Program Run

```
Enter bill value (1 = $1 bill, 5 = $5 bill, etc.): 5
Enter item price in pennies: 225
Dollar coins:      2
Quarters:          3
```

WORKED EXAMPLE 4.1

Computing the Volume and Surface Area of a Pyramid

Learn how to design a class for computing the volume and surface area of a pyramid. Go to `wiley.com/go/bjeo6examples` and download Worked Example 4.1.

© Holger Mette/iStockphoto.

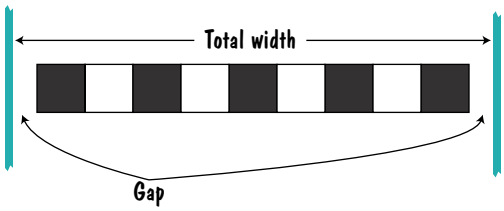
4.4 Problem Solving: First Do It By Hand

A very important step for developing an algorithm is to first carry out the computations *by hand*. If you can't compute a solution yourself, it's unlikely that you'll be able to write a program that automates the computation.

To illustrate the use of hand calculations, consider the following problem.

A row of black and white tiles needs to be placed along a wall. For aesthetic reasons, the architect has specified that the first and last tile shall be black.

Your task is to compute the number of tiles needed and the gap at each end, given the space available and the width of each tile.



Pick concrete values for a typical situation to use in a hand calculation.

To make the problem more concrete, let's assume the following dimensions:

- Total width: 100 inches
- Tile width: 5 inches

The obvious solution would be to fill the space with 20 tiles, but that would not work—the last tile would be white.

Instead, look at the problem this way: The first tile must always be black, and then we add some number of white/black pairs:

The first tile takes up 5 inches, leaving 95 inches to be covered by pairs. Each pair is 10 inches wide. Therefore the number of pairs is 95 / 10 = 9.5. However, we need to discard the fractional part because we can't have fractions of tile pairs.

Therefore, we will use 9 tile pairs or 18 tiles, plus the initial black tile. Altogether, we require 19 tiles.

The tiles span 19 × 5 = 95 inches, leaving a total gap of 100 – 19 × 5 = 5 inches.

The gap should be evenly distributed at both ends. At each end, the gap is (100 – 19 × 5) / 2 = 2.5 inches.

This computation gives us enough information to devise an algorithm with arbitrary values for the total width and tile width.

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that implements this algorithm.

```
number of pairs = integer part of (total width - tile width) / (2 x tile width)
number of tiles = 1 + 2 x number of pairs
gap at each end = (total width - number of tiles x tile width) / 2
```

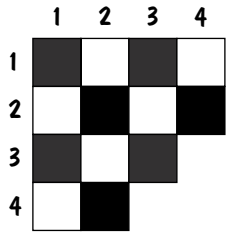
As you can see, doing a hand calculation gives enough insight into the problem that it becomes easy to develop an algorithm.

17. Translate the pseudocode for computing the number of tiles and the gap width into Java.

18. Suppose the architect specifies a pattern with black, gray, and white tiles, like this:

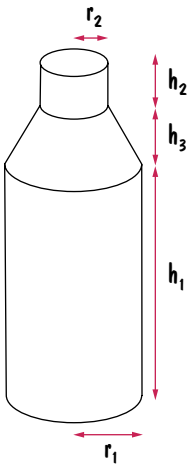
Again, the first and last tile should be black. How do you need to modify the algorithm?

19. A robot needs to tile a floor with alternating black and white tiles. Develop an algorithm that yields the color (0 for black, 1 for white), given the row and column number. Start with specific values for the row and column, and then generalize.



20. For a particular car, repair and maintenance costs in year 1 are estimated at $100; in year 10, at $1,500. Assuming that the repair cost increases by the same amount every year, develop pseudocode to compute the repair cost in year 3 and then generalize to year n.

21. The shape of a bottle is approximated by two cylinders of radius r_1 and r_2 and heights h_1 and h_2, joined by a cone section of height h_3.



Using the formulas for the volume of a cylinder, $V = \pi r^2 h$, and a cone section,

$$V = \pi \frac{\left(r_1^2 + r_1 r_2 + r_2^2\right) h}{3},$$

develop pseudocode to compute the volume of the bottle. Using an actual bottle with known volume as a sample, make a hand calculation of your pseudocode.

Practice It Now you can try these exercises at the end of the chapter: R4.18, R4.22, R4.23.

WORKED EXAMPLE 4.2 **Computing Travel Time**

Learn how to develop a hand calculation to compute the time that a robot requires to retrieve an item from rocky terrain. Go to `wiley.com/go/bjeo6examples` and download Worked Example 4.2.

Courtesy NASA.

4.5 Strings

Strings are sequences of characters.

Many programs process text, not numbers. Text consists of **characters**: letters, numbers, punctuation, spaces, and so on. A **string** is a sequence of characters. For example, the string `"Harry"` is a sequence of five characters.

© essxboy/iStockphoto.

4.5.1 The `String` Type

You can declare variables that hold strings.

```
String name = "Harry";
```

We distinguish between string variables (such as the variable `name` declared above) and string **literals** (character sequences enclosed in quotes, such as `"Harry"`). A string variable is simply a variable that can hold a string, just as an integer variable can hold an integer. A string literal denotes a particular string, just as a number literal (such as 2) denotes a particular number.

The `length` method yields the number of characters in a string.

The number of characters in a string is called the *length* of the string. For example, the length of `"Harry"` is 5. As you saw in Section 2.3, you can compute the length of a string with the `length` method.

```
int n = name.length();
```

A string of length 0 is called the *empty string*. It contains no characters and is written as `""`.

4.5.2 Concatenation

Use the + operator to *concatenate* strings; that is, to put them together to yield a longer string.

Given two strings, such as `"Harry"` and `"Morgan"`, you can **concatenate** them to one long string. The result consists of all characters in the first string, followed by all characters in the second string. In Java, you use the + operator to concatenate two strings.

For example,

```
String fName = "Harry";
String lName = "Morgan";
String name = fName + lName;
```

results in the string

```
"HarryMorgan"
```

What if you'd like the first and last name separated by a space? No problem:

```
String name = fName + " " + lName;
```

This statement concatenates three strings: `fName`, the string literal `" "`, and `lName`. The result is

```
"Harry Morgan"
```

When the expression to the left or the right of a + operator is a string, the other one is automatically forced to become a string as well, and both strings are concatenated.

For example, consider this code:

```
String jobTitle = "Agent";
int employeeId = 7;
String bond = jobTitle + employeeId;
```

Whenever one of the arguments of the + operator is a string, the other argument is converted to a string.

Because `jobTitle` is a string, `employeeId` is converted from the integer 7 to the string `"7"`. Then the two strings `"Agent"` and `"7"` are concatenated to form the string `"Agent7"`.

This concatenation is very useful for reducing the number of `System.out.print` instructions. For example, you can combine

```
System.out.print("The total is ");
System.out.println(total);
```

to the single call

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

The concatenation `"The total is " + total` computes a single string that consists of the string `"The total is "`, followed by the string equivalent of the number `total`.

4.5.3 String Input

Use the `next` method of the `Scanner` class to read a string containing a single word.

You can read a string from the console:

```
System.out.print("Please enter your name: ");
String name = in.next();
```

When a string is read with the `next` method, only one word is read. For example, suppose the user types

```
Harry Morgan
```

as the response to the prompt. This input consists of two words. The call `in.next()` yields the string `"Harry"`. You can use another call to `in.next()` to read the second word.

4.5.4 Escape Sequences

To include a quotation mark in a literal string, precede it with a backslash (\), like this:

```
"He said \"Hello\""
```

The backslash is not included in the string. It indicates that the quotation mark that follows should be a part of the string and not mark the end of the string. The sequence \" is called an **escape sequence**.

To include a backslash in a string, use the escape sequence \\, like this:

```
"C:\\Temp\\Secret.txt"
```

Another common escape sequence is \n, which denotes a **newline** character. Printing a newline character causes the start of a new line on the display. For example, the statement

```
System.out.print("*\n**\n***\n");
```

prints the characters

```
*
**
***
```

on three separate lines.

You often want to add a newline character to the end of the format string when you use `System.out.printf`:

```
System.out.printf("Price: %10.2f\n", price);
```

4.5.5 Strings and Characters

© slpix/ iStockphoto.

A string is a sequence of characters.

Strings are sequences of **Unicode** characters (see Computing & Society 4.2). In Java, a **character** is a value of the type `char`. Characters have numeric values. You can find the values of the characters that are used in Western European languages in Appendix A. For example, if you look up the value for the character `'H'`, you can see that it is actually encoded as the number 72.

Character literals are delimited by single quotes, and you should not confuse them with strings.

- `'H'` is a character, a value of type `char`.
- `"H"` is a string containing a single character, a value of type `String`.

String positions are counted starting with 0.

The `charAt` method returns a `char` value from a string. The first string position is labeled 0, the second one 1, and so on.

H	a	r	r	y
0	1	2	3	4

The position number of the last character (4 for the string `"Harry"`) is always one less than the length of the string.

For example, the statement

```
String name = "Harry";
char start = name.charAt(0);
char last = name.charAt(4);
```

sets `start` to the value `'H'` and `last` to the value `'y'`.

4.5.6 Substrings

Use the `substring` method to extract a part of a string.

Once you have a string, you can extract substrings by using the `substring` method. The method call

```
str.substring(start, pastEnd)
```

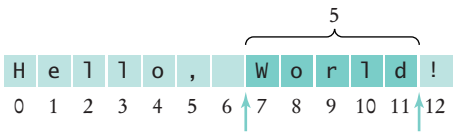
returns a string that is made up of the characters in the string `str`, starting at position `start`, and containing all characters up to, but not including, the position `pastEnd`. Here is an example:

```
String greeting = "Hello, World!";
String sub = greeting.substring(0, 5); // sub is "Hello"
```

Here the `substring` operation makes a string that consists of the first five characters taken from the string `greeting`.

Let's figure out how to extract the substring `"World"`. Count characters starting at `0`, not 1. You find that `W` has position number 7. The first character that you don't want, `!`, is the character at position 12. Therefore, the appropriate substring command is

```
String sub2 = greeting.substring(7, 12);
```



It is curious that you must specify the position of the first character that you do want and then the first character that you don't want. There is one advantage to this setup. You can easily compute the length of the substring: It is `pastEnd - start`. For example, the string `"World"` has length 12 – 7 = 5.

If you omit the end position when calling the `substring` method, then all characters from the starting position to the end of the string are copied. For example,

```
String tail = greeting.substring(7); // Copies all characters from position 7 on
```

sets `tail` to the string `"World!"`.

Following is a simple program that puts these concepts to work. The program asks for your name and that of your significant other. It then prints out your initials.

The operation `first.substring(0, 1)` makes a string consisting of one character, taken from the start of `first`. The program does the same for the `second`. Then it concatenates the resulting one-character strings with the string literal `"&"` to get a string of length 3, the `initials` string. (See Figure 3.)

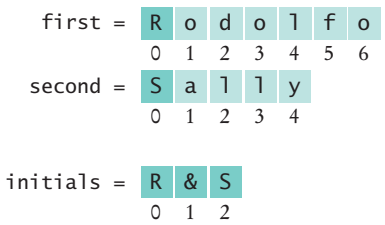


Figure 3 Building the `initials` String

Initials are formed from the first letter of each name.

© Rich Legg/iStockphoto.

section_5/Initials.java

```
1  import java.util.Scanner;
2
3  /**
4     This program prints a pair of initials.
5  */
6  public class Initials
7  {
8     public static void main(String[] args)
9     {
10       Scanner in = new Scanner(System.in);
11
12       // Get the names of the couple
13
14       System.out.print("Enter your first name: ");
15       String first = in.next();
16       System.out.print("Enter your significant other's first name: ");
17       String second = in.next();
18
19       // Compute and display the inscription
20
21       String initials = first.substring(0, 1)
22          + "&" + second.substring(0, 1);
23       System.out.println(initials);
24    }
25 }
```

Program Run

```
Enter your first name: Rodolfo
Enter your significant other's first name: Sally
R&S
```

Table 7 String Operations

Statement	Result	Comment
`string str = "Ja";` `str = str + "va";`	`str` is set to `"Java"`	When applied to strings, `+` denotes concatenation.
`System.out.println("Please"` `  + " enter your name: ");`	Prints `Please enter your name:`	Use concatenation to break up strings that don't fit into one line.
`team = 49 + "ers"`	`team` is set to `"49ers"`	Because `"ers"` is a string, 49 is converted to a string.

`String first = in.next();`
`String last = in.next();`
`(User input: Harry Morgan)`
	`first` contains `"Harry"`
	`last` contains `"Morgan"`
		The `next` method places the next word into the string variable.

`String greeting = "H & S";` `int n = greeting.length();`	`n` is set to 5	Each space counts as one character.
`String str = "Sally";` `char ch = str.charAt(1);`	`ch` is set to `'a'`	This is a `char` value, not a `String`. Note that the initial position is 0.
`String str = "Sally";` `String str2 = str.substring(1, 4);`	`str2` is set to `"all"`	Extracts the substring starting at position 1 and ending before position 4.
`String str = "Sally";` `String str2 = str.substring(1);`	`str2` is set to `"ally"`	If you omit the end position, all characters from the position until the end of the string are included.
`String str = "Sally";` `String str2 = str.substring(1, 2);`	`str2` is set to `"a"`	Extracts a `String` of length 1; contrast with `str.charAt(1)`.
`String last = str.substring(` `  str.length() - 1);`	`last` is set to the string containing the last character in `str`	The last character has position `str.length() - 1`.

22. What is the length of the string `"Java Program"`?

23. Consider this string variable.

```
String str = "Java Program";
```

Give a call to the `substring` method that returns the substring `"gram"`.

24. Use string concatenation to turn the string variable `str` from Self Check 23 into `"Java Programming"`.

25. What does the following statement sequence print?

```
String str = "Harry";
int n = str.length();
String mystery = str.substring(0, 1) + str.substring(n - 1, n);
System.out.println(mystery);
```

26. Give an input statement to read a name of the form "John Q. Public".

Practice It Now you can try these exercises at the end of the chapter: R4.10, R4.14, E4.15, P4.7.

Programming Tip 4.3

Reading Exception Reports

You will often have programs that terminate and display an error message, such as

```
Exception in thread "main" java.lang.StringIndexOutOfBoundsException:
      String index out of range: -4
   at java.lang.String.substring(String.java:1444)
   at Homework1.main(Homework1.java:16)
```

If this happens to you, don't say "it didn't work" or "my program died". Instead, read the error message. Admittedly, the format of the exception report is not very friendly. But it is actually easy to decipher it.

When you have a close look at the error message, you will notice two pieces of useful information:

1. The name of the exception, such as `StringIndexOutOfBoundsException`
2. The line number of the code that contained the statement that caused the exception, such as `Homework1.java:16`

The name of the exception is always in the first line of the report, and it ends in `Exception`. If you get a `StringIndexOutOfBoundsException`, then there was a problem with accessing an invalid position in a string. That is useful information.

The line number of the offending code is a little harder to determine. The exception report contains the entire **stack trace**—that is, the names of all methods that were pending when the exception hit. The first line of the stack trace is the method that actually generated the exception. The last line of the stack trace is a line in `main`. Often, the exception was thrown by a method that is in the standard library. Look for the first line in your code that appears in the exception report. For example, skip the line that refers to

```
java.lang.String.substring(String.java:1444)
```

The next line in our example mentions a line number in your code, `Homework1.java`. Once you have the line number in your code, open up the file, go to that line, and look at it! Also look at the name of the exception. In most cases, these two pieces of information will make it completely obvious what went wrong, and you can easily fix your error.

Special Topic 4.4

Using Dialog Boxes for Input and Output

Most program users find the console window rather old-fashioned. The easiest alternative is to create a separate pop-up window for each input.

An Input Dialog Box

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a complete program that uses option panes for input and output.

Call the static `showInputDialog` method of the `JOptionPane` class, and supply the string that prompts the input from the user. For example,

```
String input = JOptionPane.showInputDialog("Enter price:");
```

That method returns a `String` object. Of course, often you need the input as a number. Use the `Integer.parseInt` and `Double.parseDouble` methods to convert the string to a number:

```
double price = Double.parseDouble(input);
```

You can also display output in a dialog box:

```
JOptionPane.showMessageDialog(null, "Price: " + price);
```

Computing & Society 4.2 International Alphabets and Unicode

The English alphabet is pretty simple: upper- and lowercase *a* to *z*. Other European languages have accent marks and special characters. For example, German has three so-called *umlaut* characters, ä, ö, ü, and a *double-s* character ß. These are not optional frills; you couldn't write a page of German text without using these characters a few times. German keyboards have keys for these characters.

The German Keyboard Layout

Many countries don't use the Roman script at all. Russian, Greek, Hebrew, Arabic, and Thai letters, to name just a few, have completely different shapes. To complicate matters, Hebrew and Arabic are typed from right to left. Each of these alphabets has about as many characters as the English alphabet.

Hebrew, Arabic, and English

The Chinese languages as well as Japanese and Korean use Chinese characters. Each character represents an idea or thing. Words are made up of one or more of these ideographic characters. Over 70,000 ideographs are known.

Starting in 1987, a consortium of hardware and software manufacturers developed a uniform encoding scheme called **Unicode** that is capable of encoding text in essentially all written languages of the world. An early version of Unicode used 16 bits for each character. The Java `char` type corresponds to that encoding.

Today Unicode has grown to a 21-bit code, with definitions for over 100,000 characters (`www.unicode.org`). There are even plans to add codes for extinct languages, such as Egyptian hieroglyphics. Unfortunately, that means that a Java `char` value does not always correspond to a Unicode character. Some characters in languages such as Chinese or ancient Egyptian occupy two `char` values.

The Chinese Script

CHAPTER SUMMARY

Choose appropriate types for representing numeric data.

- Java has eight primitive types, including four integer types and two floating-point types.
- A numeric computation overflows if the result falls outside the range for the number type.
- Rounding errors occur when an exact conversion between numbers is not possible.
- A `final` variable is a constant. Once its value has been set, it cannot be changed.
- Use named constants to make your programs easier to read and maintain.

Write arithmetic expressions in Java.

- Mixing integers and floating-point values in an arithmetic expression yields a floating-point value.
- The `++` operator adds 1 to a variable; the `--` operator subtracts 1.
- If both arguments of `/` are integers, the remainder is discarded.
- The `%` operator computes the remainder of an integer division.
- The Java library declares many mathematical functions, such as `Math.sqrt` (square root) and `Math.pow` (raising to a power).
- You use a cast (*typeName*) to convert a value to a different type.

Write programs that read user input and print formatted output.

- Use the `Scanner` class to read keyboard input in a console window.
- Use the `printf` method to specify how values should be formatted.

Carry out hand calculations when developing an algorithm.

- Pick concrete values for a typical situation to use in a hand calculation.

Write programs that process strings.

- Strings are sequences of characters.
- The `length` method yields the number of characters in a string.
- Use the `+` operator to *concatenate* strings; that is, to put them together to yield a longer string.
- Whenever one of the arguments of the `+` operator is a string, the other argument is converted to a string.
- Use the `next` method of the `Scanner` class to read a string containing a single word.
- String positions are counted starting with `0`.
- Use the `substring` method to extract a part of a string.

STANDARD LIBRARY ITEMS INTRODUCED IN THIS CHAPTER

```
java.io.PrintStream
   printf
java.lang.Double
   parseDouble
java.lang.Integer
   MAX_VALUE
   MIN_VALUE
   parseInt
java.lang.Math
   PI
   abs
   ceil
   cos
   exp
   floor
   floorMod
   log
   log10
   max
   min
   pow
   round
   sin
   sqrt
   tan
   toDegrees
   toRadians
java.lang.String
   charAt
   length
   substring
java.lang.System
   in
java.math.BigDecimal
   add
   multiply
   subtract
java.math.BigInteger
   add
   multiply
   subtract
java.util.Scanner
   next
   nextDouble
   nextInt
javax.swing.JOptionPane
   showInputDialog
   showMessageDialog
```

REVIEW EXERCISES

■ **R4.1** Write declarations for storing the following quantities. Choose between integers and floating-point numbers. Declare constants when appropriate.

a. The number of days per week

b. The number of days until the end of the semester

c. The number of centimeters in an inch

d. The height of the tallest person in your class, in centimeters

■ **R4.2** What is the value of `mystery` after this sequence of statements?

```
int mystery = 1;
mystery = 1 - 2 * mystery;
mystery = mystery + 1;
```

■ **R4.3** What is wrong with the following sequence of statements?

```
int mystery = 1;
mystery = mystery + 1;
int mystery = 1 - 2 * mystery;
```

■■ **R4.4** Write the following Java expressions in mathematical notation.

a. `dm = m * (Math.sqrt(1 + v / c) / Math.sqrt(1 - v / c) - 1);`

b. `volume = Math.PI * r * r * h;`

c. `volume = 4 * Math.PI * Math.pow(r, 3) / 3;`

d. `z = Math.sqrt(x * x + y * y);`

■■ **R4.5** Write the following mathematical expressions in Java.

$$s = s_0 + v_0 t + \frac{1}{2} g t^2 \qquad \text{FV} = \text{PV} \cdot \left(1 + \frac{\text{INT}}{100}\right)^{\text{YRS}}$$

$$G = 4\pi^2 \frac{a^3}{p^2(m_1 + m_2)} \qquad c = \sqrt{a^2 + b^2 - 2ab\cos\gamma}$$

■■ **R4.6** Assuming that `a` and `b` are variables of type `int`, fill in the following table:

a	b	Math.pow(a, b)	Math.max(a, b)	a / b	a % b	Math.floorMod(a, b)
2	3					
3	2					
2	–3					
3	–2					
–3	2					
–3	–2					

■■ **R4.7** Suppose `direction` is an integer angle between 0 and 359 degrees. You turn by a given angle and update the direction as

```
direction = (direction + turn) % 360;
```

In which situation do you get the wrong result? How can you fix that without using the `Math.floorMod` method described in Java 8 Note 4.1?

■■ **R4.8** What are the values of the following expressions? In each line, assume that

```
double x = 2.5;
double y = -1.5;
int m = 18;
int n = 4;
```

a. `x + n * y - (x + n) * y`

b. `m / n + m % n`

c. `5 * x - n / 5`

d. `1 - (1 - (1 - (1 - (1 - n))))`

e. `Math.sqrt(Math.sqrt(n))`

■ **R4.9** What are the values of the following expressions, assuming that `n` is 17 and `m` is 18?

a. `n / 10 + n % 10`

b. `n % 2 + m % 2`

c. `(m + n) / 2`

d. `(m + n) / 2.0`

e. `(int) (0.5 * (m + n))`

f. `(int) Math.round(0.5 * (m + n))`

■■ **R4.10** What are the values of the following expressions? In each line, assume that

```
String s = "Hello";
String t = "World";
```

a. `s.length() + t.length()`

b. `s.substring(1, 2)`

c. `s.substring(s.length() / 2, s.length())`

d. `s + t`

e. `t + s`

■ **R4.11** Find at least five *compile-time* errors in the following program.

```
public class HasErrors
{
   public static void main();
   {
      System.out.print(Please enter two numbers:)
      x = in.readDouble;
      y = in.readDouble;
      System.out.printline("The sum is " + x + y);
   }
}
```

■■ **R4.12** Find three *run-time* errors in the following program.

```
public class HasErrors
{
   public static void main(String[] args)
   {
      int x = 0;
      int y = 0;
      Scanner in = new Scanner("System.in");
```

```
      System.out.print("Please enter an integer:");
      x = in.readInt();
      System.out.print("Please enter another integer: ");
      x = in.readInt();
      System.out.println("The sum is " + x + y);
   }
}
```

■■ **R4.13** Consider the following code:

```
CashRegister register = new CashRegister();
register.recordPurchase(19.93);
register.receivePayment(20, 0, 0, 0, 0);
System.out.print("Change: ");
System.out.println(register.giveChange());
```

The code segment prints the total as `0.07000000000000028`. Explain why. Give a recommendation to improve the code so that users will not be confused.

■ **R4.14** Explain the differences between `2`, `2.0`, `'2'`, `"2"`, and `"2.0"`.

■ **R4.15** Explain what each of the following program segments computes.

a.
```
x = 2;
y = x + x;
```

b.
```
s = "2";
t = s + s;
```

■■ **R4.16** Write pseudocode for a program that reads a word and then prints the first character, the last character, and the characters in the middle. For example, if the input is `Harry`, the program prints `H y arr`.

■■ **R4.17** Write pseudocode for a program that reads a name (such as `Harold James Morgan`) and then prints a monogram consisting of the initial letters of the first, middle, and last name (such as `HJM`).

■■■ **R4.18** Write pseudocode for a program that computes the first and last digit of a number. For example, if the input is `23456`, the program should print `2` and `6`. *Hint:* Use `%` and `Math.log10`.

■ **R4.19** Modify the pseudocode for the program in How To 4.1 so that the program gives change in quarters, dimes, and nickels. You can assume that the price is a multiple of 5 cents. To develop your pseudocode, first work with a couple of specific values.

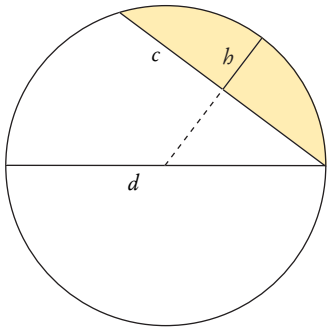
■■■ **R4.20** In Worked Example 4.1, it is easy enough to measure the width of a pyramid. To measure the height without climbing to the top, you can use a theodolite and determine the angle between the ground and the line joining the theodolite's position and the top of the pyramid. What other information do you need in order to compute the surface area?

■■■ **R4.21** Suppose an ancient civilization had constructed circular pyramids. Write a program that determines the surface area from measurements that you can determine from the ground.

■■ **R4.22** A cocktail shaker is composed of three cone sections.

Using realistic values for the radii and heights, compute the total volume, using the formula given in Self Check 21 for a cone section. Then develop an algorithm that works for arbitrary dimensions.

■■■ **R4.23** You are cutting off a piece of pie like this, where c is the length of the straight part (called the chord length) and h is the height of the piece.



There is an approximate formula for the area:

$$A \approx \frac{2}{3}ch + \frac{h^3}{2c}$$

However, h is not so easy to measure, whereas the diameter d of a pie is usually well-known. Calculate the area where the diameter of the pie is 12 inches and the chord length of the segment is 10 inches. Generalize to an algorithm that yields the area for any diameter and chord length.

■■ **R4.24** The following pseudocode describes how to obtain the name of a day, given the day number (0 = Sunday, 1 = Monday, and so on.)

```
Declare a string called names containing "SunMonTueWedThuFriSat".
Compute the starting position as 3 x the day number.
Extract the substring of names at the starting position with length 3.
```

Check this pseudocode, using the day number 4. Draw a diagram of the string that is being computed, similar to Figure 3.

■■■ **R4.25** The following pseudocode describes how to swap two letters in a word.

```
We are given a string str and two positions i and j. (i comes before j)
Set first to the substring from the start of the string to the last position before i.
Set middle to the substring from positions i + 1 to j - 1.
Set last to the substring from position j + 1 to the end of the string.
Concatenate the following five strings: first, the string containing just the character at position j,
   middle, the string containing just the character at position i, and last.
```

Check this pseudocode, using the string `"Gateway"` and positions 2 and 4. Draw a diagram of the string that is being computed, similar to Figure 3.

■■ **R4.26** How do you get the first character of a string? The last character? How do you remove the first character? The last character?

■■ **R4.27** For each of the following computations in Java, determine whether the result is exact, an overflow, or a roundoff error.

a. `2.0 - 1.1`
b. `1.0E6 * 1.0E6`
c. `65536 * 65536`
d. `1_000_000L * 1_000_000L`

■■■ **R4.28** Write a program that prints the values

```
3 * 1000 * 1000 * 1000
3.0 * 1000 * 1000 * 1000
```

Explain the results.

PRACTICE EXERCISES

■ **E4.1** Write a program that displays the dimensions of a letter-size (8.5 × 11 inches) sheet of paper in millimeters. There are 25.4 millimeters per inch. Use constants and comments in your program.

■ **E4.2** Write a program that computes and displays the perimeter of a letter-size (8.5 × 11 inches) sheet of paper and the length of its diagonal.

■ **E4.3** Write a program that reads a number and displays the square, cube, and fourth power. Use the `Math.pow` method only for the fourth power.

■■ **E4.4** Write a program that prompts the user for two integers and then prints

- The sum
- The difference
- The product
- The average
- The distance (absolute value of the difference)
- The maximum (the larger of the two)
- The minimum (the smaller of the two)

Hint: The `max` and `min` functions are declared in the `Math` class.

■■ **E4.5** Enhance the output of Exercise E4.4 so that the numbers are properly aligned:

```
Sum:             45
Difference:      -5
Product:        500
Average:         22.50
Distance:         5
Maximum:         25
Minimum:         20
```

■■ **E4.6** Write a program that prompts the user for a measurement in meters and then converts it to miles, feet, and inches.

■ **E4.7** Write a program that prompts the user for a radius and then prints

- The area and circumference of a circle with that radius
- The volume and surface area of a sphere with that radius

■■ **E4.8** Write a program that asks the user for the lengths of a rectangle's sides. Then print

- The area and perimeter of the rectangle
- The length of the diagonal (use the Pythagorean theorem)

■ **E4.9** Improve the program discussed in How To 4.1 to allow input of quarters in addition to bills.

■■ **E4.10** Write a program that asks the user to input

- The number of gallons of gas in the tank
- The fuel efficiency in miles per gallon
- The price of gas per gallon

Then print the cost per 100 miles and how far the car can go with the gas in the tank.

■■ **E4.11** Change the `Menu` class in Worked Example 3.1 so that the menu options are labeled A, B, C, and so on. *Hint:* Make a string of the labels.

■ **E4.12** *File names and extensions.* Write a program that prompts the user for the drive letter (`C`), the path (`\Windows\System`), the file name (`Readme`), and the extension (`txt`). Then print the complete file name `C:\Windows\System\Readme.txt`. (If you use UNIX or a Macintosh, skip the drive name and use / instead of \ to separate directories.)

■■■ **E4.13** Write a program that reads a number between 1,000 and 999,999 from the user, where the user enters a comma in the input. Then print the number without a comma.

Here is a sample dialog; the user input is in color:

```
Please enter an integer between 1,000 and 999,999: 23,456
23456
```

Hint: Read the input as a string. Measure the length of the string. Suppose it contains n characters. Then extract substrings consisting of the first $n - 4$ characters and the last three characters.

■■ **E4.14** Write a program that reads a number between 1,000 and 999,999 from the user and prints it with a comma separating the thousands. Here is a sample dialog; the user input is in color:

```
Please enter an integer between 1000 and 999999: 23456
23,456
```

■ **E4.15** *Printing a grid.* Write a program that prints the following grid to play tic-tac-toe.

```
+--+--+--+
|  |  |  |
+--+--+--+
|  |  |  |
+--+--+--+
|  |  |  |
+--+--+--+
```

Of course, you could simply write seven statements of the form

```
System.out.println("+--+--+--+");
```

You should do it the smart way, though. Declare string variables to hold two kinds of patterns: a comb-shaped pattern and the bottom line. Print the comb three times and the bottom line once.

■■ **E4.16** Write a program that reads in an integer and breaks it into a sequence of individual digits. For example, the input 16384 is displayed as

```
1 6 3 8 4
```

You may assume that the input has no more than five digits and is not negative.

■■ **E4.17** Write a program that reads two times in military format (0900, 1730) and prints the number of hours and minutes between the two times. Here is a sample run. User input is in color.

```
Please enter the first time: 0900
Please enter the second time: 1730
8 hours 30 minutes
```

Extra credit if you can deal with the case where the first time is later than the second:

```
Please enter the first time: 1730
Please enter the second time: 0900
15 hours 30 minutes
```

■■■ **E4.18** *Writing large letters.* A large letter H can be produced like this:

```
*   *
*   *
*****
*   *
*   *
```

It can be declared as a string literal like this:

```
final string LETTER_H = "*   *\n*   *\n*****\n*   *\n*   *\n";
```

(The `\n` escape sequence denotes a "newline" character that causes subsequent characters to be printed on a new line.) Do the same for the letters `E`, `L`, and `O`. Then write the message

```
H
E
L
L
O
```

in large letters.

■■ **E4.19** Write a program that transforms numbers `1`, `2`, `3`, …, `12` into the corresponding month names `January`, `February`, `March`, …, `December`. *Hint:* Make a very long string `"January February March ..."`, in which you add spaces such that each month name has *the same length*. Then use `substring` to extract the month you want.

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■■ **E4.20** Write a program that prints a Christmas tree:

```
   /\
  /  \
 /    \
/      \
--------
  "  "
  "  "
  "  "
```

Remember to use escape sequences.

■■ **E4.21** Enhance the `CashRegister` class by adding separate methods `enterDollars`, `enterQuarters`, `enterDimes`, `enterNickels`, and `enterPennies`.

Use this tester class:

```
public class CashRegisterTester
{
   public static void main (String[] args)
   {
      CashRegister register = new CashRegister();
      register.recordPurchase(20.37);
      register.enterDollars(20);
      register.enterQuarters(2);
      System.out.println("Change: " + register.giveChange());
      System.out.println("Expected: 0.13");
   }
}
```

■■ **E4.22** Implement a class `IceCreamCone` with methods `getSurfaceArea()` and `getVolume()`. In the constructor, supply the height and radius of the cone. Be careful when looking up the formula for the surface area—you should only include the outside area along the side of the cone because the cone has an opening on the top to hold the ice cream.

■■ **E4.23** Implement a class `SodaCan` whose constructor receives the height and diameter of the soda can. Supply methods `getVolume` and `getSurfaceArea`. Supply a `SodaCanTester` class that tests your class.

■■■ **E4.24** Implement a class `Balloon` that models a spherical balloon that is being filled with air. The constructor constructs an empty balloon. Supply these methods:

- `void addAir(double amount)` adds the given amount of air
- `double getVolume()` gets the current volume
- `double getSurfaceArea()` gets the current surface area
- `double getRadius()` gets the current radius

Supply a `BalloonTester` class that constructs a balloon, adds 100 cm^3 of air, tests the three accessor methods, adds another 100 cm^3 of air, and tests the accessor methods again.

PROGRAMMING PROJECTS

■■■ **P4.1** Write a program that helps a person decide whether to buy a hybrid car. Your program's inputs should be:

- The cost of a new car
- The estimated miles driven per year
- The estimated gas price
- The efficiency in miles per gallon
- The estimated resale value after 5 years

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Compute the total cost of owning the car for five years. (For simplicity, we will not take the cost of financing into account.) Obtain realistic prices for a new and used hybrid and a comparable car from the Web. Run your program twice, using today's gas price and 15,000 miles per year. Include pseudocode and the program runs with your assignment.

■■ **P4.2** Easter Sunday is the first Sunday after the first full moon of spring. To compute the date, you can use this algorithm, invented by the mathematician Carl Friedrich Gauss in 1800:

1. Let `y` be the year (such as 1800 or 2001).
2. Divide `y` by `19` and call the remainder `a`. Ignore the quotient.
3. Divide `y` by `100` to get a quotient `b` and a remainder `c`.
4. Divide `b` by `4` to get a quotient `d` and a remainder `e`.
5. Divide `8 * b + 13` by `25` to get a quotient `g`. Ignore the remainder.
6. Divide `19 * a + b - d - g + 15` by `30` to get a remainder `h`. Ignore the quotient.
7. Divide `c` by `4` to get a quotient `j` and a remainder `k`.
8. Divide `a + 11 * h` by `319` to get a quotient `m`. Ignore the remainder.
9. Divide `2 * e + 2 * j - k - h + m + 32` by `7` to get a remainder `r`. Ignore the quotient.
10. Divide `h - m + r + 90` by `25` to get a quotient `n`. Ignore the remainder.
11. Divide `h - m + r + n + 19` by `32` to get a remainder `p`. Ignore the quotient.

Then Easter falls on day `p` of month `n`. For example, if `y` is `2001`:

```
a = 6           g = 6           m = 0       n = 4
b = 20, c = 1   h = 18          r = 6       p = 15
d = 5, e = 0    j = 0, k = 1
```

Therefore, in 2001, Easter Sunday fell on April 15. Write a program that prompts the user for a year and prints out the month and day of Easter Sunday.

■■■ **P4.3** In this project, you will perform calculations with triangles. A triangle is defined by the x- and y-coordinates of its three corner points.

Your job is to compute the following properties of a given triangle:

- the lengths of all sides
- the angles at all corners
- the perimeter
- the area

Implement a `Triangle` class with appropriate methods. Supply a program that prompts a user for the corner point coordinates and produces a nicely formatted table of the triangle properties.

■■ **P4.4** A boat floats in a two-dimensional ocean. It has a position and a direction. It can move by a given distance in its current direction, and it can turn by a given angle. Provide methods

```
public double getX()
public double getY()
public double getDirection()
public void turn(double degrees)
public void move(double distance)
```

■■■ **P4.5** The `CashRegister` class has an unfortunate limitation: It is closely tied to the coin system in the United States and Canada. Research the system used in most of Europe. Your goal is to produce a cash register that works with euros and cents. Rather than designing another limited `CashRegister` implementation for the European market, you should design a separate `Coin` class and a cash register that can work with coins of all types.

■■ **Business P4.6** The following pseudocode describes how a bookstore computes the price of an order from the total price and the number of the books that were ordered.

```
Read the total book price and the number of books.
Compute the tax (7.5 percent of the total book price).
Compute the shipping charge ($2 per book).
The price of the order is the sum of the total book price, the tax, and the shipping charge.
Print the price of the order.
```

Translate this pseudocode into a Java program.

■■ **Business P4.7** The following pseudocode describes how to turn a string containing a ten-digit phone number (such as `"4155551212"`) into a more readable string with parentheses and dashes, like this: `"(415) 555-1212"`.

```
Take the substring consisting of the first three characters and surround it with "(" and ") ". This is
   the area code.
Concatenate the area code, the substring consisting of the next three characters, a hyphen, and the
   substring consisting of the last four characters. This is the formatted number.
```

Translate this pseudocode into a Java program that reads a telephone number into a string variable, computes the formatted number, and prints it.

■■ **Business P4.8** The following pseudocode describes how to extract the dollars and cents from a price given as a floating-point value. For example, a price 2.95 yields values 2 and 95 for the dollars and cents.

```
Assign the price to an integer variable dollars.
Multiply the difference price - dollars by 100 and add 0.5.
Assign the result to an integer variable cents.
```

Translate this pseudocode into a Java program. Read a price and print the dollars and cents. Test your program with inputs 2.95 and 4.35.

■■ **Business P4.9** *Giving change.* Implement a program that directs a cashier how to give change. The program has two inputs: the amount due and the amount received from the customer. Display the dollars, quarters, dimes, nickels, and pennies that the customer should receive in return. In order to avoid roundoff errors, the program user should supply both amounts in pennies, for example 274 instead of 2.74.

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■ **Business P4.10** An online bank wants you to create a program that shows prospective customers how their deposits will grow. Your program should read the initial balance and the annual interest rate. Interest is compounded monthly. Print out the balances after the first three months. Here is a sample run:

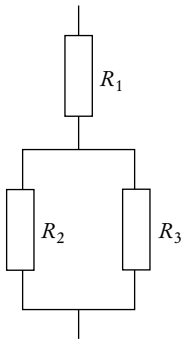
```
Initial balance: 1000
Annual interest rate in percent: 6.0
After first month:     1005.00
After second month:    1010.03
After third month:     1015.08
```

■■ **Business P4.11** A video club wants to reward its best members with a discount based on the member's number of movie rentals and the number of new members referred by the member. The discount is in percent and is equal to the sum of the rentals and the referrals, but it cannot exceed 75 percent. (*Hint:* `Math.min`.) Write a program `DiscountCalculator` to calculate the value of the discount.

Here is a sample run:

```
Enter the number of movie rentals: 56
Enter the number of members referred to the video club: 3
The discount is equal to:     59.00 percent.
```

■ **Science P4.12** Consider the following circuit.



Write a program that reads the resistances of the three resistors and computes the total resistance, using Ohm's law.

■■ Science P4.13 The dew point temperature T_d can be calculated (approximately) from the relative humidity RH and the actual temperature T by

$$T_d = \frac{b \cdot f(T, RH)}{a - f(T, RH)}$$

$$f(T, RH) = \frac{a \cdot T}{b + T} + \ln(RH)$$

where $a = 17.27$ and $b = 237.7°$ C.

Write a program that reads the relative humidity (between 0 and 1) and the temperature (in degrees C) and prints the dew point value. Use the Java function `log` to compute the natural logarithm.

■■■ Science P4.14 The pipe clip temperature sensors shown here are robust sensors that can be clipped directly onto copper pipes to measure the temperature of the liquids in the pipes.

Each sensor contains a device called a *thermistor*. Thermistors are semiconductor devices that exhibit a temperature-dependent resistance described by:

$$R = R_0 \, e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

where R is the resistance (in Ω) at the temperature T (in °K), and R_0 is the resistance (in Ω) at the temperature T_0 (in °K). β is a constant that depends on the material used to make the thermistor. Thermistors are specified by providing values for R_0, T_0, and β.

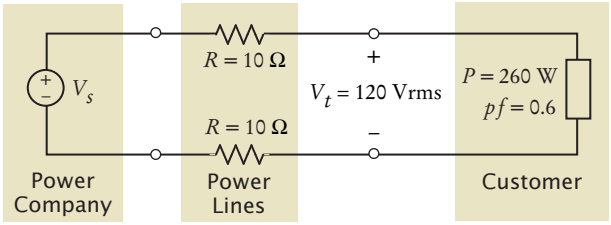
The thermistors used to make the pipe clip temperature sensors have $R_0 = 1075$ Ω at $T_0 = 85$ °C, and $\beta = 3969$ °K. (Notice that β has units of °K. Recall that the temperature in °K is obtained by adding 273 to the temperature in °C.) The liquid temperature, in °C, is determined from the resistance R, in Ω, using

$$T = \frac{\beta T_0}{T_0 \ln\left(\frac{R}{R_0}\right) + \beta} - 273$$

Write a Java program that prompts the user for the thermistor resistance R and prints a message giving the liquid temperature in °C.

■■■ Science P4.15 The circuit shown below illustrates some important aspects of the connection between a power company and one of its customers. The customer is represented by three parameters, V_t, P, and pf. V_t is the voltage accessed by plugging into a wall outlet. Customers depend on having a dependable value of V_t in order for their appliances to work properly. Accordingly, the power company regulates the value of V_t carefully.

P describes the amount of power used by the customer and is the primary factor in determining the customer's electric bill. The power factor, *pf*, is less familiar. (The power factor is calculated as the cosine of an angle so that its value will always be between zero and one.) In this problem you will be asked to write a Java program to investigate the significance of the power factor.

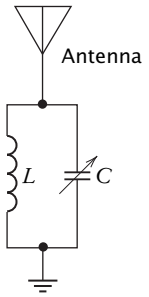


In the figure, the power lines are represented, somewhat simplistically, as resistances in Ohms. The power company is represented as an AC voltage source. The source voltage, V_s, required to provide the customer with power *P* at voltage V_t can be determined using the formula

$$V_s = \sqrt{\left(V_t + \frac{2RP}{V_t}\right)^2 + \left(\frac{2RP}{pfV_t}\right)^2 \left(1 - pf^2\right)}$$

(V_s has units of Vrms.) This formula indicates that the value of V_s depends on the value of *pf*. Write a Java program that prompts the user for a power factor value and then prints a message giving the corresponding value of V_s, using the values for *P*, *R*, and V_t shown in the figure above.

▪▪▪ Science P4.16 Consider the following tuning circuit connected to an antenna, where *C* is a variable capacitor whose capacitance ranges from C_{min} to C_{max}.



The tuning circuit selects the frequency $f = \frac{2\pi}{\sqrt{LC}}$. To design this circuit for a given frequency, take $C = \sqrt{C_{min}C_{max}}$ and calculate the required inductance *L* from *f* and *C*. Now the circuit can be tuned to any frequency in the range $f_{min} = \frac{2\pi}{\sqrt{LC_{max}}}$ to $f_{max} = \frac{2\pi}{\sqrt{LC_{min}}}$.

Write a Java program to design a tuning circuit for a given frequency, using a variable capacitor with given values for C_{min} and C_{max}. (A typical input is $f = 16.7$ MHz, $C_{min} = 14$ pF, and $C_{max} = 365$ pF.) The program should read in *f* (in Hz), C_{min} and

C_{max} (in F), and print the required inductance value and the range of frequencies to which the circuit can be tuned by varying the capacitance.

■ **Science P4.17** According to the Coulomb force law, the electric force between two charged particles of charge Q_1 and Q_2 Coulombs, that are a distance r meters apart, is $F = \frac{Q_1 Q_2}{4\pi\varepsilon r^2}$ Newtons, where $\varepsilon = 8.854 \times 10^{-12}$ Farads/meter. Write a program that calculates the force on a pair of charged particles, based on the user input of Q_1 Coulombs, Q_2 Coulombs, and r meters, and then computes and displays the electric force.

ANSWERS TO SELF-CHECK QUESTIONS

1. `int` and `double`.
2. The world's most populous country, China, has about 1.2×10^9 inhabitants. Therefore, individual population counts could be held in an `int`. However, the world population is over 6×10^9. If you compute totals or averages of multiple countries, you can exceed the largest `int` value. Therefore, `double` is a better choice. You could also use `long`, but there is no benefit because the exact population of a country is not known at any point in time.
3. The first initialization is incorrect. The right hand side is a value of type `double`, and it is not legal to initialize an `int` variable with a `double` value. The second initialization is correct—an `int` value can always be converted to a `double`.
4. The first declaration is used inside a method, the second inside a class.
5. Two things: You should use a named constant, not the "magic number" 3.14, and 3.14 is not an accurate representation of π.
6. `double interest = balance * percent / 100;`
7. `double sideLength = Math.sqrt(area);`
8. `4 * PI * Math.pow(radius, 3) / 3` or `(4.0 / 3) * PI * Math.pow(radius, 3)`, but not `(4 / 3) * PI * Math.pow(radius, 3)`
9. 17 and 29
10. It is the second-to-last digit of `n`. For example, if `n` is 1729, then `n / 10` is 172, and `(n / 10) % 10` is 2.
11.
```
System.out.print("How old are you? ");
int age = in.nextInt();
```
12. There is no prompt that alerts the program user to enter the quantity.
13. The second statement calls `nextInt`, not `nextDouble`. If the user were to enter a price such as `1.95`, the program would be terminated with an "input mismatch exception".
14. There is no colon and space at the end of the prompt. A dialog would look like this:
```
Please enter the number of cans6
```
15.
```
The total volume is    10
```
There are four spaces between `is` and `10`. One space originates from the format string (the space between `is` and `%`), and three spaces are added before `10` to achieve a field width of 5.
16. Here is a simple solution:
```
System.out.printf("Bottles: %8d\n", bottles);
System.out.printf("Cans:    %8d\n", cans);
```
Note the spaces after `Cans:`. Alternatively, you can use format specifiers for the strings. You can even combine all output into a single statement:
```
System.out.printf("%-9s%8d\n%-9s%8d\n",
"Bottles: ", bottles, "Cans:", cans);
```
17.
```
int pairs = (totalWidth - tileWidth)
   / (2 * tileWidth);
int tiles = 1 + 2 * pairs;
double gap = (totalWidth -
   tiles * tileWidth) / 2.0;
```
Be sure that `pairs` is declared as an `int`.

18. Now there are groups of four tiles (gray/white/gray/black) following the initial black tile. Therefore, the algorithm is now

number of groups = integer part of (total width - tile width) / (4 x tile width)
number of tiles = 1 + 4 x number of groups

The formula for the gap is not changed.

19. The answer depends only on whether the row and column numbers are even or odd, so let's first take the remainder after dividing by 2. Then we can enumerate all expected answers:

Row % 2	Column % 2	Color
0	0	0
0	1	1
1	0	1
1	1	0

In the first three entries of the table, the color is simply the sum of the remainders. In the fourth entry, the sum would be 2, but we want a zero. We can achieve that by taking another remainder operation:

color = ((row % 2) + (column % 2)) % 2

20. In nine years, the repair costs increased by $1,400. Therefore, the increase per year is $1,400 / 9 ≈ $156. The repair cost in year 3 would be $100 + 2 × $156 = $412. The repair cost in year n is $100 + n × $156. To avoid accumulation of roundoff errors, it is actually a good idea to use the original expression that yielded $156, that is,

Repair cost in year n = 100 + n x 1400 / 9

21. The pseudocode follows from the equations:

bottom volume = π x r_1^2 x h_1
top volume = π x r_2^2 x h_2
middle volume = π x (r_1^2 + r_1 x r_2 + r_2^2) x h_3 / 3
total volume = bottom volume + top volume + middle volume

Measuring a typical wine bottle yields $r_1 = 3.6$, $r_2 = 1.2$, $h_1 = 15$, $h_2 = 7$, $h_3 = 6$ (all in centimeters). Therefore,

bottom volume = 610.73

top volume = 31.67

middle volume = 135.72

total volume = 778.12

The actual volume is 750 ml, which is close enough to our computation to give confidence that it is correct.

22. The length is 12. The space counts as a character.

23. `str.substring(8, 12)` or `str.substring(8)`

24. `str = str + "ming";`

25. `Hy`

26.
```
String first = in.next();
String middle = in.next();
String last = in.next();
```

WORKED EXAMPLE 4.1

Computing the Volume and Surface Area of a Pyramid

In this Worked Example, we develop a solution to a computational problem.

Problem Statement Suppose that you are helping archaeologists who research Egyptian pyramids. You have taken on the task of writing a method that determines the volume and surface area of a pyramid, given its height and base length.

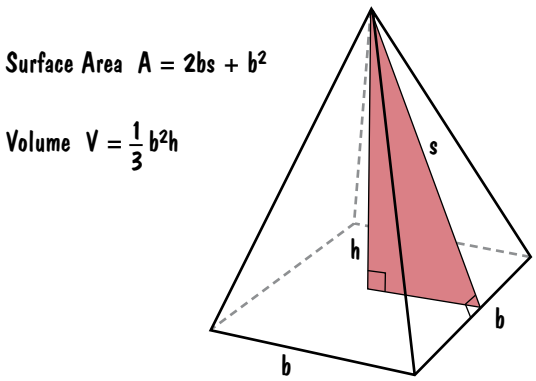
Step 1 Understand the problem: What are the inputs? What are the desired outputs?

Make a list of all the values that can vary. It is common for beginners to implement classes that are overly specific. For example, you may know that the great pyramid of Giza, the largest of the Egyptian pyramids, has a height of 146 meters and a base length of 230 meters. You should *not* use these numbers in your implementation, even if the original problem only asked about the great pyramid. It is just as easy—and far more useful—to write a class that describes *any* pyramid.

In our case, a pyramid is described by its height and base length. The desired outputs are the volume and surface area.

Step 2 Work out examples by hand.

An Internet search yields the following diagram for geometric computations with square-based pyramids:



The volume is straightforward. Consider a pyramid whose base and height are 10 cm each. Then the volume is $1/3 \times 10^2 \times 10 = 333.3$ cm^3, or 1/3 of the volume of a cube with side length of 10 cm. That makes sense if you are familiar with Archimedes' famous decomposition of a cube into three pyramids.

The surface area is not so clear. Looking at the formula $A = 2bs + b^2$, we note that the formula gives the entire area, including the square bottom. That's what you would need if you wanted to find out how much paint you need for a paper model of a pyramid. But do our researchers care about the bottom square that is not exposed? You would need to check back with them. Let's say they reply that they only want the part above the ground. Then the formula becomes $A = 2bs$.

Unfortunately, the value s is not one of our inputs, so we need to compute it. Look at the colored triangle in the figure above. It is a right triangle with sides s, h, and $b / 2$. The Pythagorean theorem tells us that $s^2 = h^2 + (b / 2)^2$.

Now let's try again. If h and b are both 10, then s^2 is $10^2 + 5^2 = 125$, and s is $\sqrt{125}$. Then the area is $A = 2bs = 20 \times \sqrt{125}$, or about 224. This is plausible because four sides of a cube with side

length 10 have area 400, and you would expect that area to be somewhat larger than the four sides of our sample pyramid.

Having solved this example by hand, we are now better prepared to implement the necessary computations in Java.

Step 3 Design a class that carries out your computations.

According to How To 3.1, we need to determine methods and instance variables for our class. In our case, the problem statement yields the following constructor and methods:

- `public Pyramid(double height, double baseLength)`
- `public double getVolume()`
- `public double getSurfaceArea()`

Determining the instance variables requires some thought. Consider these alternatives:

- A pyramid stores its height and base length. The volume and surface area are computed as needed in the `getVolume` and `getSurfaceArea` methods.
- A pyramid stores its volume and surface area. They are computed in the constructor from the `height` and `baseLength`, which are then discarded.

Both approaches will work for our problem. There is no simple rule as to which design is better. One way of settling the question is to consider how the `Pyramid` class might evolve. More methods for geometrical computations (such as angles) might be added. There might be methods to resize the pyramid. The first alternative makes it easier to accommodate those scenarios. Moreover, it seems more object-oriented. A pyramid is described by its height and base, not by its volume and surface area.

Step 4 Write pseudocode for implementing the methods.

As already described, the volume is simply

volume = (base x base x height) / 3

For the surface area, we first need the side length

side length = square root of (height x height + base x base / 4)

Then we have

surface area = 2 x base x side length

Step 5 Implement the class.

As decided in Step 3, we have instance variables for the height and base length:

```
public class Pyramid
{
   private double height;
   private double baseLength;
   . . .
}
```

The methods for computing the volume and surface area are now straightforward.

```
public double getVolume()
{
   return height * baseLength * baseLength / 3;
}

public double getSurfaceArea()
{
   double sideLength = Math.sqrt(height * height
      + baseLength * baseLength / 4);
   return 2 * baseLength * sideLength;
```

```
}
```

There is a minor issue with the constructor. As described in Step 3, the parameter variables of the constructor are identical to those of the instance variables:

```
public Pyramid(double height, double baseLength)
```

One solution is simply to rename the constructor parameter variables:

```
public Pyramid(double aHeight, double aBaseLength)
{
   height = aHeight;
   baseLength = aBaseLength;
}
```

This approach has a small disadvantage. The awkward parameter variable names leak into the API documentation:

```
/**
   Constructs a pyramid with a given height and base length.
   @param aHeight the height
   @param aBaseLength the length of one of the sides of the square base
*/
```

If you prefer, you can avoid that issue by using the `this` reference as follows:

```
public Pyramid(double height, double baseLength)
{
   this.height = height;
   this.baseLength = baseLength;
}
```

We have now completed the class implementation. You can find the complete program in the `ch04/worked_example_1` directory of the book's companion code.

Step 6 Test your class.

We can use the computations from Step 2 as a test case:

```
Pyramid sample = new Pyramid(10, 10);
System.out.println(sample.getVolume());
System.out.println("Expected: 333.33");
System.out.println(sample.getSurfaceArea());
System.out.println("Expected: 224");
```

It is a good idea to have another test case where the height and base are different, to check that the constructor is taking the parameters in the correct order. An Internet search yields an estimate of about 2,500,000 cubic meters for the Giza pyramid.

```
Pyramid gizeh = new Pyramid(146, 230);
System.out.println(gizeh.getVolume());
System.out.println("Expected: 2500000");
```

The program output is:

```
333.3333333333333
Expected: 333.33
223.60679774997897
Expected: 224
2574466.6666666665
Expected: 2500000
```

The answers match well, and we decide that the test was successful.

WORKED EXAMPLE 4.2 Computing Travel Time

In this Worked Example, we develop a hand calculation to compute travel time that we then use to develop pseudocode and program statements that will perform the calculation.

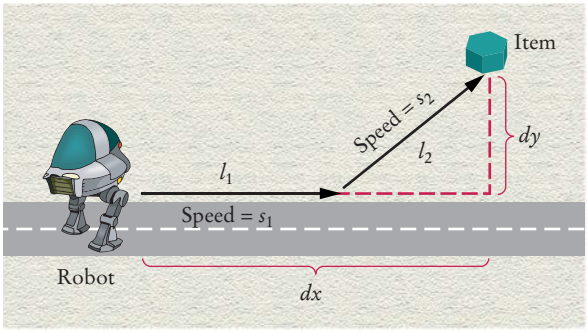
Problem Statement A robot needs to retrieve an item that is located in rocky terrain adjacent to a road. The robot can travel at a faster speed on the road than on the rocky terrain, so it will want to do so for a certain distance before moving on a straight line to the item. Your task is to compute the total time taken by the robot to reach its goal.

Courtesy NASA.

Step 1 Understand the problem: What are the inputs? What are the desired outputs?

You will be given the following inputs:

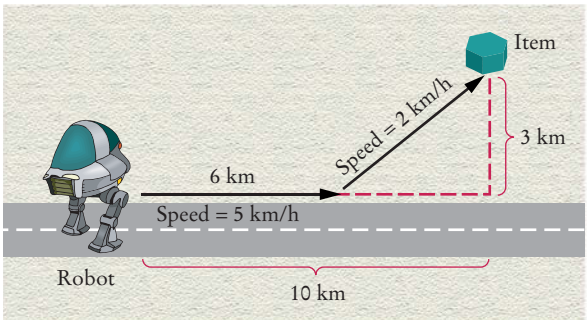
- The distance between the robot and the item in the x- and y-direction (dx and dy)
- The speed of the robot on the road and the rocky terrain (s_1 and s_2)
- The length l_1 of the first segment (on the road)



You are expected to compute the total travel time.

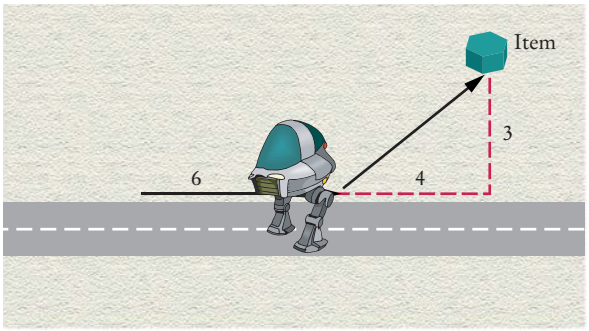
Step 2 Work out examples by hand.

To calculate an example by hand, let's assume the following dimensions:



The total time is the time for traversing both segments. The time to traverse the first segment is simply the length of the segment divided by the speed: 6 km divided by 5 km/h, or 1.2 hours.

To compute the time for the second segment, we first need to know its length. It is the hypotenuse of a right triangle with side lengths 3 and 4.



Therefore, its length is $\sqrt{3^2 + 4^2} = 5$. At 2 km/h, it takes 2.5 hours to traverse it. That makes the total travel time 3.7 hours.

Step 3 Write pseudocode for implementing the computation.

Look again at the steps in the hand calculation. The steps didn't depend on the particular values. Therefore, you can reformulate them as pseudocode by replacing the actual values with their names:

```
Time for segment 1 = l1 / s1
Length of segment 2 = square root of (dx - l1)^2 + dy^2
Time for segment 2 = length of segment 2 / s2
Total time = time for segment 1 + time for segment 2
```

Step 4 Translate the pseudocode into Java.

When you do hand calculations, it is convenient to use short variable names such as *dx* or s_1. In your program, you should change them to names that are longer and more descriptive.

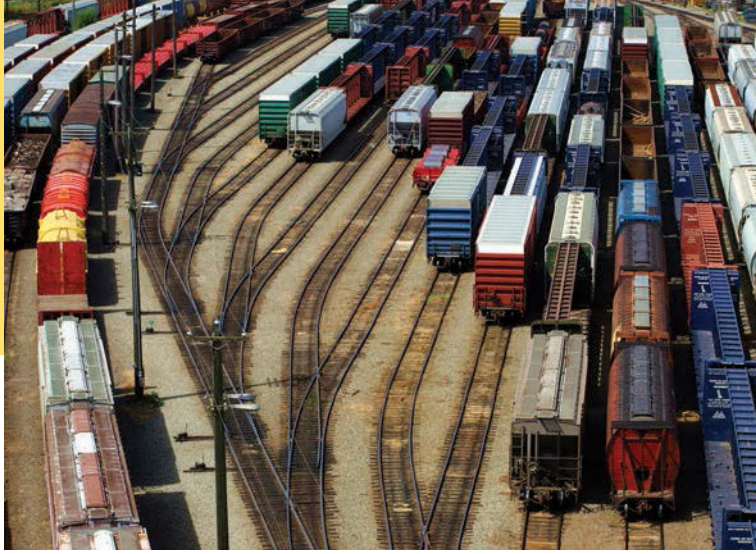
Translated into Java, the computations are

```
double segment1Time = segment1Length / segment1Speed;
double segment2Length = Math.sqrt(
   Math.pow(xDistance - segment1Length, 2)
   + Math.pow(yDistance, 2));
double segment2Time = segment2Length / segment2Speed;
double totalTime = segment1Time + segment2Time;
```

You can find the complete program in the `ch04/worked_example_2` directory of the book's companion code.

CHAPTER 5

DECISIONS



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CHAPTER GOALS

To implement decisions using `if` statements

To compare integers, floating-point numbers, and strings

To write statements using the Boolean data type

To develop strategies for testing your programs

To validate user input

CHAPTER CONTENTS

One of the essential features of computer programs is their ability to make decisions. Like a train that changes tracks depending on how the switches are set, a program can take different actions depending on inputs and other circumstances. In this chapter, you will learn how to program simple and complex decisions. You will apply what you learn to the task of checking user input.

5.1 The `if` Statement

The `if` statement allows a program to carry out different actions depending on the nature of the data to be processed.

The `if` statement is used to implement a decision (see Syntax 5.1 on page 180). When a condition is fulfilled, one set of statements is executed. Otherwise, another set of statements is executed.

Here is an example using the `if` statement: In many countries, the number 13 is considered unlucky. Rather than offending superstitious tenants, building owners sometimes skip the thirteenth floor; floor 12 is immediately followed by floor 14. Of course, floor 13 is not usually left empty. It is simply called floor 14. The computer that controls the building elevators needs to compensate for this foible and adjust all floor numbers above 13.

Let's simulate this process in Java. We will ask the user to type in the desired floor number and then compute the actual floor. When the input is above 13, then we need to decrement the input to obtain the actual floor. For example, if the user provides an input of 20, the program determines the actual floor to be 19. Otherwise, it simply uses the supplied floor number.

```
int actualFloor;

if (floor > 13)
{
   actualFloor = floor - 1;
}
else
{
   actualFloor = floor;
}
```

The flowchart in Figure 1 shows the branching behavior.

An `if` statement is like a fork in the road. Depending upon a decision, different parts of the program are executed.

In our example, each branch of the `if` statement contains a single statement. You can include as many statements in each branch as you like. Sometimes, it happens that there is nothing to do in the `else` branch of the statement. In that case, you can omit it entirely, as in this example:

```
int actualFloor = floor;

if (floor > 13)
{
   actualFloor--;
}
// No else needed
```

See Figure 2 for the flowchart.

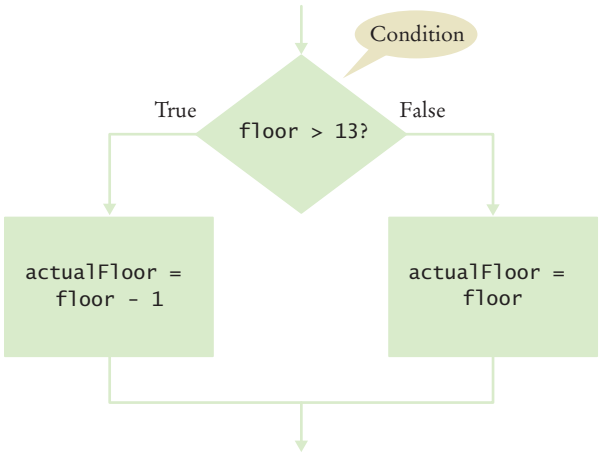


Figure 1
Flowchart for `if` Statement

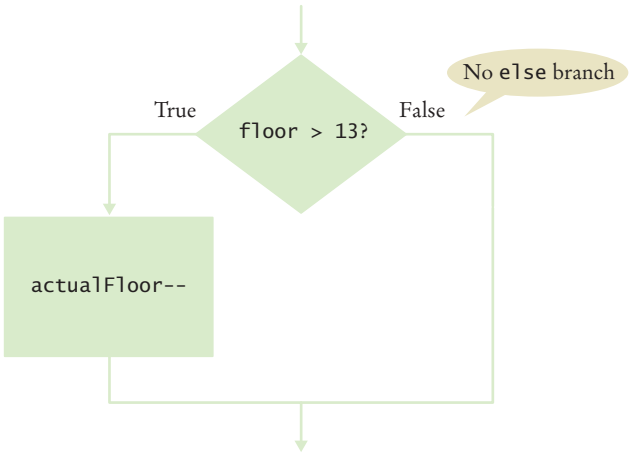
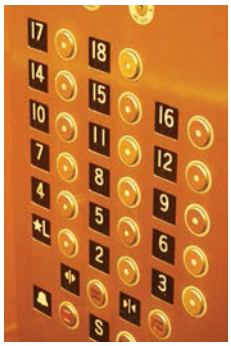


Figure 2
Flowchart for `if` Statement with No `else` Branch

The following program puts the `if` statement to work. This program asks for the desired floor and then prints out the actual floor.



This elevator panel "skips" the thirteenth floor. The floor is not actually missing—the computer that controls the elevator adjusts the floor numbers above 13.

section_1/ElevatorSimulation.java

```
1  import java.util.Scanner;
2
3  /**
4     This program simulates an elevator panel that skips the 13th floor.
5  */
6  public class ElevatorSimulation
7  {
8     public static void main(String[] args)
9     {
10       Scanner in = new Scanner(System.in);
11       System.out.print("Floor: ");
12       int floor = in.nextInt();
13
14       // Adjust floor if necessary
15
16       int actualFloor;
17       if (floor > 13)
18       {
19          actualFloor = floor - 1;
20       }
21       else
22       {
23          actualFloor = floor;
24       }
25
26       System.out.println("The elevator will travel to the actual floor "
27          + actualFloor);
28    }
29 }
```

Program Run

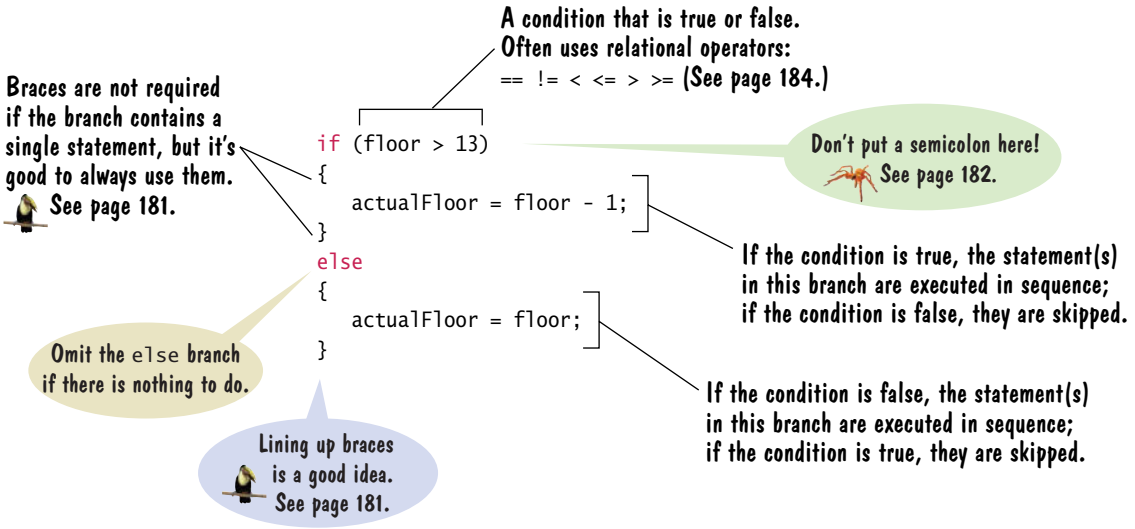
```
Floor: 20
The elevator will travel to the actual floor 19
```

Syntax 5.1 if Statement

Syntax

```
if (condition)
{
   statements
}
```

```
if (condition) { statements1 }
else { statements2 }
```



1. In some Asian countries, the number 14 is considered unlucky. Some building owners play it safe and skip *both* the thirteenth and the fourteenth floor. How would you modify the sample program to handle such a building?
2. Consider the following `if` statement to compute a discounted price:

```
if (originalPrice > 100)
{
   discountedPrice = originalPrice - 20;
}
else
{
   discountedPrice = originalPrice - 10;
}
```

   What is the discounted price if the original price is 95? 100? 105?
3. Compare this `if` statement with the one in Self Check 2:

```
if (originalPrice < 100)
{
   discountedPrice = originalPrice - 10;
}
else
{
   discountedPrice = originalPrice - 20;
}
```

   Do the two statements always compute the same value? If not, when do the values differ?

4. Consider the following statements to compute a discounted price:

```
discountedPrice = originalPrice;
if (originalPrice > 100)
{
   discountedPrice = originalPrice - 10;
}
```

   What is the discounted price if the original price is 95? 100? 105?

5. The variables `fuelAmount` and `fuelCapacity` hold the actual amount of fuel and the size of the fuel tank of a vehicle. If less than 10 percent is remaining in the tank, a status light should show a red color; otherwise it shows a green color. Simulate this process by printing out either `"red"` or `"green"`.

Practice It Now you can try these exercises at the end of the chapter: R5.5, R5.6, E5.10.

Programming Tip 5.1

Brace Layout

The compiler doesn't care where you place braces. In this book, we follow the simple rule of making `{` and `}` line up.

```
if (floor > 13)
{
   floor--;
}
```

This style makes it easy to spot matching braces. Some programmers put the opening brace on the same line as the `if`:

```
if (floor > 13) {
   floor--;
}
```

© Timothy Large/iStockphoto.

Properly lining up your code makes programs easier to read.

This style makes it harder to match the braces, but it saves a line of code, allowing you to view more code on the screen without scrolling. There are passionate advocates of both styles.

It is important that you pick a layout style and stick with it consistently within a given programming project. Which style you choose may depend on your personal preference or a coding style guide that you need to follow.

Programming Tip 5.2

Always Use Braces

When the body of an `if` statement consists of a single statement, you need not use braces. For example, the following is legal:

```
if (floor > 13)
   floor--;
```

However, it is a good idea to always include the braces:

```
if (floor > 13)
{
   floor--;
}
```

The braces make your code easier to read. They also make it easier for you to maintain the code because you won't have to worry about adding braces when you add statements inside an `if` statement.

Common Error 5.1

A Semicolon After the `if` Condition

The following code fragment has an unfortunate error:

```
if (floor > 13) ; // Error
{
   floor--;
}
```

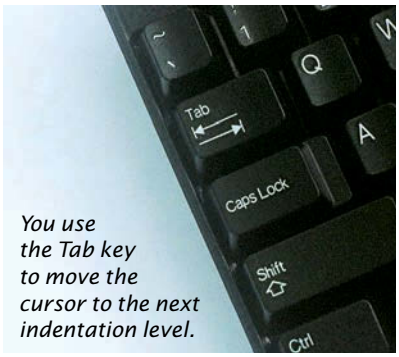
There should be no semicolon after the `if` condition. The compiler interprets this statement as follows: If `floor` is greater than 13, execute the statement that is denoted by a single semicolon, that is, the do-nothing statement. The statement in braces is no longer a part of the `if` statement. It is always executed. In other words, even if the value of `floor` is not above 13, it is decremented.

Programming Tip 5.3

Tabs

Block-structured code has the property that nested statements are indented by one or more levels:

```
public class ElevatorSimulation
{
|  public static void main(String[] args)
|  {
|  |  int floor;
|  |  . . .
|  |  if (floor > 13)
|  |  {
|  |  |  floor--;
|  |  }  |
|  |  . . .
|  }  |  |
0  1  2  3   Indentation level
```



You use the Tab key to move the cursor to the next indentation level.

Photo by Vincent LaRussa/ John Wiley & Sons, Inc.

How do you move the cursor from the leftmost column to the appropriate indentation level? A perfectly reasonable strategy is to hit the space bar a sufficient number of times. With most editors, you can use the Tab key instead. A tab moves the cursor to the next indentation level. Some editors even have an option to fill in the tabs automatically.

While the Tab *key* is nice, some editors use **tab characters** for alignment, which is not so nice. Tab characters can lead to problems when you send your file to another person or a printer. There is no universal agreement on the width of a tab character, and some software will ignore tab characters altogether. It is therefore best to save your files with spaces instead of tabs. Most editors have a setting to automatically convert all tabs to spaces. Look at the documentation of your development environment to find out how to activate this useful setting.

Special Topic 5.1

The Conditional Operator

Java has a *conditional operator* of the form

condition `?` $value_1$ `:` $value_2$

The value of that expression is either $value_1$ if the test passes or $value_2$ if it fails. For example, we can compute the actual floor number as

```
actualFloor = floor > 13 ? floor - 1 : floor;
```

which is equivalent to

```
if (floor > 13) { actualFloor = floor - 1; } else { actualFloor = floor; }
```

You can use the conditional operator anywhere that a value is expected, for example:

```
System.out.println("Actual floor: " + (floor > 13 ? floor - 1 : floor));
```

We don't use the conditional operator in this book, but it is a convenient construct that you will find in many Java programs.

Programming Tip 5.4

Avoid Duplication in Branches

Look to see whether you *duplicate code* in each branch. If so, move it out of the `if` statement. Here is an example of such duplication:

```
if (floor > 13)
{
   actualFloor = floor - 1;
   System.out.println("Actual floor: " + actualFloor);
}
else
{
   actualFloor = floor;
   System.out.println("Actual floor: " + actualFloor);
}
```

The output statement is exactly the same in both branches. This is not an error—the program will run correctly. But you can simplify the program by moving the duplicated statement:

```
if (floor > 13)
{
   actualFloor = floor - 1;
}
else
{
   actualFloor = floor;
}
System.out.println("Actual floor: " + actualFloor);
```

Removing duplication is particularly important when programs are maintained for a long time. When there are two sets of statements with the same effect, it can easily happen that a programmer modifies one set but not the other.

5.2 Comparing Values

Every `if` statement contains a condition. In many cases, the condition involves comparing two values. In the following sections, you will learn how to implement comparisons in Java.

In Java, you use a relational operator to check whether one value is greater than another.

5.2.1 Relational Operators

Use relational operators (< <= > >= == !=) to compare numbers.

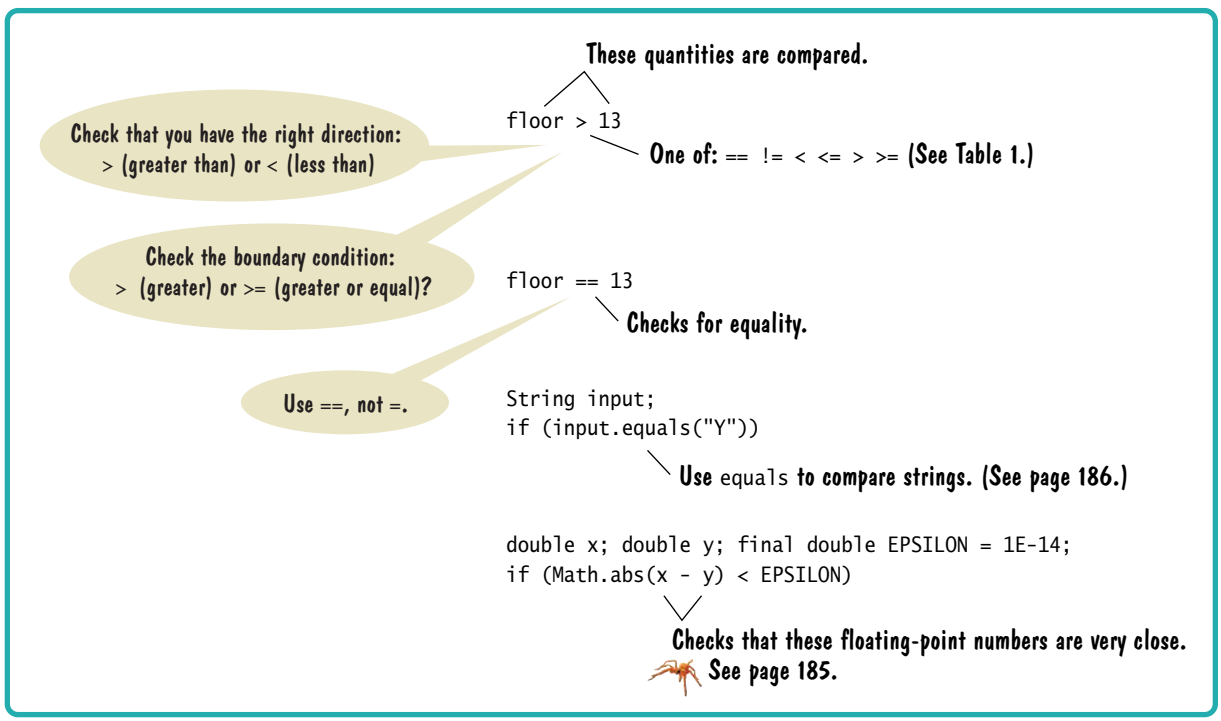
A **relational operator** tests the relationship between two values. An example is the > operator that we used in the test `floor > 13`. Java has six relational operators (see Table 1).

Table 1 Relational Operators

Java	Math Notation	Description
>	>	Greater than
>=	≥	Greater than or equal
<	<	Less than
<=	≤	Less than or equal
==	=	Equal
!=	≠	Not equal

As you can see, only two Java relational operators (> and <) look as you would expect from the mathematical notation. Computer keyboards do not have keys for ≥, ≤, or ≠, but the >=, <=, and != operators are easy to remember because they look similar. The == operator is initially confusing to most newcomers to Java.

Syntax 5.2 Comparisons



Relational operators compare values. The == operator tests for equality.

In Java, = already has a meaning, namely assignment. The == operator denotes equality testing:

```
floor = 13; // Assign 13 to floor

if (floor == 13)  // Test whether floor equals 13
```

You must remember to use == inside tests and to use = outside tests.

The relational operators in Table 1 have a lower precedence than the arithmetic operators. That means you can write arithmetic expressions on either side of the relational operator without using parentheses. For example, in the expression

```
floor - 1 < 13
```

both sides (`floor - 1` and `13`) of the < operator are evaluated, and the results are compared. Appendix B shows a table of the Java operators and their precedence.

5.2.2 Comparing Floating-Point Numbers

You have to be careful when comparing floating-point numbers in order to cope with roundoff errors. For example, the following code multiplies the square root of 2 by itself and then subtracts 2.

```
double r = Math.sqrt(2);
double d = r * r - 2;
if (d == 0)
{
   System.out.println("sqrt(2) squared minus 2 is 0");
}
else
{
   System.out.println("sqrt(2) squared minus 2 is not 0 but " + d);
}
```

Even though the laws of mathematics tell us that $(\sqrt{2})^2 - 2$ equals 0, this program fragment prints

```
sqrt(2) squared minus 2 is not 0 but 4.440892098500626E-16
```

Unfortunately, such roundoff errors are unavoidable. It plainly does not make sense in most circumstances to compare floating-point numbers exactly. Instead, test whether they are *close enough.*

When comparing floating-point numbers, don't test for equality. Instead, check whether they are close enough.

To test whether a number x is close to zero, you can test whether the absolute value $|x|$ (that is, the number with its sign removed) is less than a very small threshold number. That threshold value is often called ε (the Greek letter epsilon). It is common to set ε to 10^{-14} when testing `double` numbers.

Similarly, you can test whether two numbers are approximately equal by checking whether their difference is close to 0.

$$|x - y| \leq \varepsilon$$

In Java, we program the test as follows:

```
final double EPSILON = 1E-14;
if (Math.abs(x - y) <= EPSILON)
{
   // x is approximately equal to y
}
```

5.2.3 Comparing Strings

To test whether two strings are equal to each other, you must use the method called `equals`:

```
if (string1.equals(string2)) . . .
```

Do not use the == operator to compare strings. Use the equals method instead.

Do not use the `==` operator to compare strings. The comparison

```
if (string1 == string2) // Not useful
```

has an unrelated meaning. It tests whether the two strings are stored in the same memory location. You can have strings with identical contents stored in different locations, so this test never makes sense in actual programming; see Common Error 5.2 on page 189.

If two strings are not identical, you still may want to know the relationship between them. The `compareTo` method compares strings in **lexicographic order**. This ordering is very similar to the way in which words are sorted in a dictionary. If

```
string1.compareTo(string2) < 0
```

then the string `string1` comes before the string `string2` in the dictionary. For example, this is the case if `string1` is `"Harry"` and `string2` is `"Hello"`.

Conversely, if

```
string1.compareTo(string2) > 0
```

then `string1` comes after `string2` in dictionary order.

Finally, if

```
string1.compareTo(string2) == 0
```

then `string1` and `string2` are equal.

The compareTo method compares strings in lexicographic order.

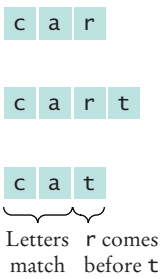
There are a few technical differences between the ordering in a dictionary and the lexicographic ordering in Java. In Java:

- All uppercase letters come before the lowercase letters. For example, `"Z"` comes before `"a"`.
- The space character comes before all printable characters.
- Numbers come before letters.
- For the ordering of punctuation marks, see Appendix A.

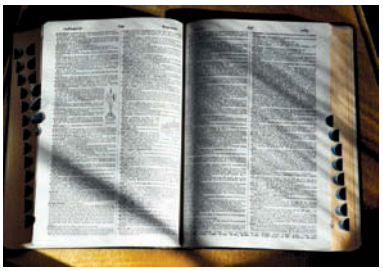
When comparing two strings, you compare the first letters of each word, then the second letters, and so on, until one of the strings ends or you find the first letter pair that doesn't match.

If one of the strings ends, the longer string is considered the "larger" one. For example, compare `"car"` with `"cart"`. The first three letters match, and we reach the end of the first string. Therefore `"car"` comes before `"cart"` in lexicographic ordering.

When you reach a mismatch, the string containing the "larger" character is considered "larger". For example, compare `"cat"` with `"cart"`. The first two letters match. Because `t` comes after `r`, the string `"cat"` comes after `"cart"` in the lexicographic ordering.



Lexicographic Ordering



Corbis Digital Stock.

To see which of two terms comes first in the dictionary, consider the first letter in which they differ.

5.2.4 Comparing Objects

If you compare two object references with the == operator, you test whether the references refer to the same object. Here is an example:

```
Rectangle box1 = new Rectangle(5, 10, 20, 30);
Rectangle box2 = box1;
Rectangle box3 = new Rectangle(5, 10, 20, 30);
```

The comparison

```
box1 == box2
```

is `true`. Both object variables refer to the same object. But the comparison

```
box1 == box3
```

The == operator tests whether two object references are identical. To compare the contents of objects, you need to use the `equals` method.

is `false`. The two object variables refer to different objects (see Figure 3). It does not matter that the objects have identical contents.

You can use the `equals` method to test whether two rectangles have the same contents, that is, whether they have the same upper-left corner and the same width and height. For example, the test

```
box1.equals(box3)
```

is true.

However, you must be careful when using the `equals` method. It works correctly only if the implementors of the class have supplied it. The `Rectangle` class has an `equals` method that is suitable for comparing rectangles.

For your own classes, you need to supply an appropriate `equals` method. You will learn how to do that in Chapter 9. Until that point, you should not use the `equals` method to compare objects of your own classes.

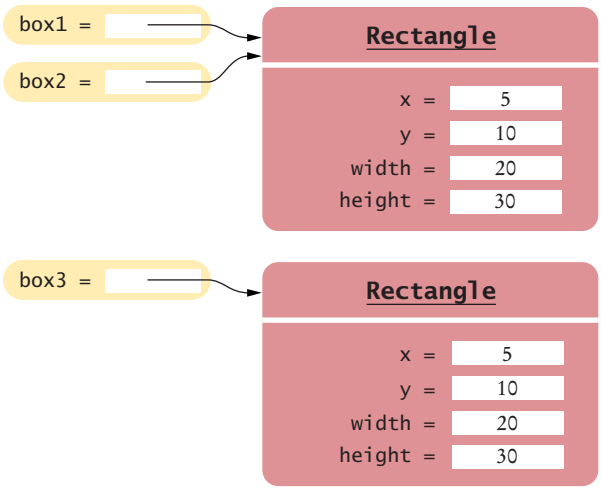


Figure 3
Comparing Object References

5.2.5 Testing for `null`

The `null` reference refers to no object.

An object reference can have the special value `null` if it refers to no object at all. It is common to use the `null` value to indicate that a value has never been set. For example,

```
String middleInitial = null; // Not set
if ( . . . )
{
   middleInitial = middleName.substring(0, 1);
}
```

Table 2 Relational Operator Examples

Expression	Value	Comment
`3 <= 4`	`true`	3 is less than 4; <= tests for "less than or equal".
`3 =< 4`	**Error**	The "less than or equal" operator is <=, not =<. The "less than" symbol comes first.
`3 > 4`	`false`	> is the opposite of <=.
`4 < 4`	`false`	The left-hand side must be strictly smaller than the right-hand side.
`4 <= 4`	`true`	Both sides are equal; <= tests for "less than or equal".
`3 == 5 - 2`	`true`	== tests for equality.
`3 != 5 - 1`	`true`	!= tests for inequality. It is true that 3 is not 5 – 1.
`3 = 6 / 2`	**Error**	Use == to test for equality.
`1.0 / 3.0 == 0.333333333`	`false`	Although the values are very close to one another, they are not exactly equal. See Section 5.2.2.
`"10" > 5`	**Error**	You cannot compare a string to a number.
`"Tomato".substring(0, 3).equals("Tom")`	`true`	Always use the `equals` method to check whether two strings have the same contents.
`"Tomato".substring(0, 3) == ("Tom")`	`false`	Never use == to compare strings; it only checks whether the strings are stored in the same location. See Common Error 5.2 on page 189.

You use the == operator (and not `equals`) to test whether an object reference is a `null` reference:

```
if (middleInitial == null)
{
   System.out.println(firstName + " " + lastName);
}
else
{
   System.out.println(firstName + " " + middleInitial + ". " + lastName);
}
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that demonstrates comparisons of numbers and strings.

Note that the **null reference** is not the same as the empty string `""`. The empty string is a valid string of length 0, whereas a `null` indicates that a string variable refers to no string at all.

Table 2 summarizes how to compare values in Java.

6. Which of the following conditions are true, provided `a` is 3 and `b` is 4?
   - **a.** `a + 1 <= b`
   - **b.** `a + 1 >= b`
   - **c.** `a + 1 != b`

7. Give the opposite of the condition

```
floor > 13
```

8. What is the error in this statement?

```
if (scoreA = scoreB)
{
   System.out.println("Tie");
}
```

9. Supply a condition in this `if` statement to test whether the user entered a Y:

```
System.out.println("Enter Y to quit.");
String input = in.next();
if (. . .)
{
   System.out.println("Goodbye.");
}
```

10. Give two ways of testing that a string `str` is the empty string.
11. What is the value of `s.length()` if `s` is
    a. the empty string `""`?
    b. the string `" "` containing a space?
    c. `null`?
12. Which of the following comparisons are syntactically incorrect? Which of them are syntactically correct, but logically questionable?

```
String a = "1";
String b = "one";
double x = 1;
double y = 3 * (1.0 / 3);
```

    a. `a == "1"`
    b. `a == null`
    c. `a.equals("")`
    d. `a == b`
    e. `a == x`
    f. `x == y`
    g. `x - y == null`
    h. `x.equals(y)`

Practice It Now you can try these exercises at the end of the chapter: R5.4, R5.7, E5.14.

Common Error 5.2

Using == to Compare Strings

If you write

```
if (nickname == "Rob")
```

then the test succeeds only if the variable `nickname` refers to the exact same location as the string literal `"Rob"`.

The test will pass if a string variable was initialized with the same string literal:

```
String nickname = "Rob";
. . .
if (nickname == "Rob") // Test is true
```

However, if the string with the letters `R o b` has been assembled in some other way, then the test will fail:

```
String name = "Robert";
String nickname = name.substring(0, 3);
. . .
if (nickname == "Rob") // Test is false
```

In this case, the `substring` method produces a string in a different memory location. Even though both strings have the same contents, the comparison fails.

You must remember never to use `==` to compare strings. Always use `equals` to check whether two strings have the same contents.

HOW TO 5.1 Implementing an `if` Statement

This How To walks you through the process of implementing an `if` statement. We will illustrate the steps with the following example problem.

Problem Statement The university bookstore has a Kilobyte Day sale every October 24, giving an 8 percent discount on all computer accessory purchases if the price is less than $128, and a 16 percent discount if the price is at least $128. Write a program that asks the cashier for the original price and then prints the discounted price.

Step 1 Decide upon the branching condition.

In our sample problem, the obvious choice for the condition is:

original price < 128?

That is just fine, and we will use that condition in our solution.

But you could equally well come up with a correct solution if you choose the opposite condition: Is the original price at least $128? You might choose this condition if you put yourself into the position of a shopper who wants to know when the bigger discount applies.

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Sales discounts are often higher for expensive products. Use the `if` statement to implement such a decision.

Step 2 Give pseudocode for the work that needs to be done when the condition is true.

In this step, you list the action or actions that are taken in the "positive" branch. The details depend on your problem. You may want to print a message, compute values, or even exit the program.

In our example, we need to apply an 8 percent discount:

discounted price = 0.92 x original price

Step 3 Give pseudocode for the work (if any) that needs to be done when the condition is *not* true.

What do you want to do in the case that the condition of Step 1 is not satisfied? Sometimes, you want to do nothing at all. In that case, use an `if` statement without an `else` branch.

In our example, the condition tested whether the price was less than $128. If that condition is *not* true, the price is at least $128, so the higher discount of 16 percent applies to the sale:

```
discounted price = 0.84 x original price
```

Step 4 Double-check relational operators.

First, be sure that the test goes in the right *direction*. It is a common error to confuse > and <. Next, consider whether you should use the < operator or its close cousin, the <= operator.

What should happen if the original price is exactly $128? Reading the problem carefully, we find that the lower discount applies if the original price is *less than* $128, and the higher discount applies when it is *at least* $128. A price of $128 should therefore *not* fulfill our condition, and we must use <, not <=.

Step 5 Remove duplication.

Check which actions are common to both branches, and move them outside. (See Programming Tip 5.4 on page 183.)

In our example, we have two statements of the form

```
discounted price = ___ x original price
```

They only differ in the discount rate. It is best to just set the rate in the branches, and to do the computation afterwards:

```
If original price < 128
   discount rate = 0.92
Else
   discount rate = 0.84
discounted price = discount rate x original price
```

Step 6 Test both branches.

Formulate two test cases, one that fulfills the condition of the `if` statement, and one that does not. Ask yourself what should happen in each case. Then follow the pseudocode and act each of them out.

In our example, let us consider two scenarios for the original price: $100 and $200. We expect that the first price is discounted by $8, the second by $32.

When the original price is 100, then the condition 100 < 128 is true, and we get

```
discount rate = 0.92
discounted price = 0.92 x 100 = 92
```

When the original price is 200, then the condition 200 < 128 is false, and

```
discount rate = 0.84
discounted price = 0.84 x 200 = 168
```

In both cases, we get the expected answer.

Step 7 Assemble the `if` statement in Java.

Type the skeleton

```
if ()
{
}
else
{
}
```

and fill it in, as shown in Syntax 5.1 on page 180. Omit the `else` branch if it is not needed.

FULL CODE EXAMPLE

Go to wiley.com/go/bjeo6code to download the complete program for calculating a discounted price.

In our example, the completed statement is

```
if (originalPrice < 128)
{
   discountRate = 0.92;
}
else
{
   discountRate = 0.84;
}
discountedPrice = discountRate * originalPrice;
```

WORKED EXAMPLE 5.1 Extracting the Middle

Learn how to extract the middle character from a string, or the two middle characters if the length of the string is even. Go to www.wiley.com/go/bjeo6examples and download Worked Example 5.1.

c	r	a	t	e
0	1	2	3	4

Computing & Society 5.1 Denver's Luggage Handling System

Making decisions is an essential part of any computer program. Nowhere is this more obvious than in a computer system that helps sort luggage at an airport. After scanning the luggage identification codes, the system sorts the items and routes them to different conveyor belts. Human operators then place the items onto trucks. When the city of Denver built a huge airport to replace an outdated and congested facility, the luggage system contractor went a step further. The new system was designed to replace the human operators with robotic carts. Unfortunately, the system plainly did not work. It was plagued by mechanical problems, such as luggage falling onto the tracks and jamming carts. Equally frustrating were the software glitches. Carts would uselessly accumulate at some locations when they were needed elsewhere.

The airport had been scheduled to open in 1993, but without a functioning luggage system, the opening was delayed for over a year while the contractor tried to fix the problems. The contractor never succeeded, and ultimately a manual system was installed. The delay cost the city and airlines close to a billion dollars, and the contractor, once the leading luggage systems vendor in the United States, went bankrupt.

Clearly, it is very risky to build a large system based on a technology that has never been tried on a smaller scale. In 2013, the rollout of universal healthcare in the United States was put in jeopardy by a dysfunctional web site for selecting insurance plans. The system promised an insurance shopping experience similar to booking airline flights. But, the HealthCare.gov site didn't simply present the available insurance plans. It also had to check the income level of each applicant and use that information to determine the subsidy level. That task turned out to be quite a bit harder than checking whether a credit card had sufficient credit to pay for an airline ticket. The Obama administration would have been well advised to design a signup process that did not rely on an untested computer program.

Lyn Alweis/The Denver Post via / Getty Images, Inc.

The Denver airport originally had a fully automatic system for moving luggage, replacing human operators with robotic carts. Unfortunately, the system never worked and was dismantled before the airport was opened.

5.3 Multiple Alternatives

Multiple `if` statements can be combined to evaluate complex decisions.

In Section 5.1, you saw how to program a two-way branch with an `if` statement. In many situations, there are more than two cases. In this section, you will see how to implement a decision with multiple alternatives.

For example, consider a program that displays the effect of an earthquake, as measured by the Richter scale (see Table 3).

The 1989 Loma Prieta earthquake that damaged the Bay Bridge in San Francisco and destroyed many buildings measured 7.1 on the Richter scale.

Table 3 Richter Scale

Value	Effect
8	Most structures fall
7	Many buildings destroyed
6	Many buildings considerably damaged, some collapse
4.5	Damage to poorly constructed buildings

The Richter scale is a measurement of the strength of an earthquake. Every step in the scale, for example from 6.0 to 7.0, signifies a tenfold increase in the strength of the quake.

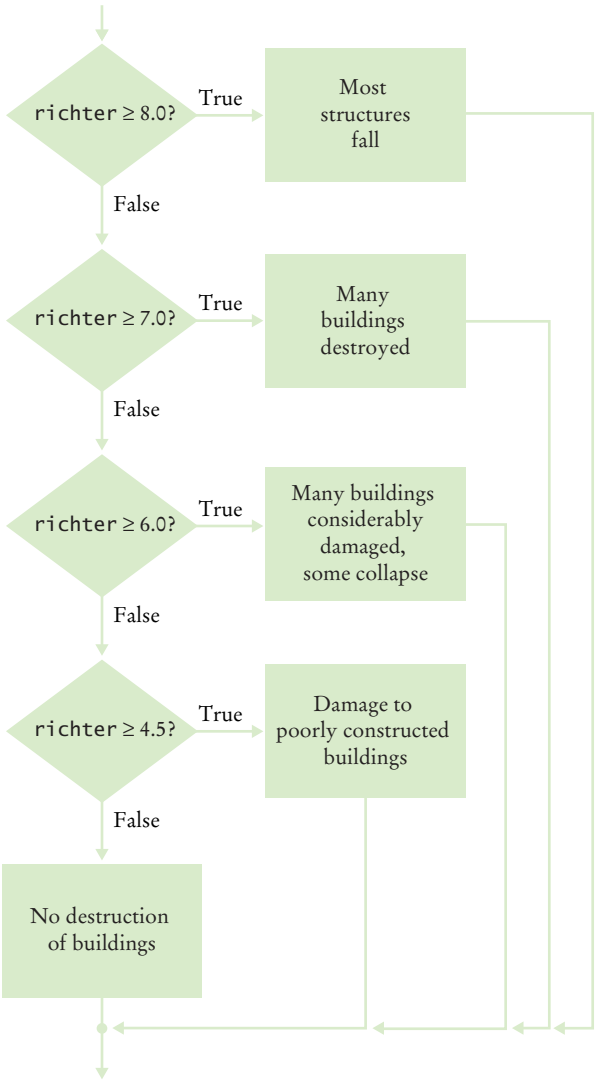
In this case, there are five branches: one each for the four descriptions of damage, and one for no destruction. Figure 4 shows the flowchart for this multiple-branch statement.

You use multiple `if` statements to implement multiple alternatives, like this:

```
if (richter >= 8.0)
{
   description = "Most structures fall";
}
else if (richter >= 7.0)
{
   description = "Many buildings destroyed";
}
else if (richter >= 6.0)
{
   description = "Many buildings considerably damaged, some collapse";
}
else if (richter >= 4.5)
{
   description = "Damage to poorly constructed buildings";
}
else
{
   description = "No destruction of buildings";
}
```

As soon as one of the four tests succeeds, the effect is displayed, and no further tests are attempted. If none of the four cases applies, the final `else` clause applies, and a default message is printed.

Figure 4
Multiple Alternatives



Here you must sort the conditions and test against the largest cutoff first. Suppose we reverse the order of tests:

```
if (richter >= 4.5) // Tests in wrong order
{
   description = "Damage to poorly constructed buildings";
}
else if (richter >= 6.0)
{
   description = "Many buildings considerably damaged, some collapse";
}
else if (richter >= 7.0)
{
   description = "Many buildings destroyed";
}
else if (richter >= 8.0)
{
   description = "Most structures fall";
}
```

When using multiple `if` statements, test general conditions after more specific conditions.

This does not work. Suppose the value of `richter` is 7.1. That value is at least 4.5, matching the first case. The other tests will never be attempted.

The remedy is to test the more specific conditions first. Here, the condition `richter >= 8.0` is more specific than the condition `richter >= 7.0`, and the condition `richter >= 4.5` is more general (that is, fulfilled by more values) than either of the first two.

In this example, it is also important that we use an `if/else if/else` sequence, not just multiple independent `if` statements. Consider this sequence of independent tests.

```
if (richter >= 8.0) // Didn't use else
{
   description = "Most structures fall";
}
if (richter >= 7.0)
{
   description = "Many buildings destroyed";
}
if (richter >= 6.0)
{
   description = "Many buildings considerably damaged, some collapse";
}
if (richter >= 4.5)
{
   "Damage to poorly constructed buildings";
}
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download the program for printing earthquake descriptions.

Now the alternatives are no longer exclusive. If `richter` is 7.1, then the last *three* tests all match. The `description` variable is set to three different strings, ending up with the wrong one.

13. In a game program, the scores of players A and B are stored in variables `scoreA` and `scoreB`. Assuming that the player with the larger score wins, write an `if/else if/else` sequence that prints out `"A won"`, `"B won"`, or `"Game tied"`.
14. Write a conditional statement with three branches that sets `s` to 1 if `x` is positive, to –1 if `x` is negative, and to 0 if `x` is zero.
15. How could you achieve the task of Self Check 14 with only two branches?
16. Beginners sometimes write statements such as the following:

```
if (price > 100)
{
   discountedPrice = price - 20;
}
else if (price <= 100)
{
   discountedPrice = price - 10;
}
```

    Explain how this code can be improved.
17. Suppose the user enters `-1` into the earthquake program. What is printed?
18. Suppose we want to have the earthquake program check whether the user entered a negative number. What branch would you add to the `if` statement, and where?

Practice It Now you can try these exercises at the end of the chapter: R5.23, E5.11, E5.24.

Special Topic 5.2

The `switch` Statement

An `if/else` `if/else` sequence that compares a *value* against several alternatives can be implemented as a `switch` statement. For example,

```
int digit = . . .;
switch (digit)
{
   case 1: digitName = "one"; break;
   case 2: digitName = "two"; break;
   case 3: digitName = "three"; break;
   case 4: digitName = "four"; break;
   case 5: digitName = "five"; break;
   case 6: digitName = "six"; break;
   case 7: digitName = "seven"; break;
   case 8: digitName = "eight"; break;
   case 9: digitName = "nine"; break;
   default: digitName = ""; break;
}
```

© travelpixpro/iStockphoto.

The `switch` statement lets you choose from a fixed set of alternatives.

This is a shortcut for

```
int digit = . . .;
if (digit == 1) { digitName = "one"; }
else if (digit == 2) { digitName = "two"; }
else if (digit == 3) { digitName = "three"; }
else if (digit == 4) { digitName = "four"; }
else if (digit == 5) { digitName = "five"; }
else if (digit == 6) { digitName = "six"; }
else if (digit == 7) { digitName = "seven"; }
else if (digit == 8) { digitName = "eight"; }
else if (digit == 9) { digitName = "nine"; }
else { digitName = ""; }
```

It isn't much of a shortcut, but it has one advantage—it is obvious that all branches test the *same* value, namely `digit`.

The `switch` statement can be applied only in narrow circumstances. The values in the case clauses must be constants. They can be integers or characters. As of Java 7, strings are permitted as well. You cannot use a `switch` statement to branch on floating-point values.

Every branch of the switch should be terminated by a `break` instruction. If the `break` is missing, execution *falls through* to the next branch, and so on, until a `break` or the end of the `switch` is reached. In practice, this fall-through behavior is rarely useful, but it is a common cause of errors. If you accidentally forget a `break` statement, your program compiles but executes unwanted code. Many programmers consider the `switch` statement somewhat dangerous and prefer the `if` statement.

We leave it to you to use the `switch` statement for your own code or not. At any rate, you need to have a reading knowledge of `switch` in case you find it in other programmers' code.

5.4 Nested Branches

When a decision statement is contained inside the branch of another decision statement, the statements are *nested*.

It is often necessary to include an `if` statement inside another. Such an arrangement is called a *nested* set of statements.

Here is a typical example: In the United States, different tax rates are used depending on the taxpayer's marital status. There are different tax schedules for single and for married taxpayers. Married taxpayers add their income together and pay taxes on the total. Table 4 gives the tax rate computations, using a simplification of the

Computing income taxes requires multiple levels of decisions.

schedules that were in effect for the 2008 tax year. A different tax rate applies to each "bracket". In this schedule, the income in the first bracket is taxed at 10 percent, and the income in the second bracket is taxed at 25 percent. The income limits for each bracket depend on the marital status.

Table 4 Federal Tax Rate Schedule

If your status is Single and if the taxable income is	the tax is	of the amount over
at most $32,000	10%	$0
over $32,000	$3,200 + 25%	$32,000
If your status is Married and if the taxable income is	**the tax is**	**of the amount over**
at most $64,000	10%	$0
over $64,000	$6,400 + 25%	$64,000

Nested decisions are required for problems that have two levels of decision making.

Now compute the taxes due, given a marital status and an income figure. The key point is that there are two *levels* of decision making. First, you must branch on the marital status. Then, for each marital status, you must have another branch on income level.

The two-level decision process is reflected in two levels of `if` statements in the program at the end of this section. (See Figure 5 for a flowchart.) In theory, nesting can go deeper than two levels. A three-level decision process (first by state, then by marital status, then by income level) requires three nesting levels.

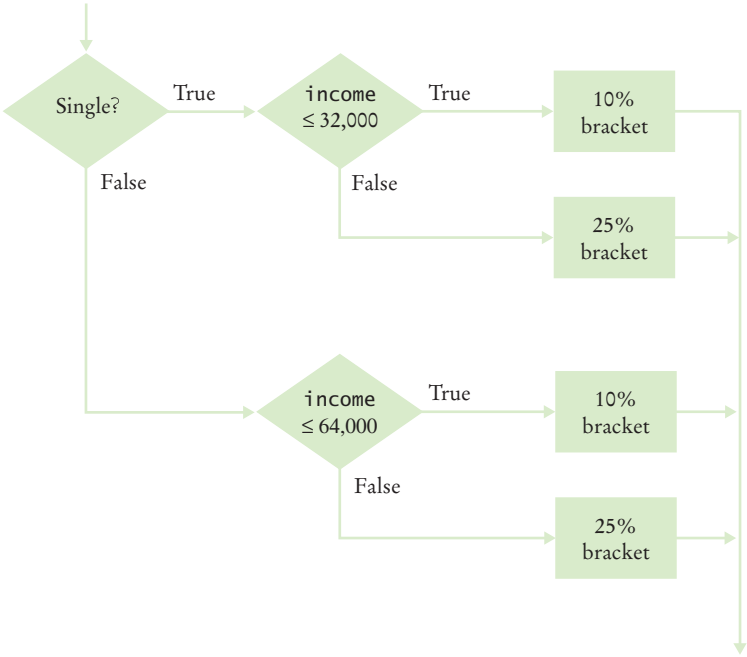


Figure 5 Income Tax Computation

section_4/TaxReturn.java

```
1  /**
2     A tax return of a taxpayer in 2008.
3  */
4  public class TaxReturn
5  {
6     public static final int SINGLE = 1;
7     public static final int MARRIED = 2;
8
9     private static final double RATE1 = 0.10;
10    private static final double RATE2 = 0.25;
11    private static final double RATE1_SINGLE_LIMIT = 32000;
12    private static final double RATE1_MARRIED_LIMIT = 64000;
13
14    private double income;
15    private int status;
16
17    /**
18       Constructs a TaxReturn object for a given income and
19       marital status.
20       @param anIncome the taxpayer income
21       @param aStatus either SINGLE or MARRIED
22    */
23    public TaxReturn(double anIncome, int aStatus)
24    {
25       income = anIncome;
26       status = aStatus;
27    }
28
29    public double getTax()
30    {
31       double tax1 = 0;
32       double tax2 = 0;
33
34       if (status == SINGLE)
35       {
36          if (income <= RATE1_SINGLE_LIMIT)
37          {
38             tax1 = RATE1 * income;
39          }
40          else
41          {
42             tax1 = RATE1 * RATE1_SINGLE_LIMIT;
43             tax2 = RATE2 * (income - RATE1_SINGLE_LIMIT);
44          }
45       }
46       else
47       {
48          if (income <= RATE1_MARRIED_LIMIT)
49          {
50             tax1 = RATE1 * income;
51          }
52          else
53          {
54             tax1 = RATE1 * RATE1_MARRIED_LIMIT;
55             tax2 = RATE2 * (income - RATE1_MARRIED_LIMIT);
56          }
57       }
58
59       return tax1 + tax2;
```

```
60    }
61 }
```

section_4/TaxCalculator.java

```
1  import java.util.Scanner;
2
3  /**
4     This program calculates a simple tax return.
5  */
6  public class TaxCalculator
7  {
8     public static void main(String[] args)
9     {
10       Scanner in = new Scanner(System.in);
11
12       System.out.print("Please enter your income: ");
13       double income = in.nextDouble();
14
15       System.out.print("Are you married? (Y/N) ");
16       String input = in.next();
17       int status;
18       if (input.equals("Y"))
19       {
20          status = TaxReturn.MARRIED;
21       }
22       else
23       {
24          status = TaxReturn.SINGLE;
25       }
26       TaxReturn aTaxReturn = new TaxReturn(income, status);
27       System.out.println("Tax: "
28             + aTaxReturn.getTax());
29    }
30 }
```

Program Run

```
Please enter your income: 80000
Are you married? (Y/N) Y
Tax: 10400.0
```

19. What is the amount of tax that a single taxpayer pays on an income of $32,000?
20. Would that amount change if the first nested `if` statement changed from

    ```
    if (income <= RATE1_SINGLE_LIMIT)
    ```

    to

    ```
    if (income < RATE1_SINGLE_LIMIT)
    ```
21. Suppose Harry and Sally each make $40,000 per year. Would they save taxes if they married?
22. How would you modify the `TaxCalculator.java` program in order to check that the user entered a correct value for the marital status (i.e., `Y` or `N`)?
23. Some people object to higher tax rates for higher incomes, claiming that you might end up with less money after taxes when you get a raise for working hard. What is the flaw in this argument?

Practice It Now you can try these exercises at the end of the chapter: R5.10, R5.22, E5.15, E5.18.

Programming Tip 5.5

Hand-Tracing

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Hand-tracing helps you understand whether a program works correctly.

A very useful technique for understanding whether a program works correctly is called *hand-tracing*. You simulate the program's activity on a sheet of paper. You can use this method with pseudocode or Java code.

Get an index card, a cocktail napkin, or whatever sheet of paper is within reach. Make a column for each variable. Have the program code ready. Use a marker, such as a paper clip, to mark the current statement. In your mind, execute statements one at a time. Every time the value of a variable changes, cross out the old value and write the new value below the old one.

For example, let's trace the `getTax` method with the data from the program run above. When the `TaxReturn` object is constructed, the `income` instance variable is set to 80,000 and `status` is set to `MARRIED`. Then the `getTax` method is called. In lines 31 and 32 of `TaxReturn.java`, `tax1` and `tax2` are initialized to 0.

```
29 public double getTax()
30 {
31    double tax1 = 0;
32    double tax2 = 0;
33
```

income	status	tax1	tax2
80000	MARRIED	0	0

Because `status` is not `SINGLE`, we move to the `else` branch of the outer `if` statement (line 46).

```
34    if (status == SINGLE)
35    {
36       if (income <= RATE1_SINGLE_LIMIT)
37       {
38          tax1 = RATE1 * income;
39       }
40       else
41       {
42          tax1 = RATE1 * RATE1_SINGLE_LIMIT;
43          tax2 = RATE2 * (income - RATE1_SINGLE_LIMIT);
44       }
45    }
46    else
47    {
```

Because `income` is not `<= 64000`, we move to the `else` branch of the inner `if` statement (line 52).

```
48       if (income <= RATE1_MARRIED_LIMIT)
49       {
50          tax1 = RATE1 * income;
51       }
52       else
53       {
54          tax1 = RATE1 * RATE1_MARRIED_LIMIT;
55          tax2 = RATE2 * (income - RATE1_MARRIED_LIMIT);
56       }
```

The values of `tax1` and `tax2` are updated.

```
53       {
54          tax1 = RATE1 * RATE1_MARRIED_LIMIT;
55          tax2 = RATE2 * (income - RATE1_MARRIED_LIMIT);
56       }
57    }
```

income	status	tax1	tax2
80000	MARRIED	~~0~~	~~0~~
		6400	4000

Their sum is returned and the method ends.

```
58
59    return tax1 + tax2;
60 }
```

income	status	tax1	tax2	return value
80000	MARRIED	~~0~~	~~0~~	
		6400	4000	10400

Because the program trace shows the expected return value ($10,400), it successfully demonstrates that this test case works correctly.

Common Error 5.3

The Dangling else Problem

When an `if` statement is nested inside another `if` statement, the following error may occur.

```
double shippingCharge = 5.00; // $5 inside continental U.S.
if (country.equals("USA"))
   if (state.equals("HI"))
      shippingCharge = 10.00; // Hawaii is more expensive
else // Pitfall!
   shippingCharge = 20.00; // As are foreign shipments
```

The indentation level seems to suggest that the `else` is grouped with the test `country.equals("USA")`. Unfortunately, that is not the case. The compiler ignores all indentation and matches the `else` with the preceding `if`. That is, the code is actually

```
double shippingCharge = 5.00; // $5 inside continental U.S.
if (country.equals("USA"))
   if (state.equals("HI"))
      shippingCharge = 10.00; // Hawaii is more expensive
   else // Pitfall!
      shippingCharge = 20.00; // As are foreign shipments
```

That isn't what you want. You want to group the `else` with the first `if`.

The ambiguous `else` is called a *dangling else*. You can avoid this pitfall if you always use braces, as recommended in Programming Tip 5.2 on page 181:

```
double shippingCharge = 5.00; // $5 inside continental U.S.
if (country.equals("USA"))
{
   if (state.equals("HI"))
   {
      shippingCharge = 10.00; // Hawaii is more expensive
   }
}
else
{
   shippingCharge = 20.00; // As are foreign shipments
}
```

Special Topic 5.3

Block Scope

A **block** is a sequence of statements that is enclosed in braces. For example, consider this statement:

```
if (status == TAXABLE)
{
   double tax = price * TAX_RATE;
   price = price + tax;
}
```

The highlighted part is a block. You can declare a variable in a block, such as the `tax` variable in this example. Such a variable is only visible inside the block.

```
{
   double tax = price * TAX_RATE; // Variable declared inside a block
   price = price + tax;
}
// You can no longer access the tax variable here
```

In fact, the variable is only created after the program enters the block, and it is removed as soon as the program exits the block. Such a variable is said to have *block scope*. In general, the **scope** of a variable is the part of the program in which the variable can be accessed. A variable with block scope is visible only inside a block.

It is considered good design to minimize the scope of a variable. This reduces the possibility of accidental modification and name conflicts. For example, as long as the tax variable is not needed outside the block, it is a good idea to declare it inside the block. However, if you need the variable outside the block, you must define it outside. For example,

```
double tax = 0;
if (status == TAXABLE)
{
   tax = price * TAX_RATE;
}
price = price + tax;
```

Here, the tax variable is used outside the block of the `if` statement, and you must declare it outside.

In Java, the scope of a local variable can never contain the declaration of another local variable with the same name. For example, the following is an error:

```
double tax = 0;
if (status == TAXABLE)
{
   double tax = price * TAX_RATE;
   // Error: Cannot declare another variable with the same name
   price = price + tax;
}
```

However, you can have local variables with identical names if their scopes do not overlap, such as

```
if (Math.random() > 0.5)
{
   Rectangle r = new Rectangle(5, 10, 20, 30);
   . . .
} // Scope of r ends here
else
{
   int r = 5;
   // OK—it is legal to declare another r here
   . . .
}
```

These variables are independent from each other. You can have local variables with the same name, as long as their scopes don't overlap.

(left) © jchamp/iStockphoto; (middle) © StevenCarrieJohnson/iStockphoto; (right) © jsmith/iStockphoto.

In the same way that there can be a street named "Main Street" in different cities, a Java program can have multiple variables with the same name.

Special Topic 5.4

Enumeration Types

In many programs, you use variables that can hold one of a finite number of values. For example, in the tax return class, the `status` instance variable holds one of the values `SINGLE` or `MARRIED`. We arbitrarily declared `SINGLE` as the number 1 and `MARRIED` as 2. If, due to some programming error, the `status` variable is set to another integer value (such as `-1`, `0`, or `3`), then the programming logic may produce invalid results.

In a simple program, this is not really a problem. But as programs grow over time, and more cases are added (such as the "married filing separately" status), errors can slip in. **Enumeration types** provide a remedy. An enumeration type has a finite set of values, for example

```
public enum FilingStatus { SINGLE, MARRIED, MARRIED_FILING_SEPARATELY }
```

You can have any number of values, but you must include them all in the `enum` declaration.

You can declare variables of the enumeration type:

```
FilingStatus status = FilingStatus.SINGLE;
```

If you try to assign a value that isn't a `FilingStatus`, such as 2 or `"S"`, then the compiler reports an error.

Use the == operator to compare enumeration values, for example:

```
if (status == FilingStatus.SINGLE) . . .
```

Place the `enum` declaration inside the class that implements your program, such as

```
public class TaxReturn
{
   public enum FilingStatus { SINGLE, MARRIED, MARRIED_FILING_SEPARATELY }
   . . .
}
```

5.5 Problem Solving: Flowcharts

Flow charts are made up of elements for tasks, input/output, and decisions.

You have seen examples of flowcharts earlier in this chapter. A flowchart shows the structure of decisions and tasks that are required to solve a problem. When you have to solve a complex problem, it can help to draw a flowchart to visualize the flow of control.

The basic flowchart elements are shown in Figure 6.

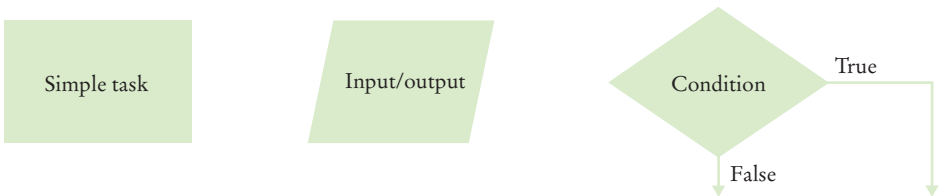


Figure 6
Flowchart Elements

The basic idea is simple enough. Link tasks and input/output boxes in the sequence in which they should be executed. Whenever you need to make a decision, draw a diamond with two outcomes (see Figure 7).

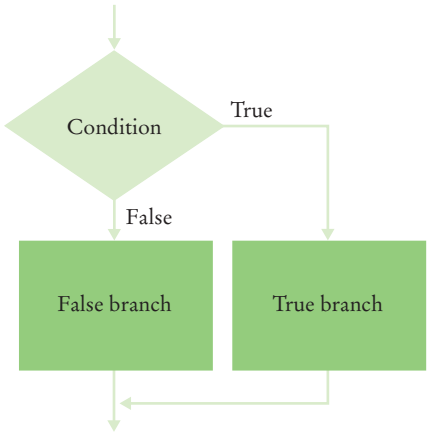


Figure 7
Flowchart with Two Outcomes

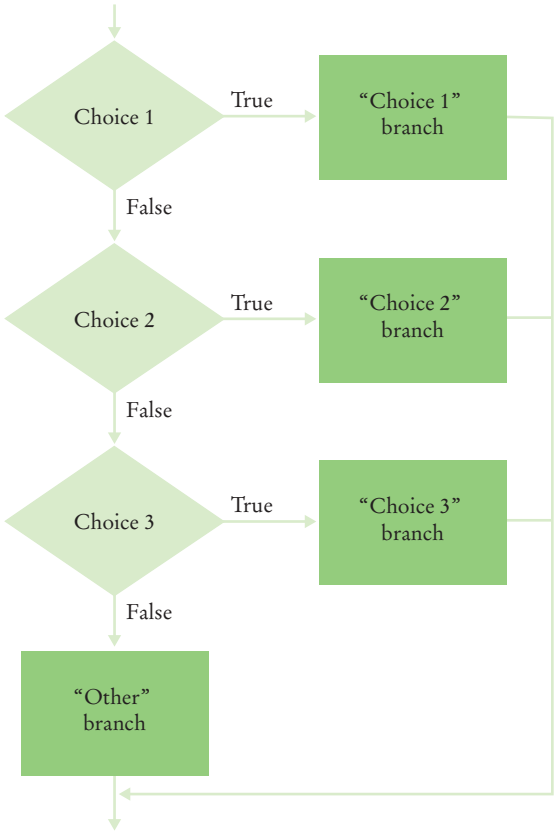


Figure 8
Flowchart with Multiple Choices

Each branch of a decision can contain tasks and further decisions.

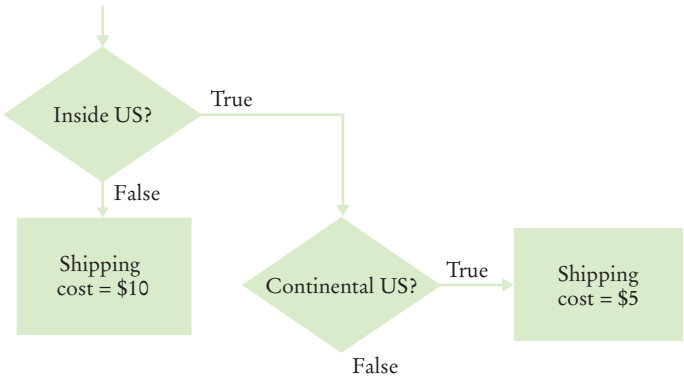
Each branch can contain a sequence of tasks and even additional decisions. If there are multiple choices for a value, lay them out as in Figure 8.

There is one issue that you need to be aware of when drawing flowcharts. Unconstrained branching and merging can lead to "spaghetti code", a messy network of possible pathways through a program.

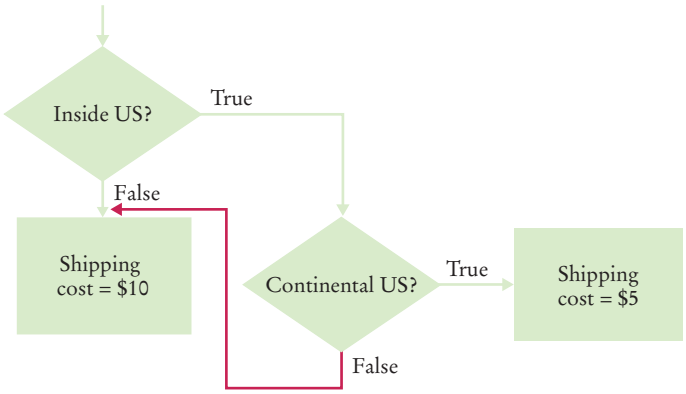
Never point an arrow inside another branch.

There is a simple rule for avoiding spaghetti code: Never point an arrow *inside another branch*.

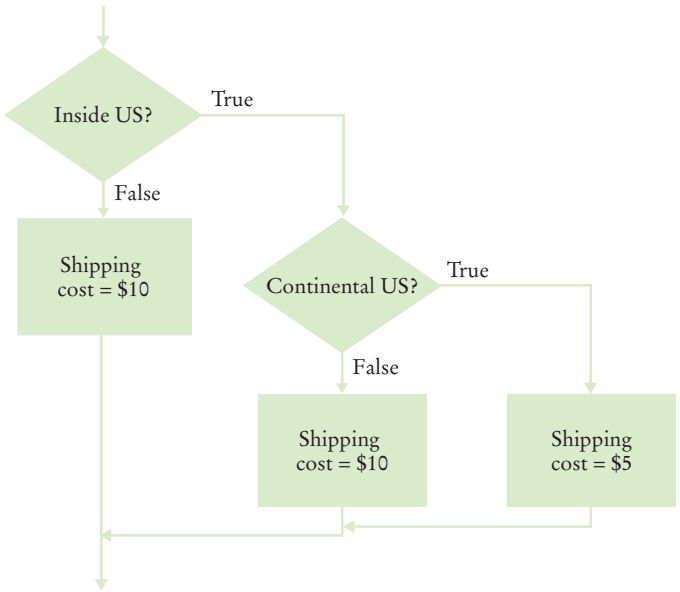
To understand the rule, consider this example: Shipping costs are $5 inside the United States, except that to Hawaii and Alaska they are $10. International shipping costs are also $10.You might start out with a flowchart like the following:



Now you may be tempted to reuse the "shipping cost = $10" task:



Don't do that! The red arrow points inside a different branch. Instead, add another task that sets the shipping cost to $10, like this:



FULL CODE EXAMPLE

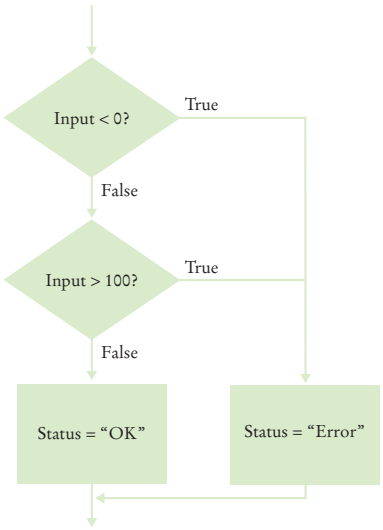
Go to `wiley.com/go/bjeo6code` to download a program that computes shipping costs.

Not only do you avoid spaghetti code, but it is also a better design. In the future it may well happen that the cost for international shipments is different from that to Alaska and Hawaii.

Flowcharts can be very useful for getting an intuitive understanding of the flow of an algorithm. However, they get large rather quickly when you add more details. At that point, it makes sense to switch from flowcharts to pseudocode.

Spaghetti code has so many pathways that it becomes impossible to understand.

24. Draw a flowchart for a program that reads a value `temp` and prints "Frozen" if it is less than zero.
25. What is wrong with the flowchart at right?
26. How do you fix the flowchart of Self Check 25?
27. Draw a flowchart for a program that reads a value `x`. If it is less than zero, print "Error". Otherwise, print its square root.
28. Draw a flowchart for a program that reads a value `temp`. If it is less than zero, print "Ice". If it is greater than 100, print "Steam". Otherwise, print "Liquid".



Practice It Now you can try these exercises at the end of the chapter: R5.13, R5.14, R5.15.

5.6 Problem Solving: Selecting Test Cases

Black-box testing describes a testing method that does not take the structure of the implementation into account.

White-box testing uses information about the structure of a program.

Code coverage is a measure of how many parts of a program have been tested.

Testing the functionality of a program without consideration of its internal structure is called **black-box testing**. This is an important part of testing, because, after all, the users of a program do not know its internal structure. If a program works perfectly on all inputs, then it surely does its job.

However, it is impossible to ensure absolutely that a program will work correctly on all inputs just by supplying a finite number of test cases. As the famous computer scientist Edsger Dijkstra pointed out, testing can show only the presence of bugs—not their absence. To gain more confidence in the correctness of a program, it is useful to consider its internal structure. Testing strategies that look inside a program are called **white-box testing**. Performing unit tests of each method is a part of white-box testing.

You want to make sure that each part of your program is exercised at least once by one of your test cases. This is called **code coverage**. If some code is never executed by any of your test cases, you have no way of knowing whether that code would perform correctly if it ever were executed by user input. That means that you need to look at every `if/else` branch to see that each of them is reached by some test case. Many conditional branches are in the code only to take care of strange and abnormal inputs, but they still do something. It is a common phenomenon that they end up doing something incorrectly, but those faults are never discovered during testing, because nobody supplied the strange and abnormal inputs. The remedy is to ensure that each part of the code is covered by some test case.

For example, in testing the `getTax` method of the `TaxReturn` class, you want to make sure that every `if` statement is entered for at least one test case. You should test both single and married taxpayers, with incomes in each of the three tax brackets.

When you select test cases, you should make it a habit to include **boundary test cases**: legal values that lie at the boundary of the set of acceptable inputs.

Boundary test cases are test cases that are at the boundary of acceptable inputs.

Here is a plan for obtaining a comprehensive set of test cases for the tax program:

- There are two possibilities for the marital status and two tax brackets for each status, yielding four test cases.
- Test a handful of *boundary* conditions, such as an income that is at the boundary between two brackets, and a zero income.
- If you are responsible for error checking (which is discussed in Section 5.8), also test an invalid input, such as a negative income.

Make a list of the test cases and the expected outputs:

Test Case	Married	Expected Output	Comment
30,000	N	3,000	10% bracket
72,000	N	13,200	3,200 + 25% of 40,000
50,000	Y	5,000	10% bracket
104,000	Y	16,400	6,400 + 25% of 40,000
32,000	N	3,200	boundary case
0		0	boundary case

It is a good idea to design test cases before implementing a program.

When you develop a set of test cases, it is helpful to have a flowchart of your program (see Section 5.5). Check off each branch that has a test case. Include test cases for the boundary cases of each decision. For example, if a decision checks whether an input is less than 100, test with an input of 100.

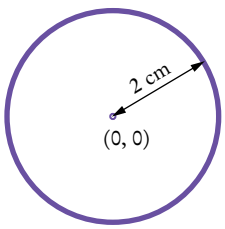
It is always a good idea to design test cases *before* starting to code. Working through the test cases gives you a better understanding of the algorithm that you are about to implement.

29. Using Figure 1 on page 179 as a guide, follow the process described in this section to design a set of test cases for the `ElevatorSimulation.java` program in Section 5.1.

30. What is a boundary test case for the algorithm in How To 5.1 on page 190? What is the expected output?

31. Using Figure 4 on page 194 as a guide, follow the process described in Section 5.6 to design a set of test cases for the `Earthquake.java` program in Section 5.3.

32. Suppose you are designing a part of a program for a medical robot that has a sensor returning an x- and y-location (measured in cm). You need to check whether the sensor location is inside the circle, outside the circle, or on the boundary (specifically, having a distance of less than 1 mm from the boundary). Assume the circle has center (0, 0) and a radius of 2 cm. Give a set of test cases.



Practice It Now you can try these exercises at the end of the chapter: R5.16, R5.17.

Programming Tip 5.6

Make a Schedule and Make Time for Unexpected Problems

Commercial software is notorious for being delivered later than promised. For example, Microsoft originally promised that its Windows Vista operating system would be available late in 2003, then in 2005, then in March 2006; it finally was released in January 2007. Some of the early promises might not have been realistic. It was in Microsoft's interest to let prospective customers expect the imminent availability of the product. Had customers known the actual delivery date, they might have switched to a different product in the meantime. Undeniably, though, Microsoft had not anticipated the full complexity of the tasks it had set itself to solve.

Microsoft can delay the delivery of its product, but it is likely that you cannot. As a student or a programmer, you are expected to manage your time wisely and to finish your assignments on time. You can probably do simple programming exercises the night before the due date, but an assignment that looks twice as hard may well take four times as long, because more things can go wrong. You should therefore make a schedule whenever you start a programming project.

First, estimate realistically how much time it will take you to:

- Design the program logic.
- Develop test cases.
- Type the program in and fix syntax errors.
- Test and debug the program.

For example, for the income tax program I might estimate an hour for the design; 30 minutes for developing test cases; an hour for data entry and fixing syntax errors; and an hour for testing and debugging. That is a total of 3.5 hours. If I work two hours a day on this project, it will take me almost two days.

Bananastock/Media Bakery.

Make a schedule for your programming work and build in time for problems.

Then think of things that can go wrong. Your computer might break down. You might be stumped by a problem with the computer system. (That is a particularly important concern for beginners. It is *very* common to lose a day over a trivial problem just because it takes time to track down a person who knows the magic command to overcome it.) As a rule of thumb, *double* the time of your estimate. That is, you should start four days, not two days, before the due date. If nothing went wrong, great; you have the program done two days early. When the inevitable problem occurs, you have a cushion of time that protects you from embarrassment and failure.

Special Topic 5.5

Logging

Sometimes you run a program and you are not sure where it spends its time. To get a printout of the program flow, you can insert **trace messages** into the program, such as this one:

```
if (status == SINGLE)
{
   System.out.println("status is SINGLE");
   . . .
}
```

However, there is a problem with using `System.out.println` for trace messages. When you are done testing the program, you need to remove all print statements that produce trace messages. If you find another error, however, you need to stick the print statements back in.

To overcome this problem, you should use the `Logger` class, which allows you to turn off the trace messages without removing them from the program.

Instead of printing directly to `System.out`, use the global logger object that is returned by the call `Logger.getGlobal()`. (Prior to Java 7, you obtained the global logger as `Logger.getLogger("global")`.) Then call the `info` method:

```
Logger.getGlobal().info("status is SINGLE");
```

Logging messages can be deactivated when testing is complete.

By default, the message is printed. But if you call

```
Logger.getGlobal().setLevel(Level.OFF);
```

at the beginning of the `main` method of your program, all log message printing is suppressed. Set the level to `Level.INFO` to turn logging of `info` messages on again. Thus, you can turn off the log messages when your program works fine, and you can turn them back on if you find another error. In other words, using `Logger.getGlobal().info` is just like `System.out.println`, except that you can easily activate and deactivate the logging.

The `Logger` class has many other options for industrial-strength logging. Check out the API documentation if you want to have more control over logging.

5.7 Boolean Variables and Operators

The Boolean type `boolean` has two values, `false` and `true`.

Sometimes, you need to evaluate a logical condition in one part of a program and use it elsewhere. To store a condition that can be true or false, you use a *Boolean variable*. Boolean variables are named after the mathematician George Boole (1815–1864), a pioneer in the study of logic.

In Java, the `boolean` data type has exactly two values, denoted `false` and `true`. These values are not strings or integers; they are special values, just for Boolean variables. Here is a declaration of a Boolean variable:

```
boolean failed = true;
```

You can use the value later in your program to make a decision:

```
if (failed) // Only executed if failed has been set to true
{
   . . .
}
```

Jon Patton/E+/Getty Images, Inc.

A Boolean variable is also called a flag because it can be either up (true) or down (false).

When you make complex decisions, you often need to combine Boolean values. An operator that combines Boolean conditions is called a **Boolean operator**. In Java, the `&&` operator (called *and*) yields `true` only when both conditions are true. The `||` operator (called *or*) yields the result `true` if at least one of the conditions is true.

A	B	A && B
true	true	true
true	false	false
false	true	false
false	false	false

A	B	A || B
true	true	true
true	false	true
false	true	true
false	false	false

A	!A
true	false
false	true

Figure 9 Boolean Truth Tables

At this geyser in Iceland, you can see ice, liquid water, and steam.

Java has two Boolean operators that combine conditions: && (*and*) and || (*or*).

Suppose you write a program that processes temperature values, and you want to test whether a given temperature corresponds to liquid water. (At sea level, water freezes at 0 degrees Celsius and boils at 100 degrees.) Water is liquid if the temperature is greater than zero *and* less than 100:

```
if (temp > 0 && temp < 100) { System.out.println("Liquid"); }
```

The condition of the test has two parts, joined by the && operator. Each part is a Boolean value that can be true or false. The combined expression is true if both individual expressions are true. If either one of the expressions is false, then the result is also false (see Figure 9).

The Boolean operators && and || have a lower precedence than the relational operators. For that reason, you can write relational expressions on either side of the Boolean operators without using parentheses. For example, in the expression

```
temp > 0 && temp < 100
```

the expressions `temp > 0` and `temp < 100` are evaluated first. Then the && operator combines the results. Appendix B shows a table of the Java operators and their precedence.

Conversely, let's test whether water is *not* liquid at a given temperature. That is the case when the temperature is at most 0 *or* at least 100.

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that compares numbers using Boolean expressions.

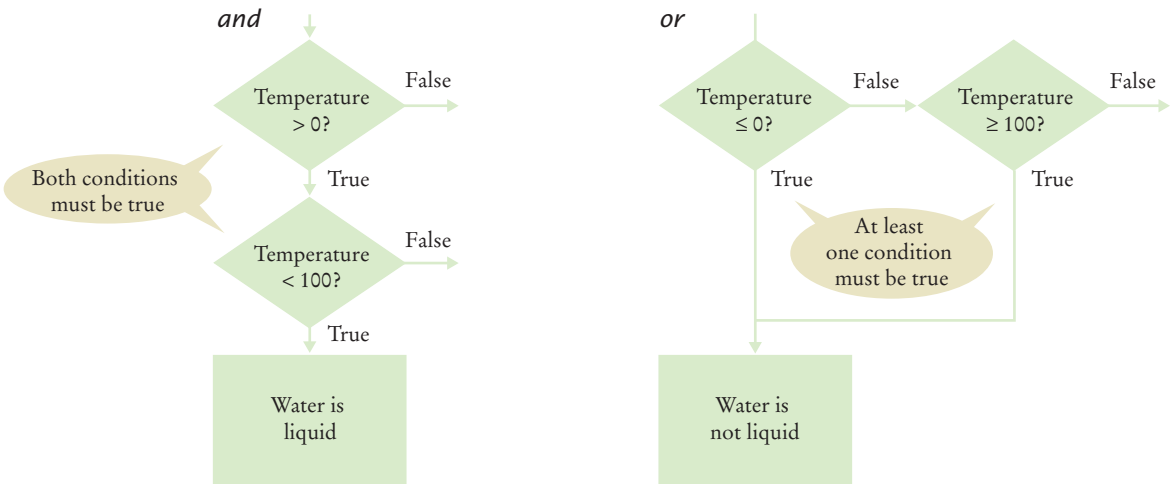


Figure 10 Flowcharts for *and* and *or* Combinations

Table 5 Boolean Operator Examples

Expression	Value	Comment
`0 < 200 && 200 < 100`	`false`	Only the first condition is true.
`0 < 200 || 200 < 100`	`true`	The first condition is true.
`0 < 200 || 100 < 200`	`true`	The `||` is not a test for "either-or". If both conditions are true, the result is true.
`0 < x && x < 100 || x == -1`	`(0 < x && x < 100) || x == -1`	The `&&` operator has a higher precedence than the `||` operator (see Appendix B).
`0 < x < 100`	**Error**	**Error:** This expression does not test whether `x` is between 0 and 100. The expression `0 < x` is a Boolean value. You cannot compare a Boolean value with the integer 100.
`x && y > 0`	**Error**	**Error:** This expression does not test whether `x` and `y` are positive. The left-hand side of `&&` is an integer, `x`, and the right-hand side, `y > 0`, is a Boolean value. You cannot use `&&` with an integer argument.
`!(0 < 200)`	`false`	`0 < 200` is `true`, therefore its negation is `false`.
`frozen == true`	`frozen`	There is no need to compare a Boolean variable with `true`.
`frozen == false`	`!frozen`	It is clearer to use `!` than to compare with `false`.

Use the `||` (*or*) operator to combine the expressions:

```
if (temp <= 0 || temp >= 100) { System.out.println("Not liquid"); }
```

Figure 10 shows flowcharts for these examples.

To invert a condition, use the `!` (*not*) operator.

Sometimes you need to *invert* a condition with the *not* Boolean operator. The `!` operator takes a single condition and evaluates to `true` if that condition is false and to `false` if the condition is true. In this example, output occurs if the value of the Boolean variable `frozen` is `false`: .

```
if (!frozen) { System.out.println("Not frozen"); }
```

Table 5 illustrates additional examples of evaluating Boolean operators.

33. Suppose `x` and `y` are two integers. How do you test whether both of them are zero?

34. How do you test whether at least one of them is zero?

35. How do you test whether *exactly one of them* is zero?

36. What is the value of `!!frozen`?

37. What is the advantage of using the type `boolean` rather than strings `"false"`/`"true"` or integers 0/1?

Practice It Now you can try these exercises at the end of the chapter: R5.30, E5.23, E5.24.

Common Error 5.4

Combining Multiple Relational Operators

Consider the expression

```
if (0 <= temp <= 100) // Error
```

This looks just like the mathematical test $0 \leq \texttt{temp} \leq 100$. But in Java, it is a compile-time error.

Let us dissect the condition. The first half, `0 <= temp`, is a test with an outcome `true` or `false`. The outcome of that test (`true` or `false`) is then compared against 100. This seems to make no sense. Is `true` larger than 100 or not? Can one compare truth values and numbers? In Java, you cannot. The Java compiler rejects this statement.

Instead, use `&&` to combine two separate tests:

```
if (0 <= temp && temp <= 100) . . .
```

Another common error, along the same lines, is to write

```
if (input == 1 || 2) . . . // Error
```

to test whether `input` is 1 or 2. Again, the Java compiler flags this construct as an error. You cannot apply the `||` operator to numbers. You need to write two Boolean expressions and join them with the `||` operator:

```
if (input == 1 || input == 2) . . .
```

Common Error 5.5

Confusing && and || Conditions

It is a surprisingly common error to confuse *and* and *or* conditions. A value lies between 0 and 100 if it is at least 0 *and* at most 100. It lies outside that range if it is less than 0 *or* greater than 100. There is no golden rule; you just have to think carefully.

Often the *and* or *or* is clearly stated, and then it isn't too hard to implement it. But sometimes the wording isn't as explicit. It is quite common that the individual conditions are nicely set apart in a bulleted list, but with little indication of how they should be combined.

Consider these instructions for filing a tax return. You can claim single filing status if any one of the following is true:

- You were never married.
- You were legally separated or divorced on the last day of the tax year.
- You were widowed, and did not remarry.

Because the test passes if *any one* of the conditions is true, you must combine the conditions with *or*.

Elsewhere, the same instructions state that you may use the more advantageous status of married filing jointly if all five of the following conditions are true:

- Your spouse died less than two years ago and you did not remarry.
- You have a child whom you can claim as dependent.
- That child lived in your home for all of the tax year.
- You paid over half the cost of keeping up your home for this child.
- You filed a joint return with your spouse the year he or she died.

Because *all* of the conditions must be true for the test to pass, you must combine them with an *and*.

Special Topic 5.6

Short-Circuit Evaluation of Boolean Operators

The && and || operators are computed using short-circuit evaluation. In other words, logical expressions are evaluated from left to right, and evaluation stops as soon as the truth value is determined. When an && is evaluated and the first condition is false, the second condition is not evaluated, because it does not matter what the outcome of the second test is.

The && and || operators are computed using *short-circuit evaluation:* As soon as the truth value is determined, no further conditions are evaluated.

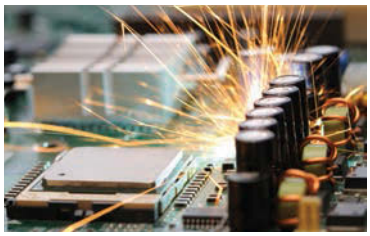
For example, consider the expression

```
quantity > 0 && price / quantity < 10
```

Suppose the value of `quantity` is zero. Then the test `quantity > 0` fails, and the second test is not attempted. That is just as well, because it is illegal to divide by zero.

Similarly, when the first condition of an || expression is true, then the remainder is not evaluated because the result must be true.

This process is called **short-circuit evaluation**.



In a short circuit, electricity travels along the path of least resistance. Similarly, short-circuit evaluation takes the fastest path for computing the result of a Boolean expression.

Special Topic 5.7

De Morgan's Law

Humans generally have a hard time comprehending logical conditions with *not* operators applied to *and*/*or* expressions. **De Morgan's Law**, named after the logician Augustus De Morgan (1806–1871), can be used to simplify these Boolean expressions.

Suppose we want to charge a higher shipping rate if we don't ship within the continental United States:

```
if (!(country.equals("USA") && !state.equals("AK") && !state.equals("HI")))
{
   shippingCharge = 20.00;
}
```

This test is a little bit complicated, and you have to think carefully through the logic. When it is *not* true that the country is USA *and* the state is not Alaska *and* the state is not Hawaii, then charge $20.00. Huh? It is not true that some people won't be confused by this code.

The computer doesn't care, but it takes human programmers to write and maintain the code. Therefore, it is useful to know how to simplify such a condition.

De Morgan's Law has two forms: one for the negation of an *and* expression and one for the negation of an *or* expression:

De Morgan's Law tells you how to negate && and || conditions.

!(A && B)	is the same as	!A || !B
!(A || B)	is the same as	!A && !B

Pay particular attention to the fact that the *and* and *or* operators are *reversed* by moving the *not* inward. For example, the negation of "the state is Alaska *or* it is Hawaii",

```
!(state.equals("AK") || state.equals("HI"))
```

is "the state is not Alaska *and* it is not Hawaii":

```
!state.equals("AK") && !state.equals("HI")
```

Now apply the law to our shipping charge computation:

```
!(country.equals("USA")
   && !state.equals("AK")
   && !state.equals("HI"))
```

is equivalent to

```
!country.equals("USA")
   || !!state.equals("AK")
   || !!state.equals("HI"))
```

Because two ! cancel each other out, the result is the simpler test

```
!country.equals("USA")
   || state.equals("AK")
   || state.equals("HI")
```

In other words, higher shipping charges apply when the destination is outside the United States or in Alaska or Hawaii.

To simplify conditions with negations of *and* or *or* expressions, it is usually a good idea to apply De Morgan's Law to move the negations to the innermost level.

5.8 Application: Input Validation

Tetra Images/Media Bakery.

Like a quality control worker, you want to make sure that user input is correct before processing it.

An important application for the `if` statement is *input validation*. Whenever your program accepts user input, you need to make sure that the user-supplied values are valid before you use them in your computations.

Consider our elevator simulation program. Assume that the elevator panel has buttons labeled 1 through 20 (but not 13). The following are illegal inputs:

- The number 13
- Zero or a negative number
- A number larger than 20
- An input that is not a sequence of digits, such as `five`

In each of these cases, we want to give an error message and exit the program. It is simple to guard against an input of 13:

```
if (floor == 13)
{
   System.out.println("Error: There is no thirteenth floor.");
}
```

Here is how you ensure that the user doesn't enter a number outside the valid range:

```
if (floor <= 0 || floor > 20)
{
   System.out.println("Error: The floor must be between 1 and 20.");
}
```

However, dealing with an input that is not a valid integer is a more serious problem. When the statement

```
floor = in.nextInt();
```

is executed, and the user types in an input that is not an integer (such as `five`), then the integer variable `floor` is not set. Instead, a run-time exception occurs and the program is terminated. To avoid this problem, you should first call the `hasNextInt` method

Call the hasNextInt or hasNextDouble method to ensure that the next input is a number.

which checks whether the next input is an integer. If that method returns true, you can safely call nextInt. Otherwise, print an error message and exit the program:

```
if (in.hasNextInt())
{
   int floor = in.nextInt();
   Process the input value.
}
else
{
   System.out.println("Error: Not an integer.");
}
```

Here is the complete elevator simulation program with input validation:

section_8/ElevatorSimulation2.java

```
1  import java.util.Scanner;
2
3  /**
4     This program simulates an elevator panel that skips the 13th floor, checking for
5     input errors.
6  */
7  public class ElevatorSimulation2
8  {
9     public static void main(String[] args)
10    {
11       Scanner in = new Scanner(System.in);
12       System.out.print("Floor: ");
13       if (in.hasNextInt())
14       {
15          // Now we know that the user entered an integer
16
17          int floor = in.nextInt();
18
19          if (floor == 13)
20          {
21             System.out.println("Error: There is no thirteenth floor.");
22          }
23          else if (floor <= 0 || floor > 20)
24          {
25             System.out.println("Error: The floor must be between 1 and 20.");
26          }
27          else
28          {
29             // Now we know that the input is valid
30
31             int actualFloor = floor;
32             if (floor > 13)
33             {
34                actualFloor = floor - 1;
35             }
36
37             System.out.println("The elevator will travel to the actual floor "
38                + actualFloor);
39          }
40       }
41       else
42       {
43          System.out.println("Error: Not an integer.");
44       }
```

```
45    }
46 }
```

Program Run

```
Floor: 13
Error: There is no thirteenth floor.
```

38. In the `ElevatorSimulation2` program, what is the output when the input is

a. 100?

b. –1?

c. 20?

d. thirteen?

39. Your task is to rewrite lines 19–26 of the `ElevatorSimulation2` program so that there is a single `if` statement with a complex condition. What is the condition?

```
if (. . .)
{
   System.out.println("Error: Invalid floor number");
}
```

40. In the Sherlock Holmes story "The Adventure of the Sussex Vampire", the inimitable detective uttered these words: "Matilda Briggs was not the name of a young woman, Watson, … It was a ship which is associated with the giant rat of Sumatra, a story for which the world is not yet prepared." Over a hundred years later, researchers found giant rats in Western New Guinea, another part of Indonesia.

Suppose you are charged with writing a program that processes rat weights. It contains the statements

```
System.out.print("Enter weight in kg: ");
double weight = in.nextDouble();
```

What input checks should you supply?

When processing inputs, you want to reject values that are too large. But how large is too large? These giant rats, found in Western New Guinea, are about five times the size of a city rat.

41. Run the following test program and supply inputs `2` and `three` at the prompts. What happens? Why?

```
import java.util.Scanner

public class Test
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      System.out.print("Enter an integer: ");
      int m = in.nextInt();
      System.out.print("Enter another integer: ");
      int n = in.nextInt();
      System.out.println(m + " " + n);
   }
}
```

Practice It Now you can try these exercises at the end of the chapter: R5.3, R5.33, E5.13.

Computing & Society 5.2 Artificial Intelligence

When one uses a sophisticated computer program such as a tax preparation package, one is bound to attribute some intelligence to the computer. The computer asks sensible questions and makes computations that we find a mental challenge. After all, if doing one's taxes were easy, we wouldn't need a computer to do it for us.

As programmers, however, we know that all this apparent intelligence is an illusion. Human programmers have carefully "coached" the software in all possible scenarios, and it simply replays the actions and decisions that were programmed into it.

Would it be possible to write computer programs that are genuinely intelligent in some sense? From the earliest days of computing, there was a sense that the human brain might be nothing but an immense computer, and that it might well be feasible to program computers to imitate some processes of human thought. Serious research into *artificial intelligence* began in the mid-1950s, and the first twenty years brought some impressive successes. Programs that play chess—surely an activity that appears to require remarkable intellectual powers—have become so good that they now routinely beat all but the best human players. As far back as 1975, an *expert-system* program called Mycin gained fame for being better in diagnosing meningitis in patients than the average physician.

From the very outset, one of the stated goals of the AI community was to produce software that could translate text from one language to another, for example from English to Russian. That undertaking proved to be enormously complicated. Human language appears to be much more subtle and interwoven with the human experience than had originally been thought. Systems such as Apple's Siri can answer common questions about the weather, appointments, and traffic. However, beyond a narrow range, they are more entertaining than useful.

In some areas, artificial intelligence technology has seen substantial advances. One of the most astounding examples is the outcome of a series of "grand challenges" for autonomous vehicles posed by the Defense Advanced Research Projects Agency (DARPA). Competitors were invited to submit a computer-controlled vehicle that had to complete an obstacle course without a human driver or remote control. The first event, in 2004, was a disappointment, with none of the entrants finishing the route. In 2005, five vehicles completed a grueling 212 km course in the Mojave desert. Stanford's Stanley came in first, with an average speed of 30 km/h. In 2007, DARPA moved the competition to an "urban" environment, an abandoned air force base. Vehicles had to be able to interact with each other, following California traffic laws. Self-driving cars are now tested on public roads in several states, and it is expected that they will become commercially available within a decade.

Vaughn Youtz/Zuma Press.

Winner of the 2007 DARPA Urban Challenge

When a system with artificial intelligence replaces a human in an activity such as giving medical advice or driving a vehicle, an important question arises. Who is responsible for mistakes? We accept that human doctors and drivers occasionally make mistakes with lethal consequences. Will we do the same for medical expert systems and self-driving cars?

CHAPTER SUMMARY

Use the `if` statement to implement a decision.

- The `if` statement allows a program to carry out different actions depending on the nature of the data to be processed.

Implement comparisons of numbers and objects.

- Use relational operators (`<` `<=` `>` `>=` `==` `!=`) to compare numbers.
- Relational operators compare values. The `==` operator tests for equality.
- When comparing floating-point numbers, don't test for equality. Instead, check whether they are close enough.
- Do not use the `==` operator to compare strings. Use the `equals` method instead.
- The `compareTo` method compares strings in lexicographic order.
- The `==` operator tests whether two object references are identical. To compare the contents of objects, you need to use the `equals` method.
- The `null` reference refers to no object.

Implement complex decisions that require multiple `if` statements.

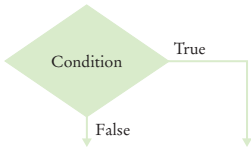
- Multiple `if` statements can be combined to evaluate complex decisions.
- When using multiple `if` statements, test general conditions after more specific conditions.

Implement decisions whose branches require further decisions.

- When a decision statement is contained inside the branch of another decision statement, the statements are *nested.*
- Nested decisions are required for problems that have two levels of decision making.

Draw flowcharts for visualizing the control flow of a program.

- Flow charts are made up of elements for tasks, input/output, and decisions.
- Each branch of a decision can contain tasks and further decisions.
- Never point an arrow inside another branch.



Design test cases for your programs.

- Black-box testing describes a testing method that does not take the structure of the implementation into account.
- White-box testing uses information about the structure of a program.
- Code coverage is a measure of how many parts of a program have been tested.
- Boundary test cases are test cases that are at the boundary of acceptable inputs.
- It is a good idea to design test cases before implementing a program.
- Logging messages can be deactivated when testing is complete.

Use the Boolean data type to store and combine conditions that can be true or false.

- The Boolean type `boolean` has two values, `false` and `true`.
- Java has two Boolean operators that combine conditions: `&&` (*and*) and `||` (*or*).
- To invert a condition, use the `!` (*not*) operator.
- The `&&` and `||` operators are computed using **short-circuit evaluation**: As soon as the truth value is determined, no further conditions are evaluated.
- De Morgan's Law tells you how to negate `&&` and `||` conditions.

Apply `if` statements to detect whether user input is valid.

- Call the `hasNextInt` or `hasNextDouble` method to ensure that the next input is a number.

STANDARD LIBRARY ITEMS INTRODUCED IN THIS CHAPTER

```
java.awt.Rectangle
   equals
java.lang.String
   equals
   compareTo
java.util.Scanner
   hasNextDouble
   hasNextInt
java.util.logging.Level
   INFO
   OFF
java.util.logging.Logger
   getGlobal
   info
   setLevel
```

REVIEW EXERCISES

■ **R5.1** What is the value of each variable after the `if` statement?

a.
```
int n = 1; int k = 2; int r = n;
if (k < n) { r = k; }
```

b.
```
int n = 1; int k = 2; int r;
if (n < k) { r = k; }
else { r = k + n; }
```

c.
```
int n = 1; int k = 2; int r = k;
if (r < k) { n = r; }
else { k = n; }
```

d.
```
int n = 1; int k = 2; int r = 3;
if (r < n + k) { r = 2 * n; }
else { k = 2 * r; }
```

■■ **R5.2** Explain the difference between

```
s = 0;
if (x > 0) { s++; }
if (y > 0) { s++; }
```

and

```
s = 0;
if (x > 0) { s++; }
else if (y > 0) { s++; }
```

■■ **R5.3** Find the errors in the following `if` statements.

a.
```
if x > 0 then System.out.print(x);
```

b.
```
if (1 + x > Math.pow(x, Math.sqrt(2)) { y = y + x; }
```

c.
```
if (x = 1) { y++; }
```

d.
```
x = in.nextInt();
if (in.hasNextInt())
{
   sum = sum + x;
}
else
{
   System.out.println("Bad input for x");
}
```

e.
```
String letterGrade = "F";
if (grade >= 90) { letterGrade = "A"; }
if (grade >= 80) { letterGrade = "B"; }
if (grade >= 70) { letterGrade = "C"; }
if (grade >= 60) { letterGrade = "D"; }
```

■ **R5.4** What do these code fragments print?

a.
```
int n = 1;
int m = -1;
if (n < -m) { System.out.print(n); }
else { System.out.print(m); }
```

b.
```
int n = 1;
int m = -1;
if (-n >= m) { System.out.print(n); }
else { System.out.print(m); }
```

c.
```
double x = 0;
double y = 1;
if (Math.abs(x - y) < 1) { System.out.print(x); }
else { System.out.print(y); }
```

d.
```
double x = Math.sqrt(2);
double y = 2;
if (x * x == y) { System.out.print(x); }
else { System.out.print(y); }
```

■■ **R5.5** Suppose `x` and `y` are variables of type `double`. Write a code fragment that sets `y` to `x` if `x` is positive and to 0 otherwise.

■■ **R5.6** Suppose `x` and `y` are variables of type `double`. Write a code fragment that sets `y` to the absolute value of `x` without calling the `Math.abs` function. Use an `if` statement.

■■ **R5.7** Explain why it is more difficult to compare floating-point numbers than integers. Write Java code to test whether an integer `n` equals 10 and whether a floating-point number `x` is approximately equal to 10.

■■ **R5.8** Given two pixels on a computer screen with integer coordinates (x_1, y_1) and (x_2, y_2), write conditions to test whether they are

a. The same pixel.

b. Very close together (with distance < 5).

■ **R5.9** It is easy to confuse the = and == operators. Write a test program containing the statement

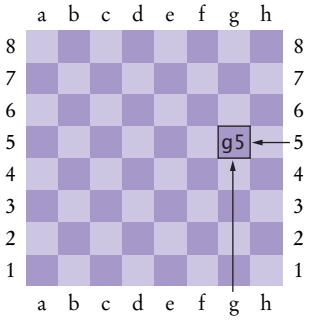
```
if (floor = 13)
```

What error message do you get? Write another test program with the statement

```
count == 0;
```

What does your compiler do when you compile the program?

■■ **R5.10** Each square on a chess board can be described by a letter and number, such as `g5` in the example at right.



The following pseudocode describes an algorithm that determines whether a square with a given letter and number is dark (black) or light (white).

```
If the letter is an a, c, e, or g
   If the number is odd
      color = "black"
   Else
      color = "white"
Else
   If the number is even
      color = "black"
   Else
      color = "white"
```

Using the procedure in Programming Tip 5.5, trace this pseudocode with input `g5`.

■■ **Testing R5.11** Give a set of four test cases for the algorithm of Exercise R5.10 that covers all branches.

■■ **R5.12** In a scheduling program, we want to check whether two appointments overlap. For simplicity, appointments start at a full hour, and we use military time (with hours 0–23). The following pseudocode describes an algorithm that determines whether the appointment with start time **start1** and end time **end1** overlaps with the appointment with start time **start2** and end time **end2**.

```
If start1 > start2
   s = start1
Else
   s = start2
If end1 < end2
   e = end1
Else
   e = end2
If s < e
   The appointments overlap.
Else
   The appointments don't overlap.
```

Trace this algorithm with an appointment from 10–12 and one from 11–13, then with an appointment from 10–11 and one from 12–13.

■ **R5.13** Draw a flow chart for the algorithm in Exercise R5.12.

■ **R5.14** Draw a flow chart for the algorithm in Exercise E5.14.

■ **R5.15** Draw a flow chart for the algorithm in Exercise E5.15.

■■ **Testing R5.16** Develop a set of test cases for the algorithm in Exercise R5.12.

■■ **Testing R5.17** Develop a set of test cases for the algorithm in Exercise E5.15.

■■ **R5.18** Write pseudocode for a program that prompts the user for a month and day and prints out whether it is one of the following four holidays:

- New Year's Day (January 1)
- Independence Day (July 4)
- Veterans Day (November 11)
- Christmas Day (December 25)

■■ **R5.19** Write pseudocode for a program that assigns letter grades for a quiz, according to the following table:

```
Score    Grade
90-100     A
80-89      B
70-79      C
60-69      D
 < 60      F
```

■■ **R5.20** Explain how the lexicographic ordering of strings in Java differs from the ordering of words in a dictionary or telephone book. *Hint:* Consider strings such as `IBM`, `wiley.com`, `Century 21`, and `While-U-Wait`.

■■ **R5.21** Of the following pairs of strings, which comes first in lexicographic order?

a. `"Tom", "Jerry"`
b. `"Tom", "Tomato"`
c. `"church", "Churchill"`
d. `"car manufacturer", "carburetor"`
e. `"Harry", "hairy"`
f. `"Java", " Car"`
g. `"Tom", "Tom"`
h. `"Car", "Carl"`
i. `"car", "bar"`

■ **R5.22** Explain the difference between an `if/else if/else` sequence and nested `if` statements. Give an example of each.

■■ **R5.23** Give an example of an `if/else if/else` sequence where the order of the tests does not matter. Give an example where the order of the tests matters.

■ **R5.24** Rewrite the condition in Section 5.3 to use `<` operators instead of `>=` operators. What is the impact on the order of the comparisons?

■■ **Testing R5.25** Give a set of test cases for the tax program in Exercise P5.2. Manually compute the expected results.

■ **R5.26** Make up a Java code example that shows the dangling `else` problem using the following statement: A student with a GPA of at least 1.5, but less than 2, is on probation. With less than 1.5, the student is failing.

■■■ **R5.27** Complete the following truth table by finding the truth values of the Boolean expressions for all combinations of the Boolean inputs `p`, `q`, and `r`.

p	q	r	(p && q) || !r	!(p && (q || !r))
false	false	false		
false	false	true		
false	true	false		
. . .				
5 more combinations				
. . .				

■■■ **R5.28** True or false? *A* && *B* is the same as *B* && *A* for any Boolean conditions *A* and *B*.

■ **R5.29** The "advanced search" feature of many search engines allows you to use Boolean operators for complex queries, such as "(cats OR dogs) AND NOT pets". Contrast these search operators with the Boolean operators in Java.

■■ **R5.30** Suppose the value of `b` is `false` and the value of `x` is `0`. What is the value of each of the following expressions?

a. `b && x == 0`
b. `b || x == 0`
c. `!b && x == 0`
d. `!b || x == 0`
e. `b && x != 0`
f. `b || x != 0`
g. `!b && x != 0`
h. `!b || x != 0`

■■ **R5.31** Simplify the following expressions. Here, `b` is a variable of type `boolean`.

a. `b == true`
b. `b == false`
c. `b != true`
d. `b != false`

■■■ **R5.32** Simplify the following statements. Here, `b` is a variable of type `boolean` and `n` is a variable of type `int`.

a. `if (n == 0) { b = true; } else { b = false; }`
(Hint: What is the value of `n == 0`?)
b. `if (n == 0) { b = false; } else { b = true; }`
c. `b = false; if (n > 1) { if (n < 2) { b = true; } }`
d. `if (n < 1) { b = true; } else { b = n > 2; }`

■ **R5.33** What is wrong with the following program?

```
System.out.print("Enter the number of quarters: ");
int quarters = in.nextInt();
if (in.hasNextInt())
{
   total = total + quarters * 0.25;
   System.out.println("Total: " + total);
}
else
{
   System.out.println("Input error.");
}
```

PRACTICE EXERCISES

■ **E5.1** Write a program that reads an integer and prints whether it is negative, zero, or positive.

■■ **E5.2** Write a program that reads a floating-point number and prints "zero" if the number is zero. Otherwise, print "positive" or "negative". Add "small" if the absolute value of the number is less than 1, or "large" if it exceeds 1,000,000.

■■ **E5.3** Write a program that reads an integer and prints how many digits the number has, by checking whether the number is ≥ 10, ≥ 100, and so on. (Assume that all integers are less than ten billion.) If the number is negative, first multiply it with –1.

■■ **E5.4** Write a program that reads three numbers and prints "all the same" if they are all the same, "all different" if they are all different, and "neither" otherwise.

■■ **E5.5** Write a program that reads three numbers and prints "increasing" if they are in increasing order, "decreasing" if they are in decreasing order, and "neither" otherwise. Here, "increasing" means "strictly increasing", with each value larger than its predecessor. The sequence 3 4 4 would not be considered increasing.

■■ **E5.6** Repeat Exercise E5.5, but before reading the numbers, ask the user whether increasing/decreasing should be "strict" or "lenient". In lenient mode, the sequence 3 4 4 is increasing and the sequence 4 4 4 is both increasing and decreasing.

■■ **E5.7** Write a program that reads in three integers and prints "in order" if they are sorted in ascending *or* descending order, or "not in order" otherwise. For example,

```
1 2 5   in order
1 5 2   not in order
5 2 1   in order
1 2 2   in order
```

■■ **E5.8** Write a program that reads four integers and prints "two pairs" if the input consists of two matching pairs (in some order) and "not two pairs" otherwise. For example,

```
1 2 2 1   two pairs
1 2 2 3   not two pairs
2 2 2 2   two pairs
```

■■ **E5.9** A compass needle points a given number of degrees away from North, measured clockwise. Write a program that reads the angle and prints out the nearest compass direction; one of N, NE, E, SE, S, SW, W, NW. In the case of a tie, prefer the nearest principal direction (N, E, S, or W).

■■ **Business E5.10** Write a program that reads in the name and salary of an employee. Here the salary will denote an *hourly* wage, such as $9.25. Then ask how many hours the employee worked in the past week. Be sure to accept fractional hours. Compute the pay. Any overtime work (over 40 hours per week) is paid at 150 percent of the regular wage. Print a paycheck for the employee. In your solution, implement a class `Paycheck`.

■ **E5.11** Write a program that reads a temperature value and the letter C for Celsius or F for Fahrenheit. Print whether water is liquid, solid, or gaseous at the given temperature at sea level.

■ **E5.12** The boiling point of water drops by about one degree centigrade for every 300 meters (or 1,000 feet) of altitude. Improve the program of Exercise E5.11 to allow the user to supply the altitude in meters or feet.

■ **E5.13** Add error handling to Exercise E5.12. If the user does not enter a number when expected, or provides an invalid unit for the altitude, print an error message and end the program.

■■ **E5.14** When two points in time are compared, each given as hours (in military time, ranging from 0 and 23) and minutes, the following pseudocode determines which comes first.

```
If hour1 < hour2
   time1 comes first.
Else if hour1 and hour2 are the same
   If minute1 < minute2
      time1 comes first.
   Else if minute1 and minute2 are the same
      time1 and time2 are the same.
   Else
      time2 comes first.
Else
   time2 comes first.
```

Write a program that prompts the user for two points in time and prints the time that comes first, then the other time. In your program, supply a class `Time` and a method

```
public int compareTo(Time other)
```

that returns –1 if the time comes before the other, 0 if both are the same, and 1 otherwise.

■■ **E5.15** The following algorithm yields the season (Spring, Summer, Fall, or Winter) for a given month and day.

```
If month is 1, 2, or 3, season = "Winter"
Else if month is 4, 5, or 6, season = "Spring"
Else if month is 7, 8, or 9, season = "Summer"
Else if month is 10, 11, or 12, season = "Fall"
If month is divisible by 3 and day >= 21
   If season is "Winter", season = "Spring"
   Else if season is "Spring", season = "Summer"
   Else if season is "Summer", season = "Fall"
   Else season = "Winter"
```

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Write a program that prompts the user for a month and day and then prints the season, as determined by this algorithm. Use a class `Date` with a method `getSeason`.

■■ **E5.16** Write a program that translates a letter grade into a number grade. Letter grades are A, B, C, D, and F, possibly followed by + or –. Their numeric values are 4, 3, 2, 1, and 0. There is no F+ or F–. A + increases the numeric value by 0.3, a – decreases it by 0.3. However, an A+ has value 4.0.

```
Enter a letter grade: B-
The numeric value is 2.7.
```

Use a class `Grade` with a method `getNumericGrade`.

■■ **E5.17** Write a program that translates a number between 0 and 4 into the closest letter grade. For example, the number 2.8 (which might have been the average of several grades) would be converted to B–. Break ties in favor of the better grade; for example 2.85 should be a B.

Use a class `Grade` with a method `getNumericGrade`.

■■ **E5.18** The original U.S. income tax of 1913 was quite simple. The tax was

- 1 percent on the first $50,000.
- 2 percent on the amount over $50,000 up to $75,000.
- 3 percent on the amount over $75,000 up to $100,000.
- 4 percent on the amount over $100,000 up to $250,000.
- 5 percent on the amount over $250,000 up to $500,000.
- 6 percent on the amount over $500,000.

There was no separate schedule for single or married taxpayers. Write a program that computes the income tax according to this schedule.

■■ **E5.19** Write a program that takes user input describing a playing card in the following shorthand notation:

`A`	Ace
`2 ... 10`	Card values
`J`	Jack
`Q`	Queen
`K`	King
`D`	Diamonds
`H`	Hearts
`S`	Spades
`C`	Clubs

Your program should print the full description of the card. For example,

```
Enter the card notation: QS
Queen of Spades
```

Implement a class `Card` whose constructor takes the card notation string and whose `getDescription` method returns a description of the card. If the notation string is not in the correct format, the `getDescription` method should return the string `"Unknown"`.

■■ **E5.20** Write a program that reads in three floating-point numbers and prints the largest of the three inputs. For example:

```
Please enter three numbers: 4 9 2.5
The largest number is 9.
```

■■ **E5.21** Write a program that reads in three strings and sorts them lexicographically.

```
Enter three strings: Charlie Able Baker
Able
Baker
Charlie
```

■■ **E5.22** Write a program that reads in two floating-point numbers and tests whether they are the same up to two decimal places. Here are two sample runs.

```
Enter two floating-point numbers: 2.0 1.99998
They are the same up to two decimal places.
Enter two floating-point numbers: 2.0 1.98999
They are different.
```

■ **E5.23** Write a program that prompts the user to provide a single character from the alphabet. Print Vowel or Consonant, depending on the user input. If the user input is not a letter (between a and z or A and Z), or is a string of length > 1, print an error message.

■■ **E5.24** Write a program that asks the user to enter a month (1 for January, 2 for February, etc.) and then prints the number of days in the month. For February, print "28 days".

```
Enter a month: 5
30 days
```

Use a class `Month` with a method

```
public int getLength()
```

Do not use a separate `if/else` branch for each month. Use Boolean operators.

■ **Business E5.25** A supermarket awards coupons depending on how much a customer spends on groceries. For example, if you spend $50, you will get a coupon worth eight percent of that amount. The following table shows the percent used to calculate the coupon awarded for different amounts spent. Write a program that calculates and prints the value of the coupon a person can receive based on groceries purchased.

Here is a sample run:

```
Please enter the cost of your groceries: 14
You win a discount coupon of $ 1.12. (8% of your purchase)
```

Money Spent	Coupon Percentage
Less than $10	No coupon
From $10 to $60	8%
More than $60 to $150	10%
More than $150 to $210	12%
More than $210	14%

PROGRAMMING PROJECTS

■■ **P5.1** Write a program that prompts for the day and month of the user's birthday and then prints a horoscope. Make up fortunes for programmers, like this:

```
Please enter your birthday (month and day): 6 16
Gemini are experts at figuring out the behavior of complicated programs.
You feel where bugs are coming from and then stay one step ahead. Tonight,
your style wins approval from a tough critic.
```

Each fortune should contain the name of the astrological sign. (You will find the names and date ranges of the signs at a distressingly large number of sites on the Internet.) Use a class `Date` with a method `getFortune`.

■■ **P5.2** Write a program that computes taxes for the following schedule.

If your status is Single and if the taxable income is over	but not over	the tax is	of the amount over
$0	$8,000	10%	$0
$8,000	$32,000	$800 + 15%	$8,000
$32,000		$4,400 + 25%	$32,000
If your status is Married and if the taxable income is over	**but not over**	**the tax is**	**of the amount over**
$0	$16,000	10%	$0
$16,000	$64,000	$1,600 + 15%	$16,000
$64,000		$8,800 + 25%	$64,000

■■■ **P5.3** The `TaxReturn.java` program uses a simplified version of the 2008 U.S. income tax schedule. Look up the tax brackets and rates for the current year, for both single and married filers, and implement a program that computes the actual income tax.

■■■ **P5.4** *Unit conversion.* Write a unit conversion program that asks the users from which unit they want to convert (fl. oz, gal, oz, lb, in, ft, mi) and to which unit they want to convert (ml, l, g, kg, mm, cm, m, km). Reject incompatible conversions (such as gal → km). Ask for the value to be converted, then display the result:

```
Convert from? gal
Convert to? ml
Value? 2.5
2.5 gal = 9462.5 ml
```

■ **P5.5** Write a program that reads in the x- and y-coordinates of two corner points of a rectangle and then prints out whether the rectangle is a square, or is in "portrait" or "landscape" orientation.

■■ **P5.6** Write a program that reads in the x- and y-coordinates of three corner points of a triangle and prints out whether it has an obtuse angle, a right angle, or only acute angles.

■■■ **P5.7** Write a program that reads in the x- and y-coordinates of four corner points of a quadrilateral and prints out whether it is a square, a rectangle, a trapezoid, a rhombus, or none of those shapes.

■■■ **P5.8** A year with 366 days is called a leap year. Leap years are necessary to keep the calendar synchronized with the sun because the earth revolves around the sun once every 365.25 days. Actually, that figure is not entirely precise, and for all dates after 1582 the *Gregorian correction* applies. Usually years that are divisible by 4 are leap years, for example 1996. However, years that are divisible by 100 (for example, 1900) are not leap years, but years that are divisible by 400 are leap years (for example, 2000). Write a program that asks the user for a year and computes whether that year is a leap year. Provide a class `Year` with a method `isLeapYear`. Use a single `if` statement and Boolean operators.

■■■ **P5.9** *Roman numbers*. Write a program that converts a positive integer into the Roman number system. The Roman number system has digits

I	1
V	5
X	10
L	50
C	100
D	500
M	1,000

Numbers are formed according to the following rules:

a. Only numbers up to 3,999 are represented.

b. As in the decimal system, the thousands, hundreds, tens, and ones are expressed separately.

c. The numbers 1 to 9 are expressed as

I	1	IV	4	VII	7
II	2	V	5	VIII	8
III	3	VI	6	IX	9

As you can see, an I preceding a V or X is subtracted from the value, and you can never have more than three I's in a row.

d. Tens and hundreds are done the same way, except that the letters X, L, C and C, D, M are used instead of I, V, X, respectively.

Your program should take an input, such as 1978, and convert it to Roman numerals, MCMLXXVIII.

■■■ **P5.10** French country names are feminine when they end with the letter e, masculine otherwise, except for the following which are masculine even though they end with e:

- le Belize
- le Cambodge
- le Mexique
- le Mozambique
- le Zaïre
- le Zimbabwe

Write a program that reads the French name of a country and adds the article: le for masculine or la for feminine, such as le Canada or la Belgique.

However, if the country name starts with a vowel, use l'; for example, l'Afghanistan.

For the following plural country names, use les:

- les Etats-Unis
- les Pays-Bas

■■■ **Business P5.11** Write a program to simulate a bank transaction. There are two bank accounts: checking and savings. First, ask for the initial balances of the bank accounts; reject negative balances. Then ask for the transactions; options are deposit, withdrawal, and transfer. Then ask for the account; options are checking and savings. Reject transactions that overdraw an account. At the end, print the balances of both accounts.

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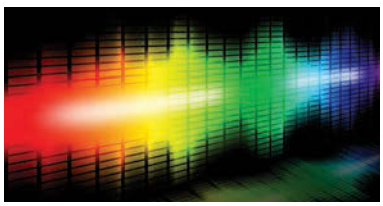
■■ Business P5.12 When you use an automated teller machine (ATM) with your bank card, you need to use a personal identification number (PIN) to access your account. If a user fails more than three times when entering the PIN, the machine will block the card. Assume that the user's PIN is "1234" and write a program that asks the user for the PIN no more than three times, and does the following:

- If the user enters the right number, print a message saying, "Your PIN is correct", and end the program.
- If the user enters a wrong number, print a message saying, "Your PIN is incorrect" and, if you have asked for the PIN less than three times, ask for it again.
- If the user enters a wrong number three times, print a message saying "Your bank card is blocked" and end the program.

■ Business P5.13 Calculating the tip when you go to a restaurant is not difficult, but your restaurant wants to suggest a tip according to the service diners receive. Write a program that calculates a tip according to the diner's satisfaction as follows:

- Ask for the diners' satisfaction level using these ratings: 1 = Totally satisfied, 2 = Satisfied, 3 = Dissatisfied.
- If the diner is totally satisfied, calculate a 20 percent tip.
- If the diner is satisfied, calculate a 15 percent tip.
- If the diner is dissatisfied, calculate a 10 percent tip.
- Report the satisfaction level and tip in dollars and cents.

■ Science P5.14 Write a program that prompts the user for a wavelength value and prints a description of the corresponding part of the electromagnetic spectrum, as given in the following table.


© drxy/iStockphoto.

Electromagnetic Spectrum		
Type	Wavelength (m)	Frequency (Hz)
Radio Waves	$> 10^{-1}$	$< 3 \times 10^{9}$
Microwaves	10^{-3} to 10^{-1}	3×10^{9} to 3×10^{11}
Infrared	7×10^{-7} to 10^{-3}	3×10^{11} to 4×10^{14}
Visible light	4×10^{-7} to 7×10^{-7}	4×10^{14} to 7.5×10^{14}
Ultraviolet	10^{-8} to 4×10^{-7}	7.5×10^{14} to 3×10^{16}
X-rays	10^{-11} to 10^{-8}	3×10^{16} to 3×10^{19}
Gamma rays	$< 10^{-11}$	$> 3 \times 10^{19}$

■ Science P5.15 Repeat Exercise P5.14, modifying the program so that it prompts for the frequency instead.

■■ Science P5.16 Repeat Exercise P5.14, modifying the program so that it first asks the user whether the input will be a wavelength or a frequency.

■■■ Science P5.17 A minivan has two sliding doors. Each door can be opened by either a dashboard switch, its inside handle, or its outside handle. However, the inside handles do not work if a child lock switch is activated. In order for the sliding doors to open, the gear shift must be in park, *and* the master unlock switch must be activated. (This book's author is the long-suffering owner of just such a vehicle.)

Your task is to simulate a portion of the control software for the vehicle. The input is a sequence of values for the switches and the gear shift, in the following order:

- Dashboard switches for left and right sliding door, child lock, and master unlock (0 for off or 1 for activated)
- Inside and outside handles on the left and right sliding doors (0 or 1)
- The gear shift setting (one of P N D 1 2 3 R).

A typical input would be `0 0 0 1 0 1 0 0 P`.

Print "left door opens" and/or "right door opens" as appropriate. If neither door opens, print "both doors stay closed".

■ Science P5.18 Sound level L in units of decibel (dB) is determined by

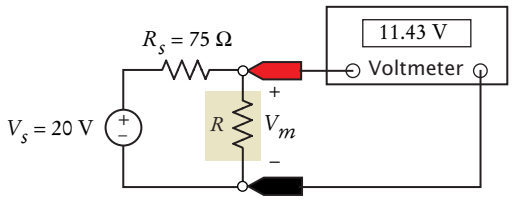
$$L = 20 \log_{10}(p/p_0)$$

where p is the sound pressure of the sound (in Pascals, abbreviated Pa), and p_0 is a reference sound pressure equal to 20×10^{-6} Pa (where L is 0 dB). The following table gives descriptions for certain sound levels.

Threshold of pain	130 dB
Possible hearing damage	120 dB
Jack hammer at 1 m	100 dB
Traffic on a busy roadway at 10 m	90 dB
Normal conversation	60 dB
Calm library	30 dB
Light leaf rustling	0 dB

Write a program that reads a value and a unit, either dB or Pa, and then prints the closest description from the list above.

■■ Science P5.19 The electric circuit shown below is designed to measure the temperature of the gas in a chamber.



The resistor R represents a temperature sensor enclosed in the chamber. The resistance R, in Ω, is related to the temperature T, in °C, by the equation

$$R = R_0 + kT$$

In this device, assume $R_0 = 100\ \Omega$ and $k = 0.5$. The voltmeter displays the value of the voltage, V_m, across the sensor. This voltage V_m indicates the temperature, T, of the gas according to the equation

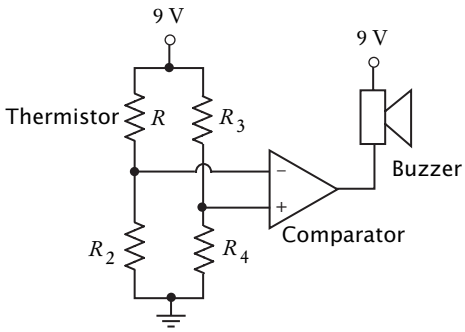
$$T = \frac{R}{k} - \frac{R_0}{k} = \frac{R_s}{k}\frac{V_m}{V_s - V_m} - \frac{R_0}{k}$$

Suppose the voltmeter voltage is constrained to the range $V_{\min} = 12$ volts $\le V_m \le V_{\max} = 18$ volts. Write a program that accepts a value of V_m and checks that it is between 12 and 18. The program should return the gas temperature in degrees Celsius when V_m is between 12 and 18 and an error message when it isn't.

■■■ Science P5.20 Crop damage due to frost is one of the many risks confronting farmers. The figure below shows a simple alarm circuit designed to warn of frost. The alarm circuit uses a device called a thermistor to sound a buzzer when the temperature drops below freezing. Thermistors are semiconductor devices that exhibit a temperature dependent resistance described by the equation

$$R = R_0 e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

where R is the resistance, in Ω, at the temperature T in °K, and R_0 is the resistance, in Ω, at the temperature T_0 in °K. β is a constant that depends on the material used to make the thermistor.



The circuit is designed so that the alarm will sound when

$$\frac{R_2}{R + R_2} < \frac{R_4}{R_3 + R_4}$$

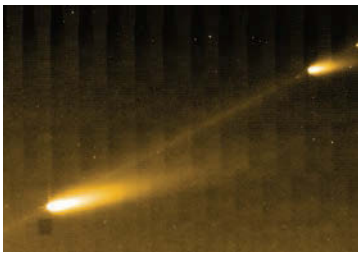
The thermistor used in the alarm circuit has $R_0 = 33{,}192\ \Omega$ at $T_0 = 40$ °C, and $\beta = 3{,}310$ °K. (Notice that β has units of °K. The temperature in °K is obtained by adding 273° to the temperature in °C.) The resistors R_2, R_3, and R_4 have a resistance of 156.3 kΩ = 156,300 Ω.

Write a Java program that prompts the user for a temperature in °F and prints a message indicating whether or not the alarm will sound at that temperature.

■ Science P5.21 A mass $m = 2$ kilograms is attached to the end of a rope of length $r = 3$ meters. The mass is whirled around at high speed. The rope can withstand a maximum tension of $T = 60$ Newtons. Write a program that accepts a rotation speed v and determines whether such a speed will cause the rope to break. *Hint:* $T = mv^2/r$.

■ **Science P5.22** A mass m is attached to the end of a rope of length $r = 3$ meters. The rope can only be whirled around at speeds of 1, 10, 20, or 40 meters per second. The rope can withstand a maximum tension of $T = 60$ Newtons. Write a program where the user enters the value of the mass m, and the program determines the greatest speed at which it can be whirled without breaking the rope. *Hint:* $T = mv^2/r$.

■■ **Science P5.23** The average person can jump off the ground with a velocity of 7 mph without fear of leaving the planet. However, if an astronaut jumps with this velocity while standing on Halley's Comet, will the astronaut ever come back down? Create a program that allows the user to input a launch velocity (in mph) from the surface of Halley's Comet and determine whether a jumper will return to the surface. If not, the program should calculate how much more massive the comet must be in order to return the jumper to the surface.



Courtesy NASA/JPL-Caltech.

Hint: Escape velocity is $v_{\text{escape}} = \sqrt{2\frac{GM}{R}}$, where $G = 6.67 \times 10^{-11} N\,m^2/kg^2$ is the gravitational constant, $M = 1.3 \times 10^{22} kg$ is the mass of Halley's comet, and $R = 1.153 \times 10^6 m$ is its radius.

ANSWERS TO SELF-CHECK QUESTIONS

1. Change the `if` statement to
```
if (floor > 14)
{
   actualFloor = floor - 2;
}
```
2. 85. 90. 85.
3. The only difference is if `originalPrice` is 100. The statement in Self Check 2 sets `discountedPrice` to 90; this one sets it to 80.
4. 95. 100. 95.
5.
```
if (fuelAmount < 0.10 * fuelCapacity)
{
   System.out.println("red");
}
else
{
   System.out.println("green");
}
```
6. (a) and (b) are both true, (c) is false.
7. `floor <= 13`
8. The values should be compared with ==, not =.
9. `input.equals("Y")`
10. `str.equals("")` or `str.length() == 0`
11. (a) 0; (b) 1; (c) An exception occurs.
12. Syntactically incorrect: e, g, h. Logically questionable: a, d, f.
13.
```
if (scoreA > scoreB)
{
   System.out.println("A won");
}
else if (scoreA < scoreB)
{
   System.out.println("B won");
}
else
{
   System.out.println("Game tied");
}
```
14.
```
if (x > 0) { s = 1; }
else if (x < 0) { s = -1; }
else { s = 0; }
```
15. You could first set `s` to one of the three values:
```
s = 0;
if (x > 0) { s = 1; }
else if (x < 0) { s = -1; }
```

16. The `if (price <= 100)` can be omitted (leaving just `else`), making it clear that the `else` branch is the sole alternative.

17. No destruction of buildings.

18. Add a branch before the final `else`:

```
else if (richter < 0)
{
   System.out.println("Error: Negative input");
}
```

19. 3200.

20. No. Then the computation is $0.10 \times 32000 + 0.25 \times (32000 - 32000)$.

21. No. Their individual tax is $5,200 each, and if they married, they would pay $10,400. Actually, taxpayers in higher tax brackets (which our program does not model) may pay higher taxes when they marry, a phenomenon known as the *marriage penalty*.

22. Change `else` in line 22 to

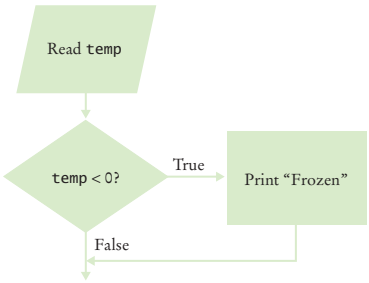
```
else if (maritalStatus.equals("N"))
```

and add another branch after line 25:

```
else
{
   System.out.println(
      "Error: Please answer Y or N.");
}
```

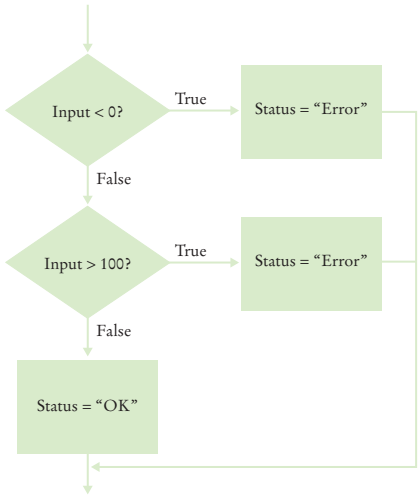
23. The higher tax rate is only applied on the income in the higher bracket. Suppose you are single and make $31,900. Should you try to get a $200 raise? Absolutely: you get to keep 90 percent of the first $100 and 75 percent of the next $100.

24.

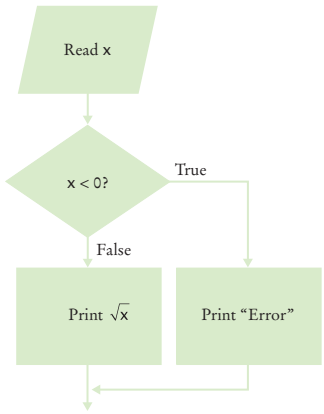


25. The "True" arrow from the first decision points into the "True" branch of the second decision, creating spaghetti code.

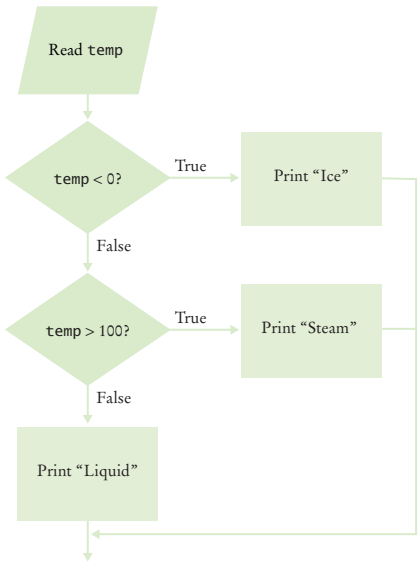
26. Here is one solution. In Section 5.7, you will see how you can combine the conditions for a more elegant solution.



27.



28.



29.

Test Case	Expected Output	Comment
12	12	Below 13th floor
14	13	Above 13th floor
13	?	The specification is not clear— See Section 5.8 for a version of this program with error handling

30. A boundary test case is a price of $128. A 16 percent discount should apply because the problem statement states that the larger discount applies if the price is *at least* $128. Thus, the expected output is $107.52.

31.

Test Case	Expected Output	Comment
9	Most structures fall	
7.5	Many buildings destroyed	
6.5	Many buildings ...	
5	Damage to poorly...	
3	No destruction...	
8.0	Most structures fall	Boundary case. In this program, boundary cases are not as significant because the behavior of an earthquake changes gradually.
-1		The specification is not clear—see Self Check 18 for a version of this program with error handling.

32.

Test Case	Expected Output	Comment
(0.5, 0.5)	inside	
(4, 2)	outside	
(0, 2)	on the boundary	Exactly on the boundary
(1.414, 1.414)	on the boundary	Close to the boundary
(0, 1.9)	inside	Not less than 1 mm from the boundary
(0, 2.1)	outside	Not less than 1 mm from the boundary

33. `x == 0 && y == 0`

34. `x == 0 || y == 0`

35. `(x == 0 && y != 0) || (y == 0 && x != 0)`

36. The same as the value of `frozen`.

37. You are guaranteed that there are no other values. With strings or integers, you would need to check that no values such as `"maybe"` or –1 enter your calculations.

38. (a) `Error: The floor must be between 1 and 20.`
(b) `Error: The floor must be between 1 and 20.`
(c) `19` (d) `Error: Not an integer.`

39. `floor == 13 || floor <= 0 || floor > 20`

40. Check for `in.hasNextDouble()`, to make sure a researcher didn't supply an input such as `oh my`. Check for `weight <= 0`, because any rat must surely have a positive weight. We don't know how giant a rat could be, but the New Guinea rats weighed no more than 2 kg. A regular house rat (*rattus rattus*) weighs up to 0.2 kg, so we'll say that any weight > 10 kg was surely an input error, perhaps confusing grams and kilograms. Thus, the checks are

```
if (in.hasNextDouble())
{
   double weight = in.nextDouble();
   if (weight < 0)
   {
      System.out.println(
         "Error: Weight cannot be negative.");
   }
   else if (weight > 10)
   {
      System.out.println(
         "Error: Weight > 10 kg.");
   }
   else
   {
      Process valid weight.
   }
}
else
}
   System.out.print("Error: Not a number");
}
```

41. The second input fails, and the program terminates without printing anything.

WORKED EXAMPLE 5.1 Extracting the Middle

Problem Statement Your task is to extract a string containing the middle character from a given string `str`. For example, if the string is `"crate"`, the result is the string `"a"`. However, if the string has an even number of letters, extract the middle two characters. If the string is `"crates"`, the result is `"at"`.

Step 1 Decide on the branching condition.

We need to take different actions for strings of odd and even length. Therefore, the condition is

Is the length of the string odd?

In Java, you use the remainder of division by 2 to find out whether a value is even or odd. Then the test becomes

str.length() % 2 == 1?

Step 2 Give pseudocode for the work that needs to be done when the condition is true.

We need to find the position of the middle character. If the length is 5, the position is 2.

c	r	a	t	e
0	1	2	3	4

In general,

position = str.length() / 2 (with the remainder discarded)
result = str.substring(position, position + 1)

Step 3 Give pseudocode for the work (if any) that needs to be done when the condition is *not* true.

Again, we need to find the position of the middle character. If the length is 6, the starting position is 2, and the ending position is 3. That is, we would call

result = str.substring(2, 4);

(Recall that the second parameter of the `substring` method is the first position that we do not extract.)

c	r	a	t	e	s
0	1	2	3	4	5

In general,

position = str.length() / 2 - 1
result = str.substring(position, position + 2)

Step 4 Double-check relational operators.

Do we really want `str.length() % 2 == 1`? For example, when the length is 5, `5 % 2` is the remainder of the division 5 / 2, which is 1. In general, dividing an odd number by 2 leaves a remainder of 1. (Actually, dividing a negative odd number by 2 leaves a remainder of –1, but the string length is never negative.) Therefore, our condition is correct.

Step 5 Remove duplication.

Here is the statement that we have developed:

```
If str.length() % 2 == 1
   position = str.length() / 2 (with remainder discarded)
   result = str.substring(position, position + 1)
Else
   position = str.length() / 2 - 1
   result = str.substring(position, position + 2)
```

The second statement in each branch is almost identical, but the length of the substring differs. Let's set the length in each branch:

```
If str.length() % 2 == 1
   position = str.length() / 2 (with remainder discarded)
   length = 1
Else
   position = str.length() / 2 - 1
   length = 2
result = str.substring(position, position + length)
```

Step 6 Test both branches.

We will use a different set of strings for testing. For an odd-length string, consider `"monitor"`. We get

```
position = str.length() / 2 = 7 / 2 = 3 (with remainder discarded)
length = 1
result = str.substring(3, 4) = "i"
```

For the even-length string `"monitors"`, we get

```
position = str.length() / 2 - 1 = 8 / 2 - 1 = 3 (with remainder discarded)
length = 2
result = str.substring(3, 5) = "it"
```

Step 7 Assemble the `if` statement in Java.

Here's the completed code segment:

```
if (str.length() % 2 == 1)
{
   position = str.length() / 2;
   length = 1;
}
else
{
   position = str.length() / 2 - 1;
   length = 2;
}
String result = str.substring(position, position + length);
```

You can find the complete program in the `ch05/worked_example_1` directory of the book's companion code.

CHAPTER 6

LOOPS

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CHAPTER GOALS

To implement `while`, `for`, and `do` loops

To hand-trace the execution of a program

To learn to use common loop algorithms

To understand nested loops

To implement programs that read and process data sets

To use a computer for simulations

To learn about the debugger

CHAPTER CONTENTS

In a loop, a part of a program is repeated over and over, until a specific goal is reached. Loops are important for calculations that require repeated steps and for processing input consisting of many data items. In this chapter, you will learn about loop statements in Java, as well as techniques for writing programs that process input and simulate activities in the real world.

6.1 The `while` Loop

In this section, you will learn about *loop statements* that repeatedly execute instructions until a goal has been reached.

Recall the investment problem from Chapter 1. You put $10,000 into a bank account that earns 5 percent interest per year. How many years does it take for the account balance to be double the original investment?

In Chapter 1 we developed the following algorithm for this problem:

Because the interest earned also earns interest, a bank balance grows exponentially.

Start with a year value of 0, a column for the interest, and a balance of $10,000.

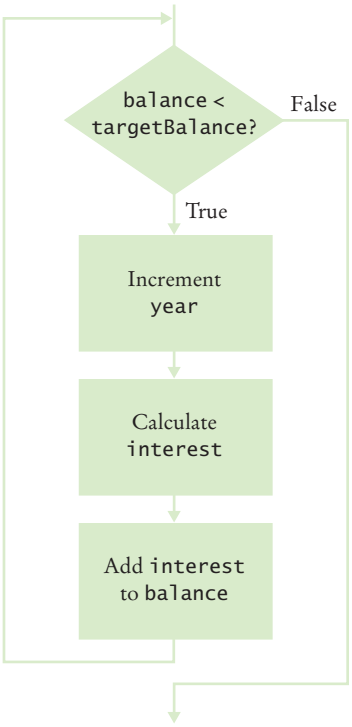
year	interest	balance
0		$10,000

Repeat the following steps while the balance is less than $20,000.
  Add 1 to the year value.
  Compute the interest as balance x 0.05 (i.e., 5 percent interest).
  Add the interest to the balance.
Report the final year value as the answer.

You now know how to declare and update the variables in Java. What you don't yet know is how to carry out "Repeat steps while the balance is less than $20,000".

In a particle accelerator, subatomic particles traverse a loop-shaped tunnel multiple times, gaining the speed required for physical experiments. Similarly, in computer science, statements in a loop are executed while a condition is true.

Figure 1 Flowchart of a `while` Loop



A loop executes instructions repeatedly while a condition is true.

In Java, the `while` statement implements such a repetition (see Syntax 6.1). It has the form

```
while (condition)
{
   statements
}
```

As long as the condition remains true, the statements inside the `while` statement are executed. These statements are called the **body** of the `while` statement.

In our case, we want to increment the year counter and add interest while the balance is less than the target balance of $20,000:

```
while (balance < targetBalance)
{
   year++;
   double interest = balance * RATE / 100;
   balance = balance + interest;
}
```

A `while` statement is an example of a **loop**. If you draw a flowchart, the flow of execution loops again to the point where the condition is tested (see Figure 1).

Syntax 6.1 `while` Statement

Syntax

```
while (condition)
{
   statements
}
```

```
double balance = 0;
.
.
.
while (balance < targetBalance)
{
   double interest = balance * RATE / 100;
   balance = balance + interest;
}
```

This variable is declared outside the loop and updated in the loop.

If the condition never becomes false, an infinite loop occurs. See page 244.

Beware of "off-by-one" errors in the loop condition. See page 244.

Don't put a semicolon here! See page 182.

This variable is created in each loop iteration.

These statements are executed while the condition is true.

Lining up braces is a good idea. See page 181.

Braces are not required if the body contains a single statement, but it's good to always use them. See page 181.

When you declare a variable *inside* the loop body, the variable is created for each iteration of the loop and removed after the end of each iteration. For example, consider the `interest` variable in this loop:

```
while (balance < targetBalance)
{
   year++;
   double interest = balance * RATE / 100;
   balance = balance + interest;
}
// interest no longer declared here
```

A new `interest` variable is created in each iteration.

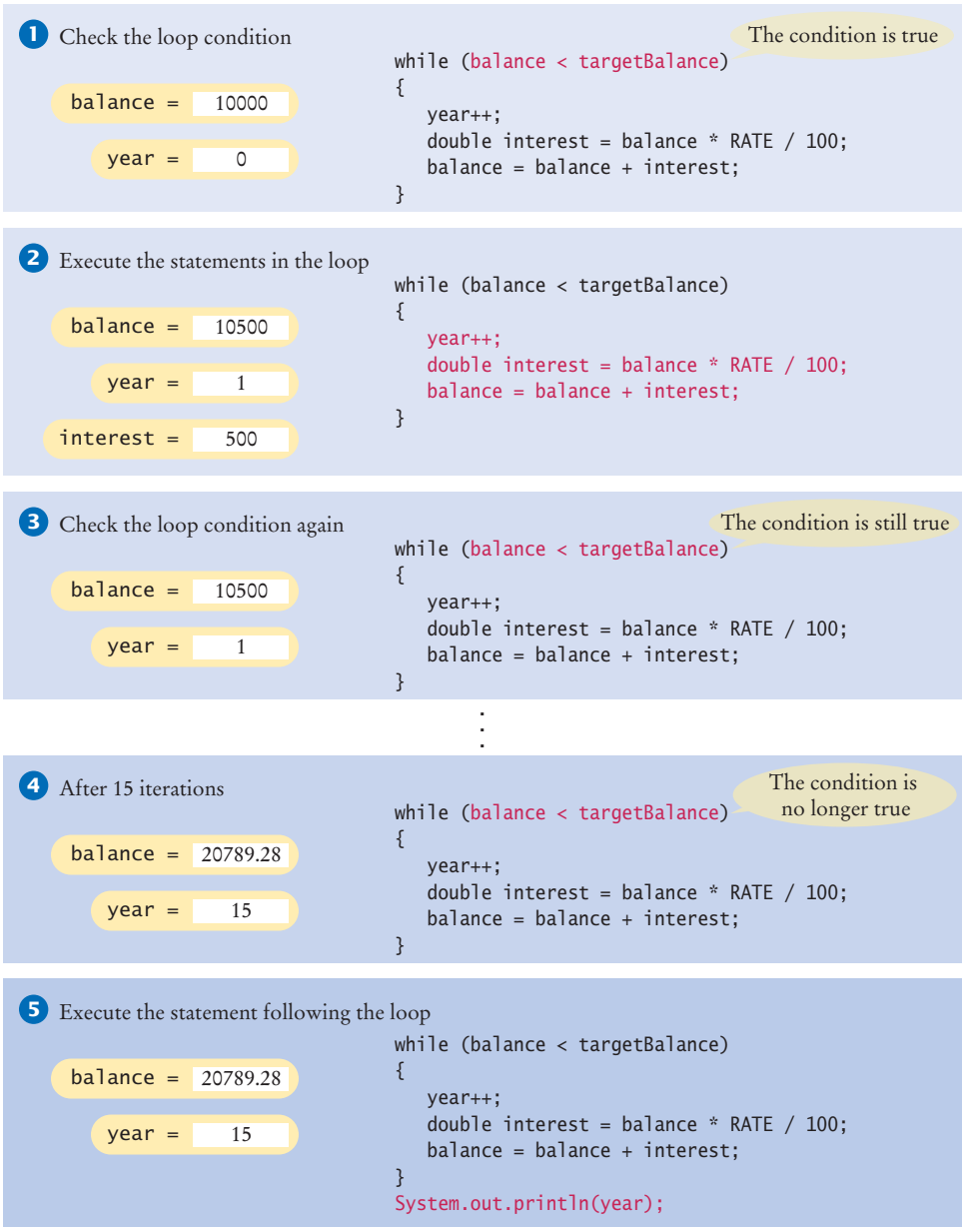


Figure 2 Execution of the `Investment` Loop

In contrast, the balance and year variables were declared outside the loop body. That way, the same variable is used for all iterations of the loop.

Here is the program that solves the investment problem. Figure 2 illustrates the program's execution.

section_1/Investment.java

```
1  /**
2     A class to monitor the growth of an investment that
3     accumulates interest at a fixed annual rate.
4  */
5  public class Investment
6  {
7     private double balance;
8     private double rate;
9     private int year;
10
11    /**
12       Constructs an Investment object from a starting balance and
13       interest rate.
14       @param aBalance the starting balance
15       @param aRate the interest rate in percent
16    */
17    public Investment(double aBalance, double aRate)
18    {
19       balance = aBalance;
20       rate = aRate;
21       year = 0;
22    }
23
24    /**
25       Keeps accumulating interest until a target balance has
26       been reached.
27       @param targetBalance the desired balance
28    */
29    public void waitForBalance(double targetBalance)
30    {
31       while (balance < targetBalance)
32       {
33          year++;
34          double interest = balance * rate / 100;
35          balance = balance + interest;
36       }
37    }
38
39    /**
40       Gets the current investment balance.
41       @return the current balance
42    */
43    public double getBalance()
44    {
45       return balance;
46    }
47
48    /**
49       Gets the number of years this investment has accumulated
50       interest.
51       @return the number of years since the start of the investment
```

```
52    */
53    public int getYears()
54    {
55       return year;
56    }
57 }
```

section_1/InvestmentRunner.java

```
1  /**
2     This program computes how long it takes for an investment
3     to double.
4  */
5  public class InvestmentRunner
6  {
7     public static void main(String[] args)
8     {
9        final double INITIAL_BALANCE = 10000;
10       final double RATE = 5;
11       Investment invest = new Investment(INITIAL_BALANCE, RATE);
12       invest.waitForBalance(2 * INITIAL_BALANCE);
13       int years = invest.getYears();
14       System.out.println("The investment doubled after "
15             + years + " years");
16    }
17 }
```

Program Run

```
The investment doubled after 15 years.
```

1. How many years does it take for the investment to triple? Modify the program and run it.
2. If the interest rate is 10 percent per year, how many years does it take for the investment to double? Modify the program and run it.
3. Modify the program so that the balance after each year is printed. How did you do that?
4. Suppose we change the program so that the condition of the `while` loop is

   ```
   while (balance <= targetBalance)
   ```

   What is the effect on the program? Why?
5. What does the following loop print?

   ```
   int n = 1;
   while (n < 100)
   {
      n = 2 * n;
      System.out.print(n + " ");
   }
   ```

Practice It Now you can try these exercises at the end of the chapter: R6.4, R6.8, E6.14.

Table 1 `while` Loop Examples

Loop	Output	Explanation

`i = 0; sum = 0;`
`while (sum < 10)`
`{`
`  i++; sum = sum + i;`
`  Print i and sum;`
`}`
	`1 1`
	`2 3`
	`3 6`
	`4 10`
		When `sum` is 10, the loop condition is false, and the loop ends.

`i = 0; sum = 0;`
`while (sum < 10)`
`{`
`  i++; sum = sum - i;`
`  Print i and sum;`
`}`
	`1 -1`
	`2 -3`
	`3 -6`
	`4 -10`
	`. . .`
		Because `sum` never reaches 10, this is an "infinite loop" (see Common Error 6.2 on page 244).

`i = 0; sum = 0;`
`while (sum < 0)`
`{`
`  i++; sum = sum - i;`
`  Print i and sum;`
`}`
	(No output)	The statement `sum < 0` is false when the condition is first checked, and the loop is never executed.

`i = 0; sum = 0;`
`while (sum >= 10)`
`{`
`  i++; sum = sum + i;`
`  Print i and sum;`
`}`
	(No output)	The programmer probably thought, "Stop when the sum is at least 10." However, the loop condition controls when the loop is executed, not when it ends (see Common Error 6.1 on page 243).

`i = 0; sum = 0;`
`while (sum < 10) ;`
`{`
`  i++; sum = sum + i;`
`  Print i and sum;`
`}`
	(No output, program does not terminate)	Note the semicolon before the `{`. This loop has an empty body. It runs forever, checking whether `sum < 10` and doing nothing in the body.

Common Error 6.1

Don't Think "Are We There Yet?"

When doing something repetitive, most of us want to know when we are done. For example, you may think, "I want to get at least $20,000," and set the loop condition to

```
balance >= targetBalance
```

But the `while` loop thinks the opposite: How long am I allowed to keep going? The correct loop condition is

```
while (balance < targetBalance)
```

In other words: "Keep at it while the balance is less than the target."

When writing a loop condition, don't ask, "Are we there yet?" The condition determines how long the loop will keep going.

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Common Error 6.2

Infinite Loops

A very annoying loop error is an *infinite loop:* a loop that runs forever and can be stopped only by killing the program or restarting the computer. If there are output statements in the program, then reams and reams of output flash by on the screen. Otherwise, the program just sits there and *hangs*, seeming to do nothing. On some systems, you can kill a hanging program by hitting Ctrl + C. On others, you can close the window in which the program runs.

A common reason for infinite loops is forgetting to update the variable that controls the loop:

Like this hamster who can't stop running in the treadmill, an infinite loop never ends.

```
int year = 1;
while (year <= 20)
{
   double interest = balance * RATE / 100;
   balance = balance + interest;
}
```

Here the programmer forgot to add a `year++` command in the loop. As a result, the year always stays at 1, and the loop never comes to an end.

Another common reason for an infinite loop is accidentally incrementing a counter that should be decremented (or vice versa). Consider this example:

```
int year = 20;
while (year > 0)
{
   double interest = balance * RATE / 100;
   balance = balance + interest;
   year++;
}
```

The `year` variable really should have been decremented, not incremented. This is a common error because incrementing counters is so much more common than decrementing that your fingers may type the `++` on autopilot. As a consequence, `year` is always larger than `0`, and the loop never ends. (Actually, `year` may eventually exceed the largest representable positive integer and *wrap around* to a negative number. Then the loop ends—of course, with a completely wrong result.)

Common Error 6.3

Off-by-One Errors

Consider our computation of the number of years that are required to double an investment:

```
int year = 0;
while (balance < targetBalance)
{
   year++;
   balance = balance * (1 + RATE / 100);
}
System.out.println("The investment doubled after "
   + year + " years.");
```

Should `year` start at `0` or at `1`? Should you test for `balance < targetBalance` or for `balance <= targetBalance`? It is easy to be *off by one* in these expressions.

Some people try to solve **off-by-one errors** by randomly inserting `+1` or `-1` until the program seems to work—a terrible strategy. It can take a long time to compile and test all the various possibilities. Expending a small amount of mental effort is a real time saver.

Fortunately, off-by-one errors are easy to avoid, simply by thinking through a couple of test cases and using the information from the test cases to come up with a rationale for your decisions.

An off-by-one error is a common error when programming loops. Think through simple test cases to avoid this type of error.

Should `year` start at `0` or at `1`? Look at a scenario with simple values: an initial balance of $100 and an interest rate of 50 percent. After year 1, the balance is $150, and after year 2 it is $225, or over $200. So the investment doubled after 2 years. The loop executed two times, incrementing `year` each time. Hence `year` must start at `0`, not at 1.

year	balance
0	$100
1	$150
2	$225

In other words, the `balance` variable denotes the balance after the end of the year. At the outset, the `balance` variable contains the balance after year `0` and not after year 1.

Next, should you use a `<` or `<=` comparison in the test? This is harder to figure out, because it is rare for the balance to be exactly twice the initial balance. There is one case when this happens, namely when the interest is 100 percent. The loop executes once. Now `year` is 1, and `balance` is exactly equal to `2 * INITIAL_BALANCE`. Has the investment doubled after one year? It has. Therefore, the loop should not execute again. If the test condition is `balance < targetBalance`, the loop stops, as it should. If the test condition had been `balance <= targetBalance`, the loop would have executed once more.

In other words, you keep adding interest while the balance *has not yet doubled*.

6.2 Problem Solving: Hand-Tracing

Hand-tracing is a simulation of code execution in which you step through instructions and track the values of the variables.

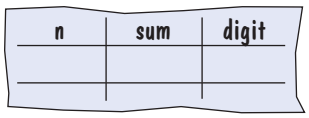
In Programming Tip 5.5, you learned about the method of hand-tracing. When you hand-trace code or pseudocode, you write the names of the variables on a sheet of paper, mentally execute each step of the code, and update the variables.

It is best to have the code written or printed on a sheet of paper. Use a marker, such as a paper clip, to mark the current line. Whenever a variable changes, cross out the old value and write the new value below. When a program produces output, also write down the output in another column.

Consider this example. What value is displayed?

```
int n = 1729;
int sum = 0;
while (n > 0)
{
   int digit = n % 10;
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum);
```

There are three variables: `n`, `sum`, and `digit`.



The first two variables are initialized with 1729 and 0 before the loop is entered.

```
int n = 1729;
int sum = 0;
while (n > 0)
{
   int digit = n % 10;
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum);
```

n	sum	digit
1729	0	

Because `n` is greater than zero, enter the loop. The variable `digit` is set to 9 (the remainder of dividing 1729 by 10). The variable `sum` is set to 0 + 9 = 9.

```
int n = 1729;
int sum = 0;
while (n > 0)
{
   int digit = n % 10;
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum);
```

n	sum	digit
1729	~~0~~	
	9	9

Finally in this iteration, `n` becomes 172. (Recall that the remainder in the division 1729 / 10 is discarded because both arguments are integers.)

Cross out the old values and write the new ones under the old ones.

```
int n = 1729;
int sum = 0;
while (n > 0)
{
   int digit = n % 10;
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum);
```

n	sum	digit
~~1729~~	~~0~~	
172	9	9

Now check the loop condition again.

```
int n = 1729;
int sum = 0;
while (n > 0)
{
   int digit = n % 10;
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum);
```

Because n is still greater than zero, repeat the loop. Now digit becomes 2, sum is set to 9 + 2 = 11, and n is set to 17.

n	sum	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
17	11	2

Repeat the loop once again, setting digit to 7, sum to 11 + 7 = 18, and n to 1.

n	sum	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
~~17~~	~~11~~	~~2~~
1	18	7

Enter the loop for one last time. Now digit is set to 1, sum to 19, and n becomes zero.

n	sum	digit
~~1729~~	~~0~~	
~~172~~	~~9~~	~~9~~
~~17~~	~~11~~	~~2~~
~~1~~	~~18~~	~~7~~
0	19	1

```
int n = 1729;
int sum = 0;
while (n > 0)
{
   int digit = n % 10;
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum);
```

Because n equals zero, this condition is not true.

The condition n > 0 is now false. Continue with the statement after the loop.

```
int n = 1729;
int sum = 0;
while (n > 0)
{
   int digit = n % 10;
   sum = sum + digit;
   n = n / 10;
}
System.out.println(sum);
```

n	sum	digit	output
~~1729~~	~~0~~		
~~172~~	~~9~~	~~9~~	
~~17~~	~~11~~	~~2~~	
~~1~~	~~18~~	~~7~~	
0	19	1	19

This statement is an output statement. The value that is output is the value of sum, which is 19.

Of course, you can get the same answer by just running the code. However, hand-tracing can give you an *insight* that you would not get if you simply ran the code. Consider again what happens in each iteration:

- We extract the last digit of `n`.
- We add that digit to `sum`.
- We strip the digit off `n`.

Hand-tracing can help you understand how an unfamiliar algorithm works.

In other words, the loop forms the sum of the digits in `n`. You now know what the loop does for any value of `n`, not just the one in the example. (Why would anyone want to form the sum of the digits? Operations of this kind are useful for checking the validity of credit card numbers and other forms of ID numbers.)

Hand-tracing can show errors in code or pseudocode.

Hand-tracing does not just help you understand code that works correctly. It is a powerful technique for finding errors in your code. When a program behaves in a way that you don't expect, get out a sheet of paper and track the values of the variables as you mentally step through the code.

You don't need a working program to do hand-tracing. You can hand-trace pseudocode. In fact, it is an excellent idea to hand-trace your pseudocode before you go to the trouble of translating it into actual code, to confirm that it works correctly.

6. Hand-trace the following code, showing the value of `n` and the output.

```
int n = 5;
while (n >= 0)
{
   n--;
   System.out.print(n);
}
```

7. Hand-trace the following code, showing the value of `n` and the output. What potential error do you notice?

```
int n = 1;
while (n <= 3)
{
   System.out.print(n + ", ");
   n++;
}
```

8. Hand-trace the following code, assuming that `a` is 2 and `n` is 4. Then explain what the code does for arbitrary values of `a` and `n`.

```
int r = 1;
int i = 1;
while (i <= n)
{
   r = r * a;
   i++;
}
```

9. Trace the following code. What error do you observe?

```
int n = 1;
while (n != 50)
{
   System.out.println(n);
   n = n + 10;
}
```

10. The following pseudocode is intended to count the number of digits in the number `n`:

```
count = 1
temp = n
while (temp > 10)
   Increment count.
   Divide temp by 10.0.
```

Trace the pseudocode for `n` = 123 and `n` = 100. What error do you find?

Practice It Now you can try these exercises at the end of the chapter: R6.6, R6.9.

Computing & Society 6.1 Digital Piracy

As you read this, you will have written a few computer programs and experienced firsthand how much effort it takes to write even the humblest of programs. Writing a real software product, such as a financial application or a computer game, takes a lot of time and money. Few people, and fewer companies, are going to spend that kind of time and money if they don't have a reasonable chance to make more money from their effort. (Actually, some companies give away their software in the hope that users will click on advertisements or upgrade to more elaborate paid versions. Other companies give away the software that enables users to read and use files but sell the software needed to create those files. Finally, there are individuals who donate their time, out of enthusiasm, and produce programs that you can copy freely.)

When selling software, a company must rely on the honesty of its customers. It is an easy matter for an unscrupulous person to make copies of computer programs without paying for them. In most countries that is illegal. Most governments provide legal protection, such as copyright laws and patents, to encourage the development of new products. Countries that tolerate widespread piracy have found that they have an ample cheap supply of foreign software, but no local manufacturers willing to design good software for their own citizens, such as word processors in the local script or financial programs adapted to the local tax laws.

When a mass market for software first appeared, vendors were enraged by the money they lost through piracy. They tried to fight back to ensure that only the legitimate owner could use the software by using various schemes, such as *dongles*—devices that must be attached to a printer port before the software will run. Legitimate users hated these measures. They paid for the software, but they had to suffer through inconveniences, such as having multiple dongles sticking out from their computer.

Because it is so easy and inexpensive to pirate software, and the chance of being found out is minimal, you have to make a moral choice for yourself. If a package that you would really like to have is too expensive for your budget, do you steal it, or do you stay honest and get by with a more affordable product?

Of course, piracy is not limited to software. The same issues arise for other digital products as well. You may have had the opportunity to obtain copies of songs or movies without payment. Or you may have been frustrated by a copy protection device on your music player that made it difficult for you to listen to songs that you paid for. Admittedly, it can be difficult to have a lot of sympathy for a musical ensemble whose publisher charges a lot of money for what seems to have been very little effort on their part, at least when compared to the effort that goes into designing and implementing a software package. Nevertheless, it seems only fair that artists and authors receive some compensation for their efforts.

How to pay artists, authors, and programmers fairly, without burdening honest customers, is an unsolved problem at the time of this writing, and many computer scientists are engaged in research in this area.

6.3 The for Loop

The for loop is used when a value runs from a starting point to an ending point with a constant increment or decrement.

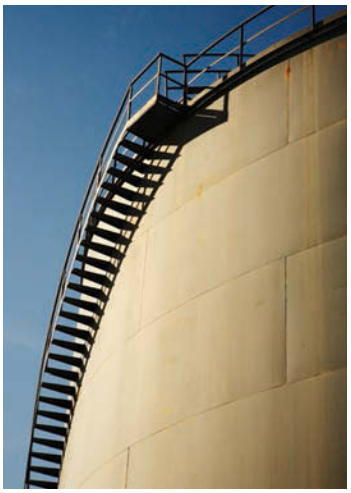
It often happens that you want to execute a sequence of statements a given number of times. You can use a `while` loop that is controlled by a counter, as in the following example:

```
int counter = 1; // Initialize the counter
while (counter <= 10) // Check the counter
{
   System.out.println(counter);
   counter++; // Update the counter
}
```

Because this loop type is so common, there is a special form for it, called the `for` loop (see Syntax 6.2).

```
for (int counter = 1; counter <= 10; counter++)
{
   System.out.println(counter);
}
```

Some people call this loop *count-controlled*. In contrast, the `while` loop of the preceding section can be called an *event-controlled* loop because it executes until an event occurs; namely that the balance reaches the target. Another commonly used term for a count-controlled loop is *definite*. You know from the outset that the loop body will be executed a definite number of times; ten times in our example. In contrast, you do not know how many iterations it takes to accumulate a target balance. Such a loop is called *indefinite*.



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You can visualize the `for` *loop as an orderly sequence of steps.*

Syntax 6.2 for Statement

Syntax

```
for (initialization; condition; update)
{
   statements
}
```

These three expressions should be related. See page 255.

This initialization happens once before the loop starts.

The condition is checked before each iteration.

This update is executed after each iteration.

```
for (int i = 5; i <= 10; i++)
{
   sum = sum + i;
}
```

The variable `i` is defined only in this `for` loop. See page 257.

This loop executes 6 times. See page 256.

The for loop neatly groups the initialization, condition, and update expressions together. However, it is important to realize that these expressions are not executed together (see Figure 3).

- The initialization is executed once, before the loop is entered. 1
- The condition is checked before each iteration. 2 5
- The update is executed after each iteration. 4

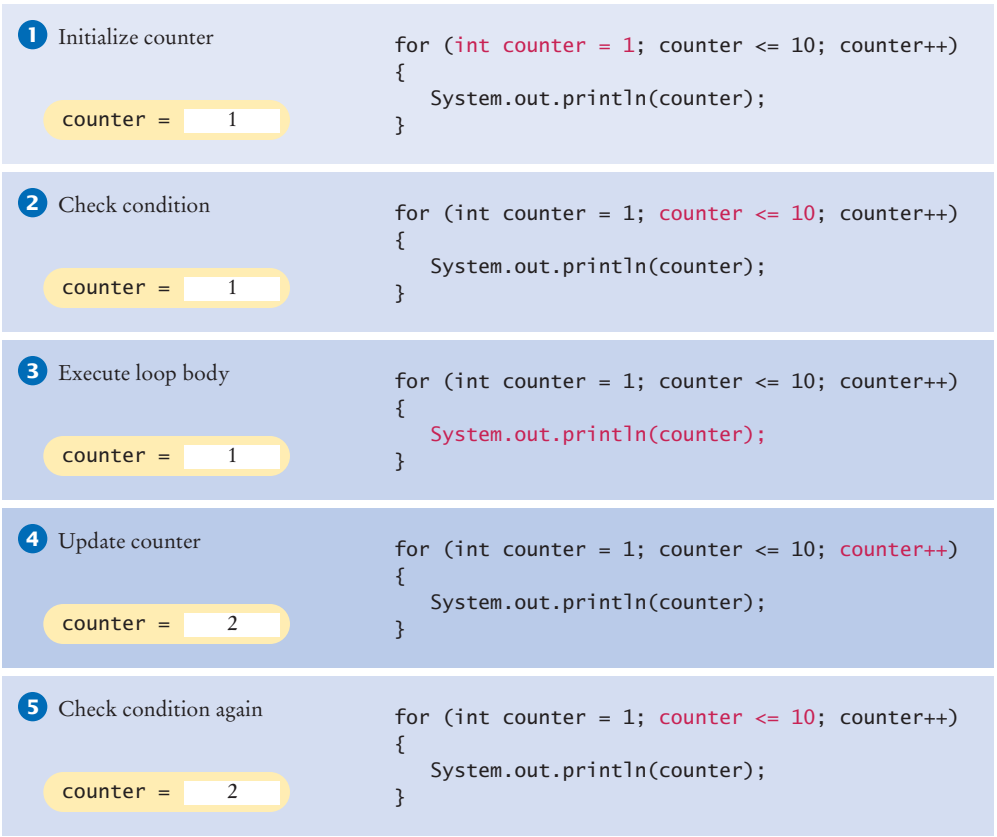

Figure 3 Execution of a for Loop

A for loop can count down instead of up:

```
for (int counter = 10; counter >= 0; counter--) . . .
```

The increment or decrement need not be in steps of 1:

```
for (int counter = 0; counter <= 10; counter = counter + 2) . . .
```

See Table 2 on page 254 for additional variations.

So far, we have always declared the counter variable in the loop initialization:

```
for (int counter = 1; counter <= 10; counter++)
{
   . . .
}
// counter no longer declared here
```

Such a variable is declared for all iterations of the loop, but you cannot use it after the loop. If you declare the `counter` variable before the loop, you can continue to use it after the loop:

```
int counter;
for (counter = 1; counter <= 10; counter++)
{
   . . .
}
// counter still declared here
```

A common use of the `for` loop is to traverse all characters of a string:

```
for (int i = 0; i < str.length(); i++)
{
   char ch = str.charAt(i);
   Process ch.
}
```

Note that the counter variable `i` starts at `0`, and the loop is terminated when `i` reaches the length of the string. For example, if `str` has length 5, `i` takes on the values `0`, 1, 2, 3, and 4. These are the valid positions in the string.

Here is another typical use of the `for` loop. We want to compute the growth of our savings account over a period of years, as shown in this table:

Year	Balance
1	10500.00
2	11025.00
3	11576.25
4	12155.06
5	12762.82

The `for` loop pattern applies because the variable `year` starts at 1 and then moves in constant increments until it reaches the target:

```
for (int year = 1; year <= numberOfYears; year++)
{
   Update balance.
}
```

Following is the complete program. Figure 4 shows the corresponding flowchart.

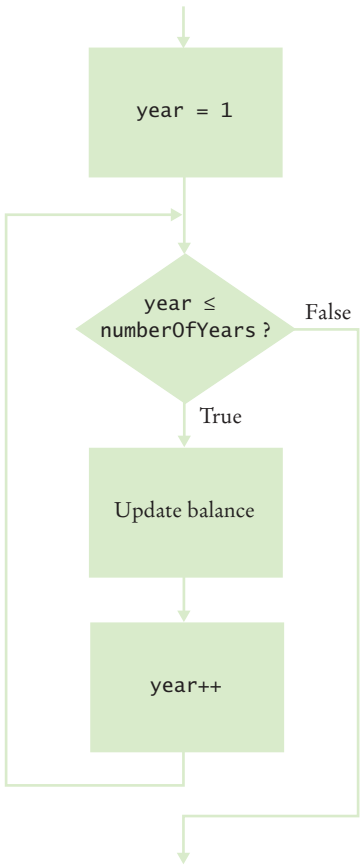

Figure 4 Flowchart of a for Loop

section_3/Investment.java

```
/**
   A class to monitor the growth of an investment that
   accumulates interest at a fixed annual rate.
*/
public class Investment
{
   private double balance;
   private double rate;
   private int year;

   /**
      Constructs an Investment object from a starting balance and
      interest rate.
      @param aBalance the starting balance
      @param aRate the interest rate in percent
   */
   public Investment(double aBalance, double aRate)
   {
      balance = aBalance;
      rate = aRate;
      year = 0;
   }

   /**
      Keeps accumulating interest until a target balance has
      been reached.
      @param targetBalance the desired balance
   */
   public void waitForBalance(double targetBalance)
   {
      while (balance < targetBalance)
      {
         year++;
         double interest = balance * rate / 100;
         balance = balance + interest;
      }
   }

   /**
      Keeps accumulating interest for a given number of years.
      @param numberOfYears the number of years to wait
   */
   public void waitYears(int numberOfYears)
   {
      for (int i = 1; i <= numberOfYears; i++)
      {
         double interest = balance * rate / 100;
         balance = balance + interest;
      }
      year = year + n;
   }

   /**
      Gets the current investment balance.
      @return the current balance
   */
   public double getBalance()
   {
```

```
59          return balance;
60       }
61
62       /**
63          Gets the number of years this investment has accumulated
64          interest.
65          @return the number of years since the start of the investment
66       */
67       public int getYears()
68       {
69          return year;
70       }
71    }
```

section_3/InvestmentRunner.java

```
1  /**
2     This program computes how much an investment grows in
3     a given number of years.
4  */
5  public class InvestmentRunner
6  {
7     public static void main(String[] args)
8     {
9        final double INITIAL_BALANCE = 10000;
10       final double RATE = 5;
11       final int YEARS = 20;
12       Investment invest = new Investment(INITIAL_BALANCE, RATE);
13       invest.waitYears(YEARS);
14       double balance = invest.getBalance();
15       System.out.printf("The balance after %d years is %.2f\n",
16             YEARS, balance);
17    }
18 }
```

Program Run

```
The balance after 20 years is 26532.98
```

Table 2 for Loop Examples

Loop	Values of i	Comment
`for (i = 0; i <= 5; i++)`	0 1 2 3 4 5	Note that the loop is executed 6 times. (See Programming Tip 6.3 on page 256.)
`for (i = 5; i >= 0; i--)`	5 4 3 2 1 0	Use `i--` for decreasing values.
`for (i = 0; i < 9; i = i + 2)`	0 2 4 6 8	Use `i = i + 2` for a step size of 2.
`for (i = 0; i != 9; i = i + 2)`	0 2 4 6 8 10 12 14 ... (infinite loop)	You can use < or <= instead of `!=` to avoid this problem.
`for (i = 1; i <= 20; i = i * 2)`	1 2 4 8 16	You can specify any rule for modifying `i`, such as doubling it in every step.
`for (i = 0; i < str.length(); i++)`	0 1 2 ... until the last valid index of the string `str`	In the loop body, use the expression `str.charAt(i)` to get the `i`th character.

11. Write the `for` loop of the `Investment` class as a `while` loop.
12. How many numbers does this loop print?

```
for (int n = 10; n >= 0; n--)
{
   System.out.println(n);
}
```

13. Write a `for` loop that prints all even numbers between 10 and 20 (inclusive).
14. Write a `for` loop that computes the sum of the integers from 1 to `n`.
15. How would you modify the `InvestmentRunner.java` program to print the balances after 20, 40, ..., 100 years?

Practice It Now you can try these exercises at the end of the chapter: R6.7, R6.13, E6.9, E6.13.

Programming Tip 6.1

Use `for` Loops for Their Intended Purpose Only

A `for` loop is an *idiom* for a loop of a particular form. A value runs from the start to the end, with a constant increment or decrement.

The compiler won't check whether the initialization, condition, and update expressions are related. For example, the following loop is legal:

```
// Confusing—unrelated expressions
for (System.out.print("Inputs: "); in.hasNextDouble(); sum = sum + x)
{
   x = in.nextDouble();
}
```

However, programmers reading such a `for` loop will be confused because it does not match their expectations. Use a `while` loop for iterations that do not follow the `for` idiom.

You should also be careful not to update the loop counter in the body of a `for` loop. Consider the following example:

```
for (int counter = 1; counter <= 100; counter++)
{
   if (counter % 10 == 0) // Skip values that are divisible by 10
   {
      counter++; // Bad style—you should not update the counter in a for loop
   }
   System.out.println(counter);
}
```

Updating the counter inside a `for` loop is confusing because the counter is updated *again* at the end of the loop iteration. In some loop iterations, `counter` is incremented once, in others twice. This goes against the intuition of a programmer who sees a `for` loop.

If you find yourself in this situation, you can either change from a `for` loop to a `while` loop, or implement the "skipping" behavior in another way. For example:

```
for (int counter = 1; counter <= 100; counter++)
{
   if (counter % 10 != 0) // Skip values that are divisible by 10
   {
      System.out.println(counter);
   }
}
```

Programming Tip 6.2

Choose Loop Bounds That Match Your Task

Suppose you want to print line numbers that go from 1 to 10. Of course, you will use a loop:

```
for (int i = 1; i <= 10; i++)
```

The values for `i` are bounded by the relation $1 \leq i \leq 10$. Because there are $\leq$ on both bounds, the bounds are called **symmetric bounds**.

When traversing the characters in a string, it is more natural to use the bounds

```
for (int i = 0; i < str.length(); i++)
```

In this loop, `i` traverses all valid positions in the string. You can access the `i`th character as `str.charAt(i)`. The values for `i` are bounded by $0 \leq i <$ `str.length()`, with a $\leq$ to the left and a $<$ to the right. That is appropriate, because `str.length()` is not a valid position. Such bounds are called **asymmetric bounds**.

In this case, it is not a good idea to use symmetric bounds:

```
for (int i = 0; i <= str.length() - 1; i++) // Use < instead
```

The asymmetric form is easier to understand.

Programming Tip 6.3

Count Iterations

Finding the correct lower and upper bounds for an iteration can be confusing. Should you start at 0 or at 1? Should you use `<= b` or `< b` as a termination condition?

Counting the number of iterations is a very useful device for better understanding a loop. Counting is easier for loops with asymmetric bounds. The loop

```
for (int i = a; i < b; i++)
```

is executed `b - a` times. For example, the loop traversing the characters in a string,

```
for (int i = 0; i < str.length(); i++)
```

runs `str.length()` times. That makes perfect sense, because there are `str.length()` characters in a string.

The loop with symmetric bounds,

```
for (int i = a; i <= b; i++)
```

is executed `b - a + 1` times. That "+1" is the source of many programming errors.

For example,

```
for (int i = 0; i <= 10; i++)
```

runs 11 times. Maybe that is what you want; if not, start at 1 or use `< 10`.

One way to visualize this "+1" error is by looking at a fence. Each section has one fence post to the left, and there is a final post on the right of the last section. Forgetting to count the last value is often called a "fence post error".

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How many posts do you need for a fence with four sections? It is easy to be "off by one" with problems such as this one.

Special Topic 6.1

Variables Declared in a for Loop Header

As mentioned, it is legal in Java to declare a variable in the header of a `for` loop. Here is the most common form of this syntax:

```
for (int i = 1; i <= n; i++)
{
   . . .
}

// i no longer defined here
```

The scope of the variable extends to the end of the `for` loop. Therefore, `i` is no longer defined after the loop ends. If you need to use the value of the variable beyond the end of the loop, then you need to declare it outside the loop. In this loop, you don't need the value of `i`—you know it is `n + 1` when the loop is finished. (Actually, that is not quite true—it is possible to break out of a loop before its end; see Special Topic 6.4 on page 263). When you have two or more exit conditions, though, you may still need the variable. For example, consider the loop

```
for (i = 1; balance < targetBalance && i <= n; i++)
{
   . . .
}
```

You want the balance to reach the target but you are willing to wait only a certain number of years. If the balance doubles sooner, you may want to know the value of `i`. Therefore, in this case, it is not appropriate to declare the variable in the loop header.

Note that the variables named `i` in the following pair of `for` loops are independent:

```
for (int i = 1; i <= 10; i++)
{
   System.out.println(i * i);
}

for (int i = 1; i <= 10; i++) // Declares a new variable i
{
   System.out.println(i * i * i);
}
```

In the loop header, you can declare multiple variables, as long as they are of the same type, and you can include multiple update expressions, separated by commas:

```
for (int i = 0, j = 10; i <= 10; i++, j--)
{
   . . .
}
```

However, many people find it confusing if a `for` loop controls more than one variable. I recommend that you not use this form of the `for` statement (see Programming Tip 6.1 on page 255). Instead, make the `for` loop control a single counter, and update the other variable explicitly:

```
int j = 10;
for (int i = 0; i <= 10; i++)
{
   . . .
   j--;
}
```

6.4 The do Loop

The do loop is appropriate when the loop body must be executed at least once.

Sometimes you want to execute the body of a loop at least once and perform the loop test after the body is executed. The `do` loop serves that purpose:

```
do
{
   statements
}
while (condition);
```

The body of the `do` loop is executed first, then the condition is tested.

Some people call such a loop a *post-test loop* because the condition is tested after completing the loop body. In contrast, `while` and `for` loops are *pre-test loops*. In those loop types, the condition is tested before entering the loop body.

A typical example for a `do` loop is input validation. Suppose you ask a user to enter a value < 100. If the user doesn't pay attention and enters a larger value, you ask again, until the value is correct. Of course, you cannot test the value until the user has entered it. This is a perfect fit for the `do` loop (see Figure 5):

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that illustrates the use of the `do` loop for input validation.

```
int value;
do
{
   System.out.print("Enter an integer < 100: ");
   value = in.nextInt();
}
while (value >= 100);
```

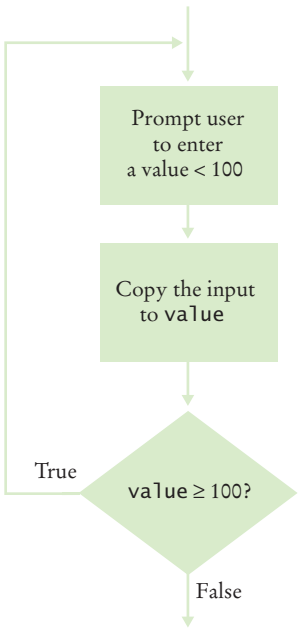


Figure 5 Flowchart of a `do` Loop

SELF CHECK

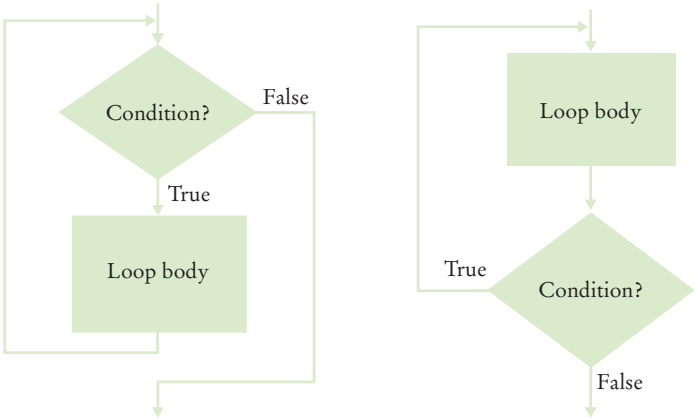
16. Suppose that we want to check for inputs that are at least 0 and at most 100. Modify the input validation `do` loop for this test.
17. Rewrite the input validation `do` loop using a `while` loop. What is the disadvantage of your solution?
18. Suppose Java didn't have a `do` loop. Could you rewrite any `do` loop as a `while` loop?
19. Write a `do` loop that reads integers and computes their sum. Stop when reading the value 0.
20. Write a `do` loop that reads integers and computes their sum. Stop when reading a zero or the same value twice in a row. For example, if the input is 1 2 3 4 4, then the sum is 14 and the loop stops.

Practice It Now you can try these exercises at the end of the chapter: R6.12, R6.19, R6.20.

Programming Tip 6.4

Flowcharts for Loops

In Section 5.5 you learned how to use flowcharts to visualize the flow of control in a program. There are two types of loops that you can include in a flowchart; they correspond to a `while` loop and a `do` loop in Java. They differ in the placement of the condition—either before or after the loop body.



As described in Section 5.5, you want to avoid "spaghetti code" in your flowcharts. For loops, that means that you never want to have an arrow that points inside a loop body.

6.5 Application: Processing Sentinel Values

In this section, you will learn how to write loops that read and process a sequence of input values.

A sentinel value denotes the end of a data set, but it is not part of the data.

Whenever you read a sequence of inputs, you need to have some method of indicating the end of the sequence. Sometimes you are lucky and no input value can be zero. Then you can prompt the user to keep entering numbers, or `0` to finish the sequence. If zero is allowed but negative numbers are not, you can use –1 to indicate termination.

Such a value, which is not an actual input, but serves as a signal for termination, is called a **sentinel**.

Let's put this technique to work in a program that computes the average of a set of salary values. In our sample program, we will use –1 as a sentinel. An employee would surely not work for a negative salary, but there may be volunteers who work for free.

In the military, a sentinel guards a border or passage. In computer science, a sentinel value denotes the end of an input sequence or the border between input sequences.

Inside the loop, we read an input. If the input is not –1, we process it. In order to compute the average, we need the total sum of all salaries, and the number of inputs.

```
salary = in.nextDouble();
if (salary != -1)
{
   sum = sum + salary;
   count++;
}
```

We stay in the loop while the sentinel value is not detected.

```
while (salary != -1)
{
   . . .
}
```

There is just one problem: When the loop is entered for the first time, no data value has been read. We must make sure to initialize `salary` with some value other than the sentinel:

```
double salary = 0;
// Any value other than –1 will do
```

After the loop has finished, we compute and print the average. Here is the complete program:

section_5/SentinelDemo.java

```
1  import java.util.Scanner;
2
3  /**
4     This program prints the average of salary values that are terminated with a sentinel.
5  */
6  public class SentinelDemo
7  {
8     public static void main(String[] args)
9     {
10       double sum = 0;
11       int count = 0;
12       double salary = 0;
13       System.out.print("Enter salaries, -1 to finish: ");
14       Scanner in = new Scanner(System.in);
15
16       // Process data until the sentinel is entered
17
18       while (salary != -1)
19       {
20          salary = in.nextDouble();
21          if (salary != -1)
22          {
23             sum = sum + salary;
24             count++;
25          }
26       }
27
28       // Compute and print the average
29
30       if (count > 0)
31       {
32          double average = sum / count;
```

```
33          System.out.println("Average salary: " + average);
34       }
35       else
36       {
37          System.out.println("No data");
38       }
39    }
40 }
```

Program Run

```
Enter salaries, -1 to finish: 10 10 40 -1
Average salary: 20
```

You can use a Boolean variable to control a loop. Set the variable before entering the loop, then set it to the opposite to leave the loop.

Some programmers don't like the "trick" of initializing the input variable with a value other than the sentinel. Another approach is to use a Boolean variable:

```
System.out.print("Enter salaries, -1 to finish: ");
boolean done = false;
while (!done)
{
   value = in.nextDouble();
   if (value == -1)
   {
      done = true;
   }
   else
   {
      Process value.
   }
}
```

Special Topic 6.4 on page 263 shows an alternative mechanism for leaving such a loop.

Now consider the case in which any number (positive, negative, or zero) can be an acceptable input. In such a situation, you must use a sentinel that is not a number (such as the letter Q). As you have seen in Section 5.8, the condition

```
in.hasNextDouble()
```

is `false` if the next input is not a floating-point number. Therefore, you can read and process a set of inputs with the following loop:

```
System.out.print("Enter values, Q to quit: ");
while (in.hasNextDouble())
{
   value = in.nextDouble();
   Process value.
}
```

21. What does the `SentinelDemo.java` program print when the user immediately types –1 when prompted for a value?
22. Why does the `SentinelDemo.java` program have *two* checks of the form
    ```
    salary != -1
    ```
23. What would happen if the declaration of the `salary` variable in `SentinelDemo.java` was changed to
    ```
    double salary = -1;
    ```

24. In the last example of this section, we prompt the user "Enter values, Q to quit: " What happens when the user enters a different letter?

25. What is wrong with the following loop for reading a sequence of values?

```
System.out.print("Enter values, Q to quit: ");
do
{
   double value = in.nextDouble();
   sum = sum + value;
   count++;
}
while (in.hasNextDouble());
```

Practice It Now you can try these exercises at the end of the chapter: R6.16, E6.20, E6.21.

Special Topic 6.2

Redirection of Input and Output

Use input redirection to read input from a file. Use output redirection to capture program output in a file.

Consider the `SentinelDemo` program that computes the average value of an input sequence. If you use such a program, then it is quite likely that you already have the values in a file, and it seems a shame that you have to type them all in again. The command line interface of your operating system provides a way to link a file to the input of a program, as if all the characters in the file had actually been typed by a user. If you type

```
java SentinelDemo < numbers.txt
```

the program is executed, but it no longer expects input from the keyboard. All input commands get their input from the file `numbers.txt`. This process is called input **redirection**.

Input redirection is an excellent tool for testing programs. When you develop a program and fix its bugs, it is boring to keep entering the same input every time you run the program. Spend a few minutes putting the inputs into a file, and use redirection.

You can also redirect output. In this program, that is not terribly useful. If you run

```
java SentinelDemo < numbers.txt > output.txt
```

the file `output.txt` contains the input prompts and the output, such as

```
Enter salaries, -1 to finish: Enter salaries, -1 to finish:
Enter salaries, -1 to finish: Enter salaries, -1 to finish:
Average salary: 15
```

However, redirecting output is obviously useful for programs that produce lots of output. You can format or print the file containing the output.

Special Topic 6.3

The "Loop and a Half" Problem

Reading input data sometimes requires a loop such as the following, which is somewhat unsightly:

```
boolean done = false;
while (!done)
{
   String input = in.next();
   if (input.equals("Q"))
   {
      done = true;
```

```
   }
   else
   {
      Process data.
   }
}
```

The true test for loop termination is in the middle of the loop, not at the top. This is called a "loop and a half", because one must go halfway into the loop before knowing whether one needs to terminate.

Some programmers dislike the introduction of an additional Boolean variable for loop control. Two Java language features can be used to alleviate the "loop and a half" problem. I don't think either is a superior solution, but both approaches are fairly common, so it is worth knowing about them when reading other people's code.

You can combine an assignment and a test in the loop condition:

```
while (!(input = in.next()).equals("Q"))
{
   Process data.
}
```

The expression

```
(input = in.next()).equals("Q")
```

means, "First call `in.next()`, then assign the result to `input`, then test whether it equals `"Q"`". This is an expression with a side effect. The primary purpose of the expression is to serve as a test for the `while` loop, but it also does some work—namely, reading the input and storing it in the variable `input`. In general, it is a bad idea to use side effects, because they make a program hard to read and maintain. In this case, however, that practice is somewhat seductive, because it eliminates the control variable `done`, which also makes the code hard to read and maintain.

The other solution is to exit the loop from the middle, either by a `return` statement or by a `break` statement (see Special Topic 6.4 on page 263).

```
public void processInput(Scanner in)
{
   while (true)
   {
      String input = in.next();
      if (input.equals("Q"))
      {
         return;
      }
      Process data.
   }
}
```

Special Topic 6.4

The `break` and `continue` Statements

You already encountered the `break` statement in Special Topic 5.2, where it was used to exit a `switch` statement. In addition to breaking out of a `switch` statement, a `break` statement can also be used to exit a `while`, `for`, or `do` loop.

For example, the `break` statement in the following loop terminates the loop when the end of input is reached.

```
while (true)
{
```

```
      String input = in.next();
      if (input.equals("Q"))
      {
         break;
      }
      double x = Double.parseDouble(input);
      data.add(x);
   }
```

A loop with `break` statements can be difficult to understand because you have to look closely to find out how to exit the loop. However, when faced with the bother of introducing a separate loop control variable, some programmers find that `break` statements are beneficial in the "loop and a half" case. This issue is often the topic of heated (and quite unproductive) debate. In this book, we won't use the `break` statement, and we leave it to you to decide whether you like to use it in your own programs.

In Java, there is a second form of the `break` statement that is used to break out of a nested statement. The statement `break` *label*; immediately jumps to the *end* of the statement that is tagged with a label. Any statement (including `if` and block statements) can be tagged with a label—the syntax is

label: *statement*

The labeled `break` statement was invented to break out of a set of nested loops.

```
outerloop:
while (outer loop condition)
{  . . .
   while (inner loop condition)
   {  . . .
      if (something really bad happened)
      {
         break outerloop;
      }
   }
}
Jumps here if something really bad happened.
```

Naturally, this situation is quite rare. We recommend that you try to introduce additional methods instead of using complicated nested loops.

Finally, there is the `continue` statement, which jumps to the end of the *current iteration* of the loop. Here is a possible use for this statement:

```
while (!done)
{
   String input = in.next();
   if (input.equals("Q"))
   {
      done = true;
      continue; // Jump to the end of the loop body
   }
   double x = Double.parseDouble(input);
   data.add(x);
   // continue statement jumps here
}
```

By using the `continue` statement, you don't need to place the remainder of the loop code inside an `else` clause. This is a minor benefit. Few programmers use this statement.

6.6 Problem Solving: Storyboards

When you design a program that interacts with a user, you need to make a plan for that interaction. What information does the user provide, and in which order? What information will your program display, and in which format? What should happen when there is an error? When does the program quit?

A storyboard consists of annotated sketches for each step in an action sequence.

This planning is similar to the development of a movie or a computer game, where *storyboards* are used to plan action sequences. A storyboard is made up of panels that show a sketch of each step. Annotations explain what is happening and note any special situations. Storyboards are also used to develop software—see Figure 6.

Making a storyboard is very helpful when you begin designing a program. You need to ask yourself which information you need in order to compute the answers that the program user wants. You need to decide how to present those answers. These are important considerations that you want to settle before you design an algorithm for computing the answers.

Developing a storyboard helps you understand the inputs and outputs that are required for a program.

Let's look at a simple example. We want to write a program that helps users with questions such as "How many tablespoons are in a pint?" or "How many inches are 30 centimeters?"

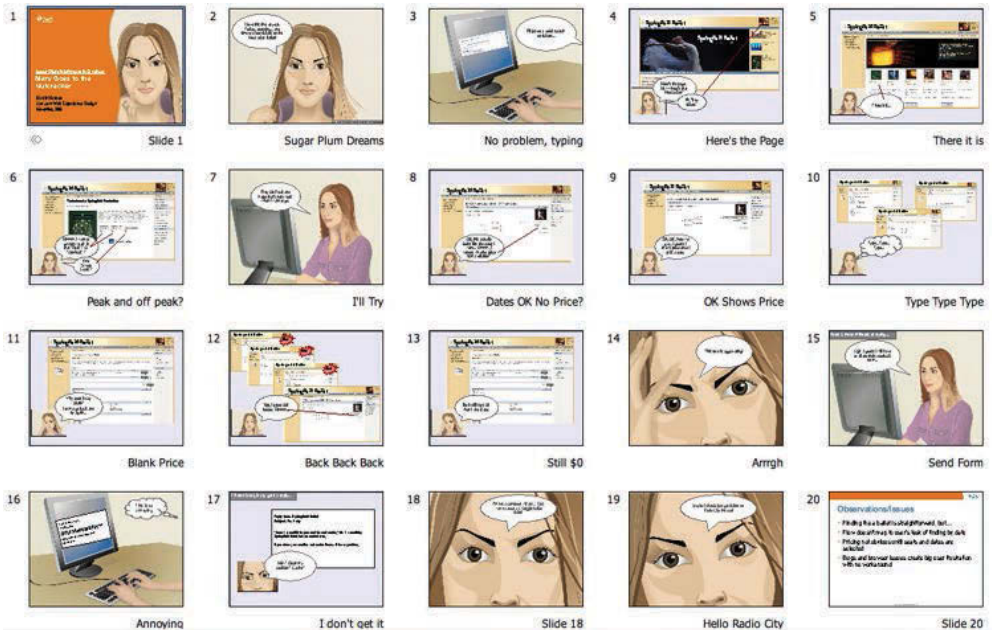
What information does the user provide?

- The quantity and unit to convert from
- The unit to convert to

What if there is more than one quantity? A user may have a whole table of centimeter values that should be converted into inches.

What if the user enters units that our program doesn't know how to handle, such as ångström?

What if the user asks for impossible conversions, such as inches to gallons?



Courtesy of Martin Hardee.

Figure 6 Storyboard for the Design of a Web Application

Let's get started with a storyboard panel. It is a good idea to write the user inputs in a different color. (Underline them if you don't have a color pen handy.)

Converting a Sequence of Values

```
What unit do you want to convert from? cm
What unit do you want to convert to? in
Enter values, terminated by zero
30
30 cm = 11.81 in
100
100 cm = 39.37 in
0
What unit do you want to convert from?
```

Allows conversion of multiple values

Format makes clear what got converted

The storyboard shows how we deal with a potential confusion. A user who wants to know how many inches are 30 centimeters may not read the first prompt carefully and specify inches. But then the output is "30 in = 76.2 cm", alerting the user to the problem.

The storyboard also raises an issue. How is the user supposed to know that "cm" and "in" are valid units? Would "centimeter" and "inches" also work? What happens when the user enters a wrong unit? Let's make another storyboard to demonstrate error handling.

Handling Unknown Units (needs improvement)

```
What unit do you want to convert from? cm
What unit do you want to convert to? inches
Sorry, unknown unit.
What unit do you want to convert to? inch
Sorry, unknown unit.
What unit do you want to convert to? grrr
```

To eliminate frustration, it is better to list the units that the user can supply.

```
From unit (in, ft, mi, mm, cm, m, km, oz, lb, g, kg, tsp, tbsp, pint, gal): cm
To unit: in
```

No need to list the units again

We switched to a shorter prompt to make room for all the unit names. Exercise R6.25 explores a different alternative.

There is another issue that we haven't addressed yet. How does the user quit the program? The first storyboard suggests that the program will go on forever.

We can ask the user after seeing the sentinel that terminates an input sequence.

Exiting the Program

```
From unit (in, ft, mi, mm, cm, m, km, oz, lb, g, kg, tsp, tbsp, pint, gal): cm
To unit: in
Enter values, terminated by zero
30
30 cm = 11.81 in
0
More conversions (y, n)? n
(Program exits)
```

Sentinel triggers the prompt to exit

As you can see from this case study, a storyboard is essential for developing a working program. You need to know the flow of the user interaction in order to structure your program.

26. Provide a storyboard panel for a program that reads a number of test scores and prints the average score. The program only needs to process one set of scores. Don't worry about error handling.

27. Google has a simple interface for converting units. You just type the question, and you get the answer.

Make storyboards for an equivalent interface in a Java program. Show a scenario in which all goes well, and show the handling of two kinds of errors.

28. Consider a modification of the program in Self Check 26. Suppose we want to drop the lowest score before computing the average. Provide a storyboard for the situation in which a user only provides one score.

29. What is the problem with implementing the following storyboard in Java?

Computing Multiple Averages

```
Enter scores: 90 80 90 100 80
The average is 88
Enter scores: 100 70 70 100 80
The average is 88
Enter scores: -1
(Program exits)
```

-1 is used as a sentinel to exit the program

30. Produce a storyboard for a program that compares the growth of a $10,000 investment for a given number of years under two interest rates.

Practice It Now you can try these exercises at the end of the chapter: R6.24, R6.25, R6.26.

6.7 Common Loop Algorithms

In the following sections, we discuss some of the most common algorithms that are implemented as loops. You can use them as starting points for your loop designs.

6.7.1 Sum and Average Value

Computing the sum of a number of inputs is a very common task. Keep a *running total*, a variable to which you add each input value. Of course, the total should be initialized with 0.

```
double total = 0;
while (in.hasNextDouble())
{
   double input = in.nextDouble();
   total = total + input;
}
```

Note that the `total` variable is declared outside the loop. We want the loop to update a single variable. The `input` variable is declared inside the loop. A separate variable is created for each input and removed at the end of each loop iteration.

To compute an average, keep a total and a count of all values.

To compute an average, count how many values you have, and divide by the count. Be sure to check that the count is not zero.

```
double total = 0;
int count = 0;
while (in.hasNextDouble())
{
   double input = in.nextDouble();
   total = total + input;
   count++;
}
double average = 0;
if (count > 0)
{
   average = total / count;
}
```

6.7.2 Counting Matches

To count values that fulfill a condition, check all values and increment a counter for each match.

You often want to know how many values fulfill a particular condition. For example, you may want to count how many spaces are in a string. Keep a *counter*, a variable that is initialized with 0 and incremented whenever there is a match.

```
int spaces = 0;
for (int i = 0; i < str.length(); i++)
{
   char ch = str.charAt(i);
   if (ch == ' ')
   {
      spaces++;
   }
}
```

For example, if `str` is `"My Fair Lady"`, `spaces` is incremented twice (when `i` is 2 and 7).

Note that the `spaces` variable is declared outside the loop. We want the loop to update a single variable. The `ch` variable is declared inside the loop. A separate variable is created for each iteration and removed at the end of each loop iteration.

This loop can also be used for scanning inputs. The following loop reads text a word at a time and counts the number of words with at most three letters:

```
int shortWords = 0;
while (in.hasNext())
{
   String input = in.next();
   if (input.length() <= 3)
   {
      shortWords++;
   }
}
```

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In a loop that counts matches, a counter is incremented whenever a match is found.

6.7.3 Finding the First Match

If your goal is to find a match, exit the loop when the match is found.

When you count the values that fulfill a condition, you need to look at all values. However, if your task is to find a match, then you can stop as soon as the condition is fulfilled.

Here is a loop that finds the first space in a string. Because we do not visit all elements in the string, a `while` loop is a better choice than a `for` loop:

```
boolean found = false;
char ch = '?';
int position = 0;
while (!found && position < str.length())
{
   ch = str.charAt(position);
   if (ch == ' ') { found = true; }
   else { position++; }
}
```

If a match was found, then `found` is `true`, `ch` is the first matching character, and `position` is the index of the first match. If the loop did not find a match, then `found` remains `false` after the end of the loop.

Note that the variable `ch` is declared *outside* the `while` loop because you may want to use the input after the loop has finished. If it had been declared inside the loop body, you would not be able to use it outside the loop.

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When searching, you look at items until a match is found.

6.7.4 Prompting Until a Match is Found

In the preceding example, we searched a string for a character that matches a condition. You can apply the same process to user input. Suppose you are asking a user to enter a positive value < 100. Keep asking until the user provides a correct input:

```
boolean valid = false;
double input = 0;
while (!valid)
{
   System.out.print("Please enter a positive value < 100: ");
   input = in.nextDouble();
   if (0 < input && input < 100) { valid = true; }
   else { System.out.println("Invalid input."); }
}
```

Note that the variable `input` is declared *outside* the `while` loop because you will want to use the input after the loop has finished.

6.7.5 Maximum and Minimum

To find the largest value, update the largest value seen so far whenever you see a larger one.

To compute the largest value in a sequence, keep a variable that stores the largest element that you have encountered, and update it when you find a larger one.

```
double largest = in.nextDouble();
while (in.hasNextDouble())
{
   double input = in.nextDouble();
   if (input > largest)
   {
      largest = input;
   }
}
```

This algorithm requires that there is at least one input.

To compute the smallest value, simply reverse the comparison:

```
double smallest = in.nextDouble();
while (in.hasNextDouble())
{
   double input = in.nextDouble();
   if (input < smallest)
   {
      smallest = input;
   }
}
```

To find the height of the tallest bus rider, remember the largest height so far, and update it whenever you see a taller one.

6.7.6 Comparing Adjacent Values

To compare adjacent inputs, store the preceding input in a variable.

When processing a sequence of values in a loop, you sometimes need to compare a value with the value that just preceded it. For example, suppose you want to check whether a sequence of inputs, such as 1 7 2 9 9 4 9, contains adjacent duplicates.

Now you face a challenge. Consider the typical loop for reading a value:

```
double input;
while (in.hasNextDouble())
{
   input = in.nextDouble();
   . . .
}
```

How can you compare the current input with the preceding one? At any time, `input` contains the current input, overwriting the previous one.

The answer is to store the previous input, like this:

```
double input = 0;
while (in.hasNextDouble())
{
   double previous = input;
   input = in.nextDouble();
   if (input == previous)
   {
      System.out.println("Duplicate input");
   }
}
```

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When comparing adjacent values, store the previous value in a variable.

One problem remains. When the loop is entered for the first time, `input` has not yet been read. You can solve this problem with an initial input operation outside the loop:

```
double input = in.nextDouble();
while (in.hasNextDouble())
{
   double previous = input;
   input = in.nextDouble();
   if (input == previous)
   {
      System.out.println("Duplicate input");
   }
}
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that uses common loop algorithms.

SELF CHECK

31. What total is computed when no user input is provided in the algorithm in Section 6.7.1?
32. How do you compute the total of all positive inputs?
33. What are the values of `position` and `ch` when no match is found in the algorithm in Section 6.7.3?
34. What is wrong with the following loop for finding the position of the first space in a string?

```
boolean found = false;
for (int position = 0; !found && position < str.length(); position++)
{
```

```
      char ch = str.charAt(position);
      if (ch == ' ') { found = true; }
   }
```

35. How do you find the position of the *last* space in a string?
36. What happens with the algorithm in Section 6.7.6 when no input is provided at all? How can you overcome that problem?

Practice It Now you can try these exercises at the end of the chapter: E6.6, E6.10, E6.11.

HOW TO 6.1 Writing a Loop

This How To walks you through the process of implementing a loop statement. We will illustrate the steps with the following example problem.

Problem Statement Read twelve temperature values (one for each month) and display the number of the month with the highest temperature. For example, according to `worldclimate.com`, the average maximum temperatures for Death Valley are (in order by month, in degrees Celsius):

18.2 22.6 26.4 31.1 36.6 42.2 45.7 44.5 40.2 33.1 24.2 17.6

In this case, the month with the highest temperature (45.7 degrees Celsius) is July, and the program should display 7.

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Step 1 Decide what work must be done *inside* the loop.

Every loop needs to do some kind of repetitive work, such as

- Reading another item.
- Updating a value (such as a bank balance or total).
- Incrementing a counter.

If you can't figure out what needs to go inside the loop, start by writing down the steps that you would take if you solved the problem by hand. For example, with the temperature reading problem, you might write

```
Read first value.
Read second value.
If second value is higher than the first, set highest temperature to that value, highest month to 2.
Read next value.
If value is higher than the first and second, set highest temperature to that value, highest month to 3.
Read next value.
If value is higher than the highest temperature seen so far, set highest temperature to that value,
   highest month to 4.
. . .
```

Now look at these steps and reduce them to a set of *uniform* actions that can be placed into the loop body. The first action is easy:

```
Read next value.
```

The next action is trickier. In our description, we used tests "higher than the first", "higher than the first and second", "higher than the highest temperature seen so far". We need to settle on one test that works for all iterations. The last formulation is the most general.

Similarly, we must find a general way of setting the highest month. We need a variable that stores the current month, running from 1 to 12. Then we can formulate the second loop action:

```
If value is higher than the highest temperature, set highest temperature to that value,
   highest month to current month.
```

Altogether our loop is

```
Repeat
   Read next value.
   If value is higher than the highest temperature,
      set highest temperature to that value,
      set highest month to current month.
   Increment current month.
```

Step 2 Specify the loop condition.

What goal do you want to reach in your loop? Typical examples are

- Has a counter reached its final value?
- Have you read the last input value?
- Has a value reached a given threshold?

In our example, we simply want the current month to reach 12.

Step 3 Determine the loop type.

We distinguish between two major loop types. A *count-controlled* loop is executed a definite number of times. In an *event-controlled* loop, the number of iterations is not known in advance—the loop is executed until some event happens.

Count-controlled loops can be implemented as `for` statements. For other loops, consider the loop condition. Do you need to complete one iteration of the loop body before you can tell when to terminate the loop? In that case, choose a `do` loop. Otherwise, use a `while` loop.

Sometimes, the condition for terminating a loop changes in the middle of the loop body. In that case, you can use a Boolean variable that specifies when you are ready to leave the loop. Follow this pattern:

```
boolean done = false;
while (!done)
{
   Do some work.
   If all work has been completed
   {
      done = true;
   }
   else
   {
      Do more work.
   }
}
```

Such a variable is called a **flag**.

In summary,

- If you know in advance how many times a loop is repeated, use a `for` loop.
- If the loop body must be executed at least once, use a `do` loop.
- Otherwise, use a `while` loop.

In our example, we read 12 temperature values. Therefore, we choose a `for` loop.

Step 4 Set up variables for entering the loop for the first time.

List all variables that are used and updated in the loop, and determine how to initialize them. Commonly, counters are initialized with `0` or `1`, totals with `0`.

In our example, the variables are

```
current month
highest value
highest month
```

We need to be careful how we set up the highest temperature value. We can't simply set it to 0. After all, our program needs to work with temperature values from Antarctica, all of which may be negative.

A good option is to set the highest temperature value to the first input value. Of course, then we need to remember to read in only 11 more values, with the current month starting at 2.

We also need to initialize the highest month with 1. After all, in an Australian city, we may never find a month that is warmer than January.

Step 5 Process the result after the loop has finished.

In many cases, the desired result is simply a variable that was updated in the loop body. For example, in our temperature program, the result is the highest month. Sometimes, the loop computes values that contribute to the final result. For example, suppose you are asked to average the temperatures. Then the loop should compute the sum, not the average. After the loop has completed, you are ready to compute the average: divide the sum by the number of inputs.

Here is our complete loop.

```
Read first value; store as highest value.
highest month = 1
For current month from 2 to 12
   Read next value.
   If value is higher than the highest value
      Set highest value to that value.
      Set highest month to current month.
```

Step 6 Trace the loop with typical examples.

Hand-trace your loop code, as described in Section 6.2. Choose example values that are not too complex—executing the loop 3–5 times is enough to check for the most common errors. Pay special attention when entering the loop for the first and last time.

Sometimes, you want to make a slight modification to make tracing feasible. For example, when hand-tracing the investment doubling problem, use an interest rate of 20 percent rather than 5 percent. When hand-tracing the temperature loop, use 4 data values, not 12.

Let's say the data are 22.6 36.6 44.5 24.2. Here is the walkthrough:

current month	current value	highest month	highest value
		~~1~~	~~22.6~~
~~2~~	~~36.6~~	~~2~~	~~36.6~~
~~3~~	~~44.5~~	3	44.5
4	24.2		

The trace demonstrates that **highest month** and **highest value** are properly set.

Step 7 Implement the loop in Java.

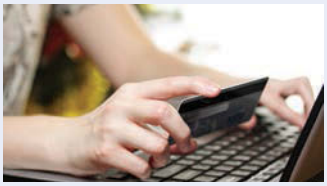
Here's the loop for our example. Exercise E6.5 asks you to complete the program.

```
double highestValue;
highestValue = in.nextDouble();
int highestMonth = 1;
```

```
for (int currentMonth = 2; currentMonth <= 12; currentMonth++)
{
   double nextValue = in.nextDouble();
   if (nextValue > highestValue)
   {
      highestValue = nextValue;
      highestMonth = currentMonth;
   }
}
System.out.println(highestMonth);
```

WORKED EXAMPLE 6.1 **Credit Card Processing**

Learn how to use a loop to remove spaces from a credit card number. Go to `wiley.com/go/bjeo6examples` and download Worked Example 6.1.



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6.8 Nested Loops

When the body of a loop contains another loop, the loops are nested. A typical use of nested loops is printing a table with rows and columns.

In Section 5.4, you saw how to nest two `if` statements. Similarly, complex iterations sometimes require a **nested loop**: a loop inside another loop statement. When processing tables, nested loops occur naturally. An outer loop iterates over all rows of the table. An inner loop deals with the columns in the current row.

In this section you will see how to print a table. For simplicity, we will simply print the powers of x, x^n, as in the table at right.

Here is the pseudocode for printing the table:

```
Print table header.
For x from 1 to 10
   Print table row.
   Print new line.
```

x^1	x^2	x^3	x^4
1	1	1	1
2	4	8	16
3	9	27	81
…	…	…	…
10	100	1000	10000

How do you print a table row? You need to print a value for each exponent. This requires a second loop.

```
For n from 1 to 4
   Print x^n.
```

This loop must be placed inside the preceding loop. We say that the inner loop is *nested* inside the outer loop.

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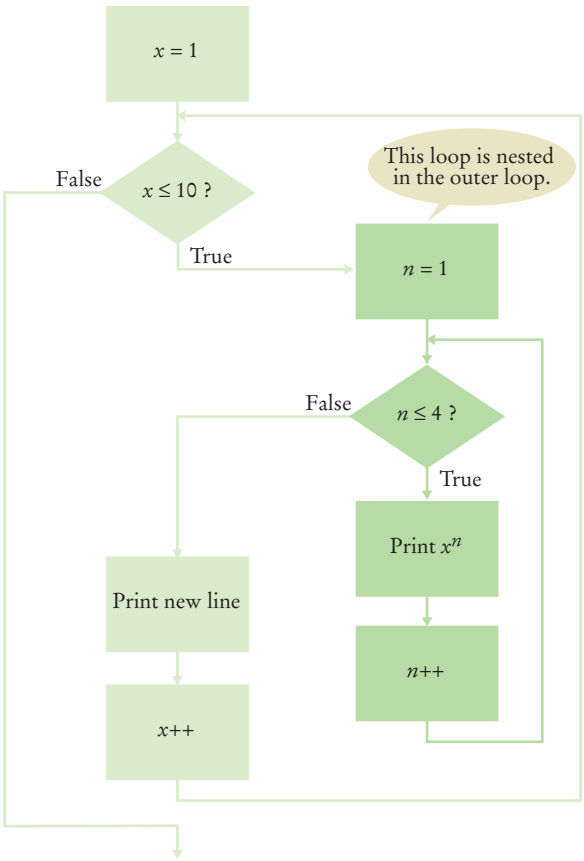
The hour and minute displays in a digital clock are an example of nested loops. The hours loop 12 times, and for each hour, the minutes loop 60 times.

Figure 7
Flowchart of a Nested Loop



There are 10 rows in the outer loop. For each x, the program prints four columns in the inner loop (see Figure 7). Thus, a total of $10 \times 4 = 40$ values are printed.

Following is the complete program. Note that we also use two loops to print the table header. However, those loops are not nested.

section_8/PowerTable.java

```
1  /**
2     This program prints a table of powers of x.
3  */
4  public class PowerTable
5  {
6     public static void main(String[] args)
7     {
8        final int NMAX = 4;
9        final double XMAX = 10;
10
11       // Print table header
12
13       for (int n = 1; n <= NMAX; n++)
14       {
15          System.out.printf("%10d", n);
16       }
17       System.out.println();
```

```
18         for (int n = 1; n <= NMAX; n++)
19         {
20            System.out.printf("%10s", "x ");
21         }
22         System.out.println();
23
24         // Print table body
25
26         for (double x = 1; x <= XMAX; x++)
27         {
28            // Print table row
29
30            for (int n = 1; n <= NMAX; n++)
31            {
32               System.out.printf("%10.0f", Math.pow(x, n));
33            }
34            System.out.println();
35         }
36      }
37   }
```

Program Run

```
         1         2         3         4
         x         x         x         x

         1         1         1         1
         2         4         8        16
         3         9        27        81
         4        16        64       256
         5        25       125       625
         6        36       216      1296
         7        49       343      2401
         8        64       512      4096
         9        81       729      6561
        10       100      1000     10000
```

37. Why is there a statement `System.out.println();` in the outer loop but not in the inner loop?

38. How would you change the program to display all powers from x^0 to x^5?

39. If you make the change in Self Check 38, how many values are displayed?

40. What do the following nested loops display?

```
for (int i = 0; i < 3; i++)
{
   for (int j = 0; j < 4; j++)
   {
      System.out.print(i + j);
   }
   System.out.println();
}
```

41. Write nested loops that make the following pattern of brackets:

```
[][][][]
[][][][]
[][][][]
```

Practice It Now you can try these exercises at the end of the chapter: R6.30, E6.17, E6.19.

Table 3 Nested Loop Examples

Nested Loops	Output	Explanation

`for (i = 1; i <= 3; i++)`
`{`
`  for (j = 1; j <= 4; j++) { Print "*" }`
`  System.out.println();`
`}`
	`****`
	`****`
	`****`
		Prints 3 rows of 4 asterisks each.

`for (i = 1; i <= 4; i++)`
`{`
`  for (j = 1; j <= 3; j++) { Print "*" }`
`  System.out.println();`
`}`
	`***`
	`***`
	`***`
	`***`
		Prints 4 rows of 3 asterisks each.

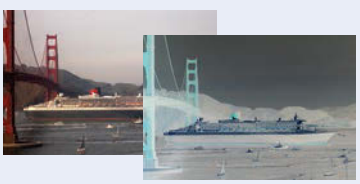
`for (i = 1; i <= 4; i++)`
`{`
`  for (j = 1; j <= i; j++) { Print "*" }`
`  System.out.println();`
`}`
	`*`
	`**`
	`***`
	`****`
		Prints 4 rows of lengths 1, 2, 3, and 4.

`for (i = 1; i <= 3; i++)`
`{`
`  for (j = 1; j <= 5; j++)`
`  {`
`  if (j % 2 == 0) { Print "*" }`
`  else { Print "-" }`
`  }`
`  System.out.println();`
`}`
	`-*-*-`
	`-*-*-`
	`-*-*-`
		Prints asterisks in even columns, dashes in odd columns.

`for (i = 1; i <= 3; i++)`
`{`
`  for (j = 1; j <= 5; j++)`
`  {`
`  if (i % 2 == j % 2) { Print "*" }`
`  else { Print " " }`
`  }`
`  System.out.println();`
`}`
	`* * *`
	`  * *`
	`* * *`
		Prints a checkerboard pattern.

WORKED EXAMPLE 6.2 Manipulating the Pixels in an Image

Learn how to use nested loops for manipulating the pixels in an image. The outer loop traverses the rows of the image, and the inner loop accesses each pixel of a row. Go to `wiley.com/go/bjeo6examples` and download Worked Example 6.2.



Cay Horstmann.

6.9 Application: Random Numbers and Simulations

In a simulation, you use the computer to simulate an activity.

A *simulation program* uses the computer to simulate an activity in the real world (or an imaginary one). Simulations are commonly used for predicting climate change, analyzing traffic, picking stocks, and many other applications in science and business. In many simulations, one or more loops are used to modify the state of a system and observe the changes. You will see examples in the following sections.

6.9.1 Generating Random Numbers

Many events in the real world are difficult to predict with absolute precision, yet we can sometimes know the average behavior quite well. For example, a store may know from experience that a customer arrives every five minutes. Of course, that is an average—customers don't arrive in five minute intervals. To accurately model customer traffic, you want to take that random fluctuation into account. Now, how can you run such a simulation in the computer?

You can introduce randomness by calling the random number generator.

The `Random` class of the Java library implements a *random number generator* that produces numbers that appear to be completely random. To generate random numbers, you construct an object of the `Random` class, and then apply one of the following methods:

Method	Returns
`nextInt(n)`	A random integer between the integers `0` (inclusive) and `n` (exclusive)
`nextDouble()`	A random floating-point number between `0` (inclusive) and `1` (exclusive)

For example, you can simulate the cast of a die as follows:

```
Random generator = new Random();
int d = 1 + generator.nextInt(6);
```

The call `generator.nextInt(6)` gives you a random number between `0` and `5` (inclusive). Add `1` to obtain a number between 1 and 6.

To give you a feeling for the random numbers, run the following program a few times.

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section_9_1/Die.java

```
1  import java.util.Random;
2
3  /**
4     This class models a die that, when cast, lands on a
5     random face.
6  */
7  public class Die
8  {
9     private Random generator;
10    private int sides;
```

```
11
12    /**
13       Constructs a die with a given number of sides.
14       @param s the number of sides, e.g., 6 for a normal die
15    */
16    public Die(int s)
17    {
18       sides = s;
19       generator = new Random();
20    }
21
22    /**
23       Simulates a throw of the die.
24       @return the face of the die
25    */
26    public int cast()
27    {
28       return 1 + generator.nextInt(sides);
29    }
30 }
```

section_9_1/DieSimulator.java

```
1  /**
2     This program simulates casting a die ten times.
3  */
4  public class DieSimulator
5  {
6     public static void main(String[] args)
7     {
8        Die d = new Die(6);
9        final int TRIES = 10;
10       for (int i = 1; i <= TRIES; i++)
11       {
12          int n = d.cast();
13          System.out.print(n + " ");
14       }
15       System.out.println();
16    }
17 }
```

Typical Program Run

```
6 5 6 3 2 6 3 4 4 1
```

Typical Program Run (Second Run)

```
3 2 2 1 6 5 3 4 1 2
```

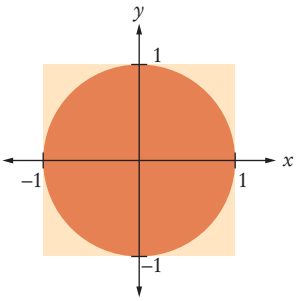
As you can see, this program produces a different stream of simulated die casts every time it is run.

Actually, the numbers are not completely random. They are drawn from very long sequences of numbers that don't repeat for a long time. These sequences are computed from fairly simple formulas; they just behave like random numbers. For that reason, they are often called **pseudorandom numbers**. Generating good sequences of numbers that behave like truly random sequences is an important and well-studied problem in computer science. We won't investigate this issue further, though; we'll just use the random numbers produced by the `Random` class.

6.9.2 The Monte Carlo Method

The Monte Carlo method is an ingenious method for finding approximate solutions to problems that cannot be precisely solved. (The method is named after the famous casino in Monte Carlo.) Here is a typical example. It is difficult to compute the number π, but you can approximate it quite well with the following simulation.

Simulate shooting a dart into a square surrounding a circle of radius 1. That is easy: generate random x- and y-coordinates between –1 and 1.



If the generated point lies inside the circle, we count it as a *hit*. That is the case when $x^2 + y^2 \leq 1$. Because our shots are entirely random, we expect that the ratio of *hits / tries* is approximately equal to the ratio of the areas of the circle and the square, that is, $\pi / 4$. Therefore, our estimate for π is $4 \times hits / tries$. This method yields an estimate for π, using nothing but simple arithmetic.

To generate a random floating-point value between –1 and 1, you compute:

```
double r = generator.nextDouble(); // 0 ≤ r < 1
double x = -1 + 2 * r; // –1 ≤ x < 1
```

As r ranges from 0 (inclusive) to 1 (exclusive), x ranges from $-1 + 2 \times 0 = -1$ (inclusive) to $-1 + 2 \times 1 = 1$ (exclusive). In our application, it does not matter that x never reaches 1. The points that fulfill the equation $x = 1$ lie on a line with area 0.

Here is the program that carries out the simulation:

section_9_2/MonteCarlo.java

```
1  import java.util.Random;
2
3  /**
4     This program computes an estimate of pi by simulating dart throws onto a square.
5  */
6  public class MonteCarlo
7  {
8     public static void main(String[] args)
9     {
10       final int TRIES = 10000;
11       Random generator = new Random();
12
13       int hits = 0;
14       for (int i = 1; i <= TRIES; i++)
15       {
16          // Generate two random numbers between –1 and 1
17
18          double r = generator.nextDouble();
19          double x = -1 + 2 * r; // Between –1 and 1
20          r = generator.nextDouble();
21          double y = -1 + 2 * r;
```

```
22
23          // Check whether the point lies in the unit circle
24
25          if (x * x + y * y <= 1) { hits++; }
26       }
27
28       /*
29          The ratio hits / tries is approximately the same as the ratio
30          circle area / square area = pi / 4
31       */
32
33       double piEstimate = 4.0 * hits / TRIES;
34       System.out.println("Estimate for pi: " + piEstimate);
35    }
36 }
```

Program Run

```
Estimate for pi: 3.1504
```

42. How do you simulate a coin toss with the `Random` class?
43. How do you simulate the picking of a random playing card?
44. How would you modify the `DieSimulator` program to simulate tossing a pair of dice?
45. In many games, you throw a pair of dice to get a value between 2 and 12. What is wrong with this simulated throw of a pair of dice?

    ```
    int sum = 2 + generator.nextInt(11);
    ```

46. How do you generate a random floating-point number ≥ 0 and < 100?

Practice It Now you can try these exercises at the end of the chapter: R6.31, E6.8, E6.22.

6.10 Using a Debugger

A debugger is a program that you can use to execute another program and analyze its run-time behavior.

As you have undoubtedly realized by now, computer programs rarely run perfectly the first time. At times, it can be quite frustrating to find the bugs. Of course, you can insert print commands, run the program, and try to analyze the printout. If the printout does not clearly point to the problem, you may need to add and remove print commands and run the program again. That can be a time-consuming process.

Modern development environments contain special programs, called **debuggers**, that help you locate bugs by letting you follow the execution of a program. You can stop and restart your program and see the contents of variables whenever your program is temporarily stopped. At each stop, you have the choice of what variables to inspect and how many program steps to run until the next stop.

Some people feel that debuggers are just a tool to make programmers lazy. Admittedly some people write sloppy programs and then fix them up with a debugger, but the majority of programmers make an honest effort to write the best program they can before trying to run it through a debugger. These programmers realize that a debugger, while more convenient than print commands, is not cost-free. It does take time to set up and carry out an effective debugging session.

In actual practice, you cannot avoid using a debugger. The larger your programs get, the harder it is to debug them simply by inserting print commands. The time invested in learning about a debugger will be amply repaid in your programming career.

Like compilers, debuggers vary widely from one system to another. Some are quite primitive and require you to memorize a small set of arcane commands; others have an intuitive window interface. Figure 8 shows the debugger in the Eclipse development environment, downloadable for free from the Eclipse Foundation (`eclipse.org`). Other development environments, such as BlueJ, Netbeans, and IntelliJ IDEA also include debuggers.

You will have to find out how to prepare a program for debugging and how to start a debugger on your system. If you use an integrated development environment (with an editor, compiler, and debugger), this step is usually easy. You build the program in the usual way and pick a command to start debugging. On some systems, you must manually build a debug version of your program and invoke the debugger.

You can make effective use of a debugger by mastering just three concepts: breakpoints, single-stepping, and inspecting variables.

Once you have started the debugger, you can go a long way with just three debugging commands: "set breakpoint", "single step", and "inspect variable". The names and keystrokes or mouse clicks for these commands differ widely, but all debuggers support these basic commands. You can find out how, either from the documentation or a lab manual, or by asking someone who has used the debugger before.

When a debugger executes a program, the execution is suspended whenever a breakpoint is reached.

When you start the debugger, it runs at full speed until it reaches a **breakpoint**. Then execution stops, and the breakpoint that causes the stop is displayed (Figure 8). You can now inspect variables and step through the program one line at a time, or continue running the program at full speed until it reaches the next breakpoint. When the program terminates, the debugger stops as well.

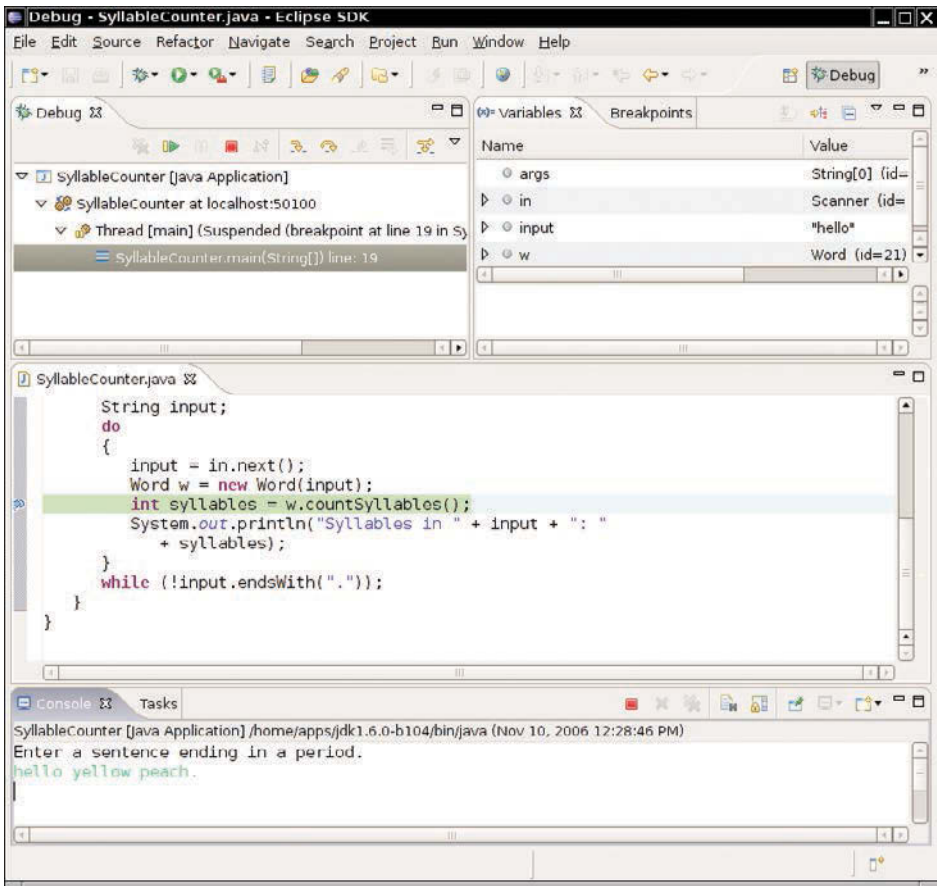


Figure 8
Stopping at a Breakpoint

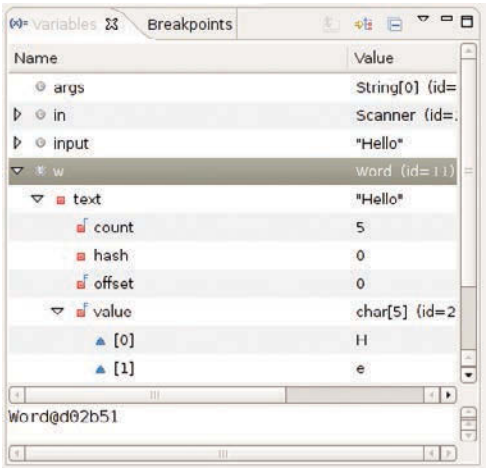


Figure 9 Inspecting Variables

Breakpoints stay active until you remove them, so you should periodically clear the breakpoints that you no longer need.

Once the program has stopped, you can look at the current values of variables. Again, the method for selecting the variables differs among debuggers. Some debuggers always show you a window with the current local variables. On other debuggers you issue a command such as "inspect variable" and type in or click on the variable. The debugger then displays the contents of the variable. If all variables contain what you expected, you can run the program until the next point where you want to stop.

The single-step command executes the program one line at a time.

When inspecting objects, you often need to give a command to "open up" the object, for example by clicking on a tree node. Once the object is opened up, you see its instance variables (see Figure 9).

Running to a breakpoint gets you there speedily, but you don't know how the program got there. You can also step through the program one line at a time. Then you know how the program flows, but it can take a long time to step through it. The *single-step command* executes the current line and stops at the next program line. Most debuggers have two single-step commands, one called *step into*, which steps inside method calls, and one called *step over*, which skips over method calls.

For example, suppose the current line is

```
String input = in.next();
Word w = new Word(input);
int syllables = w.countSyllables();
System.out.println("Syllables in " + input + ": " + syllables);
```

When you step over method calls, you get to the next line:

```
String input = in.next();
Word w = new Word(input);
int syllables = w.countSyllables();
System.out.println("Syllables in " + input + ": " + syllables);
```

However, if you step into method calls, you enter the first line of the `countSyllables` method.

```
public int countSyllables()
{
   int count = 0;
```

```
      int end = text.length() - 1;
      . . .
   }
```

You should step *into* a method to check whether it carries out its job correctly. You should step *over* a method if you know it works correctly.

Finally, when the program has finished running, the debug session is also finished. To debug the program again, you must restart it in the debugger.

A debugger can be an effective tool for finding and removing bugs in your program. However, it is no substitute for good design and careful programming. If the debugger does not find any errors, it does not mean that your program is bug-free. Testing and debugging can only show the presence of bugs, not their absence.

47. In the debugger, you are reaching a call to `System.out.println`. Should you step into the method or step over it?

48. In the debugger, you are reaching the beginning of a method with a couple of loops inside. You want to find out the return value that is computed at the end of the method. Should you set a breakpoint, or should you step through the method?

49. When using the debugger, you find that a variable has an unexpected value. How can you go backwards to see when the variable changed?

50. When using a debugger, should you insert statements to print the values of variables?

51. Instead of using a debugger, could you simply trace a program by hand?

Practice It Now you can try these exercises at the end of the chapter: R6.33, R6.34, R6.35.

HOW TO 6.2

Debugging

Knowing all about the mechanics of debugging may still leave you helpless when you fire up a debugger to look at a sick program. This How To presents a number of strategies that you can use to recognize bugs and their causes.

Step 1 Reproduce the error.

As you test your program, you notice that it sometimes does something wrong. It gives the wrong output, it seems to print something random, it goes in an infinite loop, or it crashes. Find out exactly how to reproduce that behavior. What numbers did you enter? Where did you click with the mouse?

Run the program again; type in exactly the same numbers, and click with the mouse on the same spots (or as close as you can get). Does the program exhibit the same behavior? If so, then it makes sense to fire up a debugger to study this particular problem. Debuggers are good for analyzing particular failures. They aren't terribly useful for studying a program in general.

Step 2 Simplify the error.

Before you start up a debugger, it makes sense to spend a few minutes trying to come up with a simpler input that also produces an error. Can you use shorter words or simpler numbers and still have the program misbehave? If so, use those values during your debugging session.

Step 3 Divide and conquer.

Use the divide-and-conquer technique to locate the point of failure of a program.

Now that you have a particular failure, you want to get as close to the failure as possible. The key point of debugging is to locate the code that produces the failure. Just as with real insect pests, finding the bug can be hard, but once you find it, squashing it is usually the easy part. Suppose your program dies with a division by `0`. Because there are many division operations in a typical program, it is often not feasible to set breakpoints to all of them. Instead, use a technique of *divide and conquer*. Step over the methods in `main`, but don't step inside them. Eventually, the failure will happen again. Now you know which method contains the bug: It is the last method that was called from `main` before the program died. Restart the debugger and go back to that line in `main`, then step inside that method. Repeat the process.

Eventually, you will have pinpointed the line that contains the bad division. Maybe it is obvious from the code why the denominator is not correct. If not, you need to find the location where it is computed. Unfortunately, you can't go back in the debugger. You need to restart the program and move to the point where the denominator computation happens.

Step 4 Know what your program should do.

During debugging, compare the actual contents of variables against the values you know they should have.

A debugger shows you what the program does. You must know what the program *should* do, or you will not be able to find bugs. Before you trace through a loop, ask yourself how many iterations you expect the program to make. Before you inspect a variable, ask yourself what you expect to see. If you have no clue, set aside some time and think first. Have a calculator handy to make independent computations. When you know what the value should be, inspect the variable. If the value is what you expected, you must look further for the bug. If the value is different, you may be on to something. Double-check your computation. If you are sure your value is correct, find out why your program comes up with a different value.

In many cases, program bugs are the result of simple errors such as loop termination conditions that are off by one. Quite often, however, programs make computational errors. Maybe they are supposed to add two numbers, but by accident the code was written to subtract them. Programs don't make a special effort to ensure that everything is a simple integer (and neither do real-world problems). You will need to make some calculations with large integers or nasty floating-point numbers. Sometimes these calculations can be avoided if you just ask yourself, "Should this quantity be positive? Should it be larger than that value?" Then inspect variables to verify those theories.

Step 5 Look at all details.

When you debug a program, you often have a theory about what the problem is. Nevertheless, keep an open mind and look at all details. What strange messages are displayed? Why does the program take another unexpected action? These details count. When you run a debugging session, you really are a detective who needs to look at every clue available.

If you notice another failure on the way to the problem that you are about to pin down, don't just say, "I'll come back to it later". That very failure may be the original cause for your current problem. It is better to make a note of the current problem, fix what you just found, and then return to the original mission.

Step 6 Make sure you understand each bug before you fix it.

Once you find that a loop makes too many iterations, it is very tempting to apply a "Band-Aid" solution and subtract 1 from a variable so that the particular problem doesn't appear again. Such a quick fix has an overwhelming probability of creating trouble elsewhere. You really need to have a thorough understanding of how the program should be written before you apply a fix.

It does occasionally happen that you find bug after bug and apply fix after fix, and the problem just moves around. That usually is a symptom of a larger problem with the program logic. There is little you can do with the debugger. You must rethink the program design and reorganize it.

WORKED EXAMPLE 6.3 A Sample Debugging Session

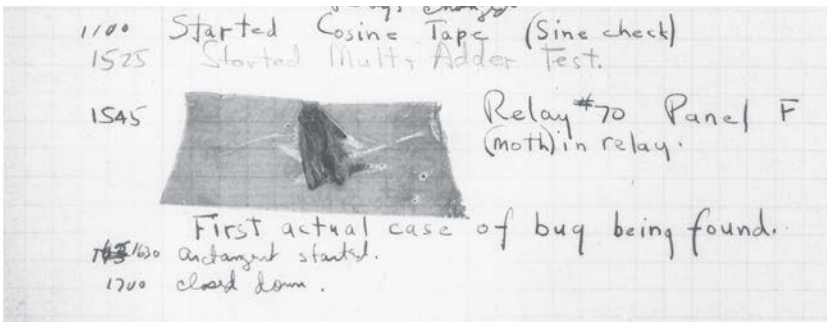
Learn how to find bugs in an algorithm for counting the syllables of a word. Go to `wiley.com/go/bjeo6examples` and download Worked Example 6.3.

Computing & Society 6.2 The First Bug

According to legend, the first bug was found in the Mark II, a huge electromechanical computer at Harvard University. It really was caused by a bug—a moth was trapped in a relay switch.

Actually, from the note that the operator left in the log book next to the moth (see the photo), it appears as if the term "bug" had already been in active use at the time.

The pioneering computer scientist Maurice Wilkes wrote, "Somehow, at the Moore School and afterwards, one had always assumed there would be no particular difficulty in getting programs right. I can remember the exact instant in time at which it dawned on me that a great part of my future life would be spent finding mistakes in my own programs."



The First Bug

CHAPTER SUMMARY

Explain the flow of execution in a loop.

- A loop executes instructions repeatedly while a condition is true.
- An off-by-one error is a common error when programming loops. Think through simple test cases to avoid this type of error.

Use the technique of hand-tracing to analyze the behavior of a program.

- Hand-tracing is a simulation of code execution in which you step through instructions and track the values of the variables.
- Hand-tracing can help you understand how an unfamiliar algorithm works.
- Hand-tracing can show errors in code or pseudocode.

Use `for` loops for implementing count-controlled loops.

- The `for` loop is used when a value runs from a starting point to an ending point with a constant increment or decrement.

Choose between the `while` loop and the `do` loop.

- The `do` loop is appropriate when the loop body must be executed at least once.

Implement loops that read sequences of input data.

- A sentinel value denotes the end of a data set, but it is not part of the data.
- You can use a Boolean variable to control a loop. Set the variable to `true` before entering the loop, then set it to `false` to leave the loop.
- Use input redirection to read input from a file. Use output redirection to capture program output in a file.

Use the technique of storyboarding for planning user interactions.

- A storyboard consists of annotated sketches for each step in an action sequence.
- Developing a storyboard helps you understand the inputs and outputs that are required for a program.

Know the most common loop algorithms.

- To compute an average, keep a total and a count of all values.
- To count values that fulfill a condition, check all values and increment a counter for each match.
- If your goal is to find a match, exit the loop when the match is found.
- To find the largest value, update the largest value seen so far whenever you see a larger one.
- To compare adjacent inputs, store the preceding input in a variable.

Use nested loops to implement multiple levels of iteration.

- When the body of a loop contains another loop, the loops are nested. A typical use of nested loops is printing a table with rows and columns.

Apply loops to the implementation of simulations.

- In a simulation, you use the computer to simulate an activity.
- You can introduce randomness by calling the random number generator.

Use a debugger to analyze your programs.

- A debugger is a program that you can use to execute another program and analyze its run-time behavior.
- You can make effective use of a debugger by mastering just three concepts: breakpoints, single-stepping, and inspecting variables.
- When a debugger executes a program, the execution is suspended whenever a breakpoint is reached.
- The single-step command executes the program one line at a time.
- Use the divide-and-conquer technique to locate the point of failure of a program.
- During debugging, compare the actual contents of variables against the values you know they should have.

STANDARD LIBRARY ITEMS INTRODUCED IN THIS CHAPTER

```
java.util.Random
   nextDouble
   nextInt
```

REVIEW EXERCISES

■ **R6.1** Given the variables

```
String stars = "*****";
String stripes = "=====";
```

what do these loops print?

a.
```
int i = 0;
while (i < 5)
{
   System.out.println(stars.substring(0, i));
   i++;
}
```

b.
```
int i = 0;
while (i < 5)
{
   System.out.print(stars.substring(0, i));
   System.out.println(stripes.substring(i, 5));
   i++;
}
```

c.
```
int i = 0;
while (i < 10)
{
   if (i % 2 == 0) { System.out.println(stars); }
   else { System.out.println(stripes); }
}
```

■ **R6.2** What do these loops print?

a.
```
int i = 0; int j = 10;
while (i < j) { System.out.println(i + " " + j); i++; j--; }
```

b.
```
int i = 0; int j = 10;
while (i < j) { System.out.println(i + j); i++; j++; }
```

■ **R6.3** What do these code snippets print?

a.
```
int result = 0;
for (int i = 1; i <= 10; i++) { result = result + i; }
System.out.println(result);
```

b.
```
int result = 1;
for (int i = 1; i <= 10; i++) { result = i - result; }
System.out.println(result);
```

c.
```
int result = 1;
for (int i = 5; i > 0; i--) { result = result * i; }
System.out.println(result);
```

d.
```
int result = 1;
for (int i = 1; i <= 10; i = i * 2) { result = result * i; }
System.out.println(result);
```

■ **R6.4** Write a `while` loop that prints

a. All squares less than `n`. For example, if `n` is 100, print 0 1 4 9 16 25 36 49 64 81.

b. All positive numbers that are divisible by 10 and less than `n`. For example, if `n` is 100, print 10 20 30 40 50 60 70 80 90.

c. All powers of two less than `n`. For example, if `n` is 100, print 1 2 4 8 16 32 64.

■■ **R6.5** Write a loop that computes

a. The sum of all even numbers between 2 and 100 (inclusive).

b. The sum of all squares between 1 and 100 (inclusive).

c. The sum of all odd numbers between `a` and `b` (inclusive).

d. The sum of all odd digits of `n`. (For example, if `n` is 32677, the sum would be 3 + 7 + 7 = 17.)

■ **R6.6** Provide trace tables for these loops.

a.
```
int i = 0; int j = 10; int n = 0;
while (i < j) { i++; j--; n++; }
```

b.
```
int i = 0; int j = 0; int n = 0;
while (i < 10) { i++; n = n + i + j; j++; }
```

c.
```
int i = 10; int j = 0; int n = 0;
while (i > 0) { i--; j++; n = n + i - j; }
```

d.
```
int i = 0; int j = 10; int n = 0;
while (i != j) { i = i + 2; j = j - 2; n++; }
```

■ **R6.7** What do these loops print?

a. `for (int i = 1; i < 10; i++) { System.out.print(i + " "); }`

b. `for (int i = 1; i < 10; i += 2) { System.out.print(i + " "); }`

c. `for (int i = 10; i > 1; i--) { System.out.print(i + " "); }`

d. `for (int i = 0; i < 10; i++) { System.out.print(i + " "); }`

e. `for (int i = 1; i < 10; i = i * 2) { System.out.print(i + " "); }`

f. `for (int i = 1; i < 10; i++) { if (i % 2 == 0) { System.out.print(i + " "); } }`

■ **R6.8** What is an infinite loop? On your computer, how can you terminate a program that executes an infinite loop?

■ **R6.9** Write a program trace for the pseudocode in Exercise E6.7, assuming the input values are 4 7 –2 –5 0.

■■ **R6.10** What is an "off-by-one" error? Give an example from your own programming experience.

■ **R6.11** What is a sentinel value? Give a simple rule when it is appropriate to use a numeric sentinel value.

■ **R6.12** Which loop statements does Java support? Give simple rules for when to use each loop type.

■ **R6.13** How many iterations do the following loops carry out? Assume that `i` is not changed in the loop body.

a. `for (int i = 1; i <= 10; i++) . . .`

b. `for (int i = 0; i < 10; i++) . . .`

c. `for (int i = 10; i > 0; i--) . . .`

d. `for (int i = -10; i <= 10; i++) . . .`

e. `for (int i = 10; i >= 0; i++) . . .`

f. `for (int i = -10; i <= 10; i = i + 2) . . .`

g. `for (int i = -10; i <= 10; i = i + 3) . . .`

■■ **R6.14** Write pseudocode for a program that prints a calendar such as the following.

```
Su  M  T  W Th  F Sa
          1  2  3  4
 5  6  7  8  9 10 11
12 13 14 15 16 17 18
19 20 21 22 23 24 25
26 27 28 29 30 31
```

■ **R6.15** Write pseudocode for a program that prints a Celsius/Fahrenheit conversion table such as the following.

```
Celsius | Fahrenheit
--------+-----------
      0 |          32
     10 |          50
     20 |          68
  . . .        . . .
    100 |         212
```

■ **R6.16** Write pseudocode for a program that reads a student record, consisting of the student's first and last name, followed by a sequence of test scores and a sentinel of –1. The program should print the student's average score. Then provide a trace table for this sample input:

```
Harry Morgan 94 71 86 95 -1
```

■■ **R6.17** Write pseudocode for a program that reads a sequence of student records and prints the total score for each student. Each record has the student's first and last name, followed by a sequence of test scores and a sentinel of –1. The sequence is terminated by the word `END`. Here is a sample sequence:

```
Harry Morgan 94 71 86 95 -1
Sally Lin 99 98 100 95 90 -1
END
```

Provide a trace table for this sample input.

■ **R6.18** Rewrite the following `for` loop into a `while` loop.

```
int s = 0;
for (int i = 1; i <= 10; i++)
{
   s = s + i;
}
```

■ **R6.19** Rewrite the following `do` loop into a `while` loop.

```
int n = in.nextInt();
double x = 0;
double s;
do
{
   s = 1.0 / (1 + n * n);
   n++;
   x = x + s;
}
while (s > 0.01);
```

■ **R6.20** Provide trace tables of the following loops.

a.
```
int s = 1;
int n = 1;
while (s < 10) { s = s + n; }
n++;
```

b.
```
int s = 1;
for (int n = 1; n < 5; n++) { s = s + n; }
```

c.
```
int s = 1;
int n = 1;
do
{
   s = s + n;
   n++;
}
while (s < 10 * n);
```

■ **R6.21** What do the following loops print? Work out the answer by tracing the code, not by using the computer.

a.
```
int s = 1;
for (int n = 1; n <= 5; n++)
{
   s = s + n;
   System.out.print(s + " ");
}
```

b.
```
int s = 1;
for (int n = 1; s <= 10; System.out.print(s + " "))
{
   n = n + 2;
   s = s + n;
}
```

c.
```
int s = 1;
int n;
for (n = 1; n <= 5; n++)
{
   s = s + n;
   n++;
}
System.out.print(s + " " + n);
```

■ **R6.22** What do the following program segments print? Find the answers by tracing the code, not by using the computer.

a.
```
int n = 1;
for (int i = 2; i < 5; i++) { n = n + i; }
System.out.print(n);
```

b.
```
int i;
double n = 1 / 2;
for (i = 2; i <= 5; i++) { n = n + 1.0 / i; }
System.out.print(i);
```

c.
```
double x = 1;
double y = 1;
int i = 0;
do
{
   y = y / 2;
   x = x + y;
   i++;
}
while (x < 1.8);
System.out.print(i);
```

d.
```
double x = 1;
double y = 1;
int i = 0;
while (y >= 1.5)
{
   x = x / 2;
   y = x + y;
   i++;
}
System.out.print(i);
```

■■ **R6.23** Give an example of a `for` loop where symmetric bounds are more natural. Give an example of a `for` loop where asymmetric bounds are more natural.

■ **R6.24** Add a storyboard panel for the conversion program in Section 6.6 on page 265 that shows a scenario where a user enters incompatible units.

■ **R6.25** In Section 6.6, we decided to show users a list of all valid units in the prompt. If the program supports many more units, this approach is unworkable. Give a storyboard panel that illustrates an alternate approach: If the user enters an unknown unit, a list of all known units is shown.

■ **R6.26** Change the storyboards in Section 6.6 to support a menu that asks users whether they want to convert units, see program help, or quit the program. The menu should be displayed at the beginning of the program, when a sequence of values has been converted, and when an error is displayed.

■ **R6.27** Draw a flow chart for a program that carries out unit conversions as described in Section 6.6.

■■ **R6.28** In Section 6.7.5, the code for finding the largest and smallest input initializes the `largest` and `smallest` variables with an input value. Why can't you initialize them with zero?

■ **R6.29** What are nested loops? Give an example where a nested loop is typically used.

■■ **R6.30** The nested loops

```
for (int i = 1; i <= height; i++)
{
   for (int j = 1; j <= width; j++) { System.out.print("*"); }
   System.out.println();
}
```

display a rectangle of a given width and height, such as

```
****
****
****
```

Write a *single* `for` loop that displays the same rectangle.

■■ **R6.31** Suppose you design an educational game to teach children how to read a clock. How do you generate random values for the hours and minutes?

■■■ **R6.32** In a travel simulation, Harry will visit one of his friends that are located in three states. He has ten friends in California, three in Nevada, and two in Utah. How do you produce a random number between 1 and 3, denoting the destination state, with a probability that is proportional to the number of friends in each state?

■ **Testing R6.33** Explain the differences between these debugger operations:

- Stepping into a method
- Stepping over a method

■■ **Testing R6.34** Explain in detail how to inspect the string stored in a `String` object in your debugger.

■■ **Testing R6.35** Explain in detail how to inspect the information stored in a `Rectangle` object in your debugger.

■■ **Testing R6.36** Explain in detail how to use your debugger to inspect the balance stored in a `BankAccount` object.

■■ **Testing R6.37** Explain the divide-and-conquer strategy to get close to a bug in a debugger.

PRACTICE EXERCISES

■ **E6.1** Write a program that reads an initial investment balance and an interest rate, then prints the number of years it takes for the investment to reach one million dollars.

■ **E6.2** Write programs with loops that compute

a. The sum of all even numbers between 2 and 100 (inclusive).

b. The sum of all squares between 1 and 100 (inclusive).

c. All powers of 2 from 2^0 up to 2^{20}.

d. The sum of all odd numbers between `a` and `b` (inclusive), where `a` and `b` are inputs.

e. The sum of all odd digits of an input. (For example, if the input is 32677, the sum would be 3 + 7 + 7 = 17.)

■■ **E6.3** Write programs that read a sequence of integer inputs and print

a. The smallest and largest of the inputs.

b. The number of even and odd inputs.

c. Cumulative totals. For example, if the input is 1 7 2 9, the program should print 1 8 10 19.

d. All adjacent duplicates. For example, if the input is 1 3 3 4 5 5 6 6 6 2, the program should print 3 5 6.

■■ **E6.4** Write programs that read a line of input as a string and print

a. Only the uppercase letters in the string.

b. Every second letter of the string.

c. The string, with all vowels replaced by an underscore.

d. The number of vowels in the string.

e. The positions of all vowels in the string.

■■ **E6.5** Complete the program in How To 6.1 on page 272. Your program should read twelve temperature values and print the month with the highest temperature.

■■ **E6.6** Write a program that reads a set of floating-point values. Ask the user to enter the values (prompting only a single time for the values), then print

- the average of the values.
- the smallest of the values.
- the largest of the values.
- the range, that is the difference between the smallest and largest.

Your program should use a class `DataSet`. That class should have a method

```
public void add(double value)
```

and methods `getAverage`, `getSmallest`, `getLargest`, and `getRange`.

■ **E6.7** Translate the following pseudocode for finding the minimum value from a set of inputs into a Java program.

```
Set a Boolean variable "first" to true.
While another value has been read successfully
   If first is true
      Set the minimum to the value.
      Set first to false.
   Else if the value is less than the minimum
      Set the minimum to the value.
Print the minimum.
```

■■■ **E6.8** Translate the following pseudocode for randomly permuting the characters in a string into a Java program.


```
Read a word.
Repeat word.length() times
   Pick a random position i in the word, but not the last position.
   Pick a random position j > i in the word.
   Swap the letters at positions j and i.
Print the word.
```

To swap the letters, construct substrings as follows:

Then replace the string with

```
first + word.charAt(j) + middle + word.charAt(i) + last
```

■ **E6.9** Write a program that reads a word and prints each character of the word on a separate line. For example, if the user provides the input `"Harry"`, the program prints

```
H
a
r
r
y
```

■■ **E6.10** Write a program that reads a word and prints the word in reverse. For example, if the user provides the input `"Harry"`, the program prints

```
yrraH
```

■ **E6.11** Write a program that reads a word and prints the number of vowels in the word. For this exercise, assume that `a e i o u y` are vowels. For example, if the user provides the input `"Harry"`, the program prints `2 vowels`.

■■■ **E6.12** Write a program that reads a word and prints all substrings, sorted by length. For example, if the user provides the input `"rum"`, the program prints

```
r
u
m
ru
um
rum
```

■ **E6.13** Write a program that prints all powers of 2 from 2^0 up to 2^{20}.

■■ **E6.14** Write a program that reads a number and prints all of its *binary digits:* Print the remainder `number % 2`, then replace the number with `number / 2`. Keep going until the number is `0`. For example, if the user provides the input 13, the output should be

```
1
0
1
1
```

■ **E6.15** Using the `Picture` class from Worked Example 6.2, apply a sunset effect to a picture, increasing the red value of each pixel by 30 percent (up to a maximum of 255).

■■ **E6.16** Using the `Picture` class from Worked Example 6.2, apply a "telescope" effect, turning all pixels black that are outside a circle. The center of the circle should be the image center, and the radius should be 40 percent of the width or height, whichever is smaller.

Cay Horstmann.

▪ **E6.17** Write a program that prints a multiplication table, like this:

```
 1   2   3   4   5   6   7   8   9  10
 2   4   6   8  10  12  14  16  18  20
 3   6   9  12  15  18  21  24  27  30
 . . .
10  20  30  40  50  60  70  80  90 100
```

▪▪ **E6.18** Write a program that reads an integer and displays, using asterisks, a filled and hollow square, placed next to each other. For example, if the side length is 5, the program should display

```
***** *****
***** *   *
***** *   *
***** *   *
***** *****
```

▪▪ **E6.19** Write a program that reads an integer and displays, using asterisks, a filled diamond of the given side length. For example, if the side length is 4, the program should display

```
   *
  ***
 *****
*******
 *****
  ***
   *
```

▪▪ **Business E6.20** *Currency conversion*. Write a program that first asks the user to type today's price for one dollar in Japanese yen, then reads U.S. dollar values and converts each to yen. Use 0 as a sentinel.

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▪▪ **Business E6.21** Write a program that first asks the user to type in today's price of one dollar in Japanese yen, then reads U.S. dollar values and converts each to Japanese yen. Use 0 as the sentinel value to denote the end of dollar inputs. Then the program reads a sequence of yen amounts and converts them to dollars. The second sequence is terminated by another zero value.

▪▪ **E6.22** *The Monty Hall Paradox*. Marilyn vos Savant described the following problem (loosely based on a game show hosted by Monty Hall) in a popular magazine: "Suppose you're on a game show, and you're given the choice of three doors: Behind one door is a car; behind the others, goats. You pick a door, say No. 1, and the host, who knows what's behind the doors, opens another door, say No. 3, which has a goat. He then says to you, "Do you want to pick door No. 2?" Is it to your advantage to switch your choice?"

Ms. vos Savant proved that it is to your advantage, but many of her readers, including some mathematics professors, disagreed, arguing that the probability would not change because another door was opened.

Your task is to simulate this game show. In each iteration, randomly pick a door number between 1 and 3 for placing the car. Randomly have the player pick a door. Randomly have the game show host pick a door having a goat (but not the door that the player picked). Increment a counter for strategy 1 if the player wins by switching

to the third door, and increment a counter for strategy 2 if the player wins by sticking with the original choice. Run 1,000 iterations and print both counters.

PROGRAMMING PROJECTS

■■ **P6.1** Enhance Worked Example 6.1 to check that the credit card number is valid. A valid credit card number will yield a result divisible by 10 when you:

Form the sum of all digits. Add to that sum every second digit, starting with the second digit from the right. Then add the number of digits in the second step that are greater than four. The result should be divisible by 10.

For example, consider the number 4012 8888 8888 1881. The sum of all digits is 89. The sum of the colored digits is 46. There are five colored digits larger than four, so the result is 140. 140 is divisible by 10 so the card number is valid.

■■ **P6.2** *Mean and standard deviation*. Write a program that reads a set of floating-point data values. Choose an appropriate mechanism for prompting for the end of the data set.

When all values have been read, print out the count of the values, the average, and the standard deviation. The average of a data set $\{x_1, \ldots, x_n\}$ is $\overline{x} = \sum x_i / n$, where $\sum x_i = x_1 + \cdots + x_n$ is the sum of the input values. The standard deviation is

$$s = \sqrt{\frac{\sum (x_i - \overline{x})^2}{n - 1}}$$

However, this formula is not suitable for the task. By the time the program has computed $\overline{x}$, the individual x_i are long gone. Until you know how to save these values, use the numerically less stable formula

$$s = \sqrt{\frac{\sum x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2}{n - 1}}$$

You can compute this quantity by keeping track of the count, the sum, and the sum of squares as you process the input values.

Your program should use a class `DataSet`. That class should have a method

```
public void add(double value)
```

and methods `getAverage` and `getStandardDeviation`.

■■ **P6.3** The *Fibonacci numbers* are defined by the sequence

$$f_1 = 1$$
$$f_2 = 1$$
$$f_n = f_{n-1} + f_{n-2}$$

Fibonacci numbers describe the growth of a rabbit population.

Reformulate that as

```
fold1 = 1;
fold2 = 1;
fnew = fold1 + fold2;
```

After that, discard `fold2`, which is no longer needed, and set `fold2` to `fold1` and `fold1` to `fnew`. Repeat an appropriate number of times.

Implement a program that prompts the user for an integer *n* and prints the *n*th Fibonacci number, using the above algorithm.

■■■ **P6.4** *Factoring of integers*. Write a program that asks the user for an integer and then prints out all its factors. For example, when the user enters 150, the program should print

```
2
3
5
5
```

Use a class `FactorGenerator` with a constructor `FactorGenerator(int numberToFactor)` and methods `nextFactor` and `hasMoreFactors`. Supply a class `FactorPrinter` whose `main` method reads a user input, constructs a `FactorGenerator` object, and prints the factors.

■■■ **P6.5** *Prime numbers*. Write a program that prompts the user for an integer and then prints out all prime numbers up to that integer. For example, when the user enters 20, the program should print

```
2
3
5
7
11
13
17
19
```

Recall that a number is a prime number if it is not divisible by any number except 1 and itself.

Use a class `PrimeGenerator` with methods `nextPrime` and `isPrime`. Supply a class `PrimePrinter` whose `main` method reads a user input, constructs a `PrimeGenerator` object, and prints the primes.

■■■ **P6.6** *The game of Nim*. This is a well-known game with a number of variants. The following variant has an interesting winning strategy. Two players alternately take marbles from a pile. In each move, a player chooses how many marbles to take. The player must take at least one but at most half of the marbles. Then the other player takes a turn. The player who takes the last marble loses.

Write a program in which the computer plays against a human opponent. Generate a random integer between 10 and 100 to denote the initial size of the pile. Generate a random integer between 0 and 1 to decide whether the computer or the human takes the first turn. Generate a random integer between 0 and 1 to decide whether the computer plays *smart* or *stupid*. In stupid mode the computer simply takes a random legal value (between 1 and *n* / 2) from the pile whenever it has a turn. In smart mode the computer takes off enough marbles to make the size of the pile a power of two minus 1—that is, 3, 7, 15, 31, or 63. That is always a legal move, except when the size of the pile is currently one less than a power of two. In that case, the computer makes a random legal move.

You will note that the computer cannot be beaten in smart mode when it has the first move, unless the pile size happens to be 15, 31, or 63. Of course, a human player who has the first turn and knows the winning strategy can win against the computer.

■■ **P6.7** *The Drunkard's Walk.* A drunkard in a grid of streets randomly picks one of four directions and stumbles to the next intersection, then again randomly picks one of

four directions, and so on. You might think that on average the drunkard doesn't move very far because the choices cancel each other out, but that is not the case.

Represent locations as integer pairs (x, y). Implement the drunkard's walk over 100 intersections, starting at (0, 0), and print the ending location.

■ **P6.8** A simple random generator is obtained by the formula

$$r_{\text{new}} = (a \cdot r_{\text{old}} + b)\%m$$

and then setting r_{old} to r_{new}. If m is chosen as 2^{32}, then you can compute

$$r_{\text{new}} = a \cdot r_{\text{old}} + b$$

because the truncation of an overflowing result to the `int` type is equivalent to computing the remainder.

Write a program that asks the user to enter a value for r_{old}. (Such a value is often called a *seed*). Then print the first 100 random integers generated by this formula, using $a = 32310901$ and $b = 1729$.

■■ **P6.9** *The Buffon Needle Experiment*. The following experiment was devised by Comte Georges-Louis Leclerc de Buffon (1707–1788), a French naturalist. A needle of length 1 inch is dropped onto paper that is ruled with lines 2 inches apart. If the needle drops onto a line, we count it as a *hit*. (See Figure 10.) Buffon discovered that the quotient *tries/hits* approximates π.

For the Buffon needle experiment, you must generate two random numbers: one to describe the starting position and one to describe the angle of the needle with the x-axis. Then you need to test whether the needle touches a grid line.

Generate the *lower* point of the needle. Its x-coordinate is irrelevant, and you may assume its y-coordinate y_{low} to be any random number between 0 and 2. The angle α between the needle and the x-axis can be any value between 0 degrees and 180 degrees (π radians). The upper end of the needle has y-coordinate

$$y_{\text{high}} = y_{\text{low}} + \sin\alpha$$

The needle is a hit if y_{high} is at least 2, as shown in Figure 11. Stop after 10,000 tries and print the quotient *tries/hits*. (This program is not suitable for computing the value of π. You need π in the computation of the angle.)

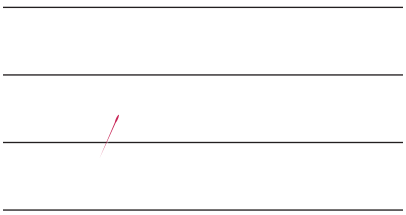


Figure 10
The Buffon Needle Experiment

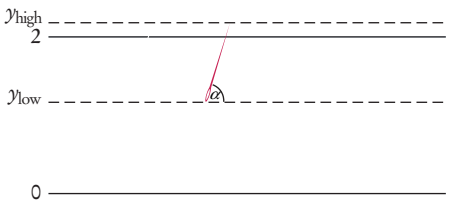


Figure 11
A Hit in the Buffon Needle Experiment

■■ **P6.10** In the 17th century, the discipline of probability theory got its start when a gambler asked a mathematician friend to explain some observations about dice games. Why did he, on average, lose a bet that at least one six would appear when rolling a die four times? And why did he seem to win a similar bet, getting at least one double-six when rolling a pair of dice 24 times?

Nowadays, it seems astounding that any person would roll a pair of dice 24 times in a row, and then repeat that many times over. Let's do that experiment on a computer instead. Simulate each game a million times and print out the wins and losses, assuming each bet was for $1.

■■ Business P6.11 Your company has shares of stock it would like to sell when their value exceeds a certain target price. Write a program that reads the target price and then reads the current stock price until it is at least the target price. Your program should use a `Scanner` to read a sequence of `double` values from standard input. Once the minimum is reached, the program should report that the stock price exceeds the target price.

■■ Business P6.12 Write an application to pre-sell a limited number of cinema tickets. Each buyer can buy as many as 4 tickets. No more than 100 tickets can be sold. Implement a program called `TicketSeller` that prompts the user for the desired number of tickets and then displays the number of remaining tickets. Repeat until all tickets have been sold, and then display the total number of buyers.

■■ Business P6.13 You need to control the number of people who can be in an oyster bar at the same time. Groups of people can always leave the bar, but a group cannot enter the bar if they would make the number of people in the bar exceed the maximum of 100 occupants. Write a program that reads the sizes of the groups that arrive or depart. Use negative numbers for departures. After each input, display the current number of occupants. As soon as the bar holds the maximum number of people, report that the bar is full and exit the program.

■■ Science P6.14 In a predator-prey simulation, you compute the populations of predators and prey, using the following equations:

$$prey_{n+1} = prey_n \times (1 + A - B \times pred_n)$$
$$pred_{n+1} = pred_n \times (1 - C + D \times prey_n)$$

Here, A is the rate at which prey birth exceeds natural death, B is the rate of predation, C is the rate at which predator deaths exceed births without food, and D represents predator increase in the presence of food.

Write a program that prompts users for these rates, the initial population sizes, and the number of periods. Then print the populations for the given number of periods. As inputs, try $A = 0.1$, $B = C = 0.01$, and $D = 0.00002$ with initial prey and predator populations of 1,000 and 20.

■■ Science P6.15 *Projectile flight*. Suppose a cannonball is propelled straight into the air with a starting velocity v_0. Any calculus book will state that the position of the ball after t seconds is $s(t) = -\frac{1}{2}gt^2 + v_0t$, where $g = 9.81\ \text{m/s}^2$ is the gravitational force of the earth. No calculus textbook ever states why someone would want to carry out such an obviously dangerous experiment, so we will do it in the safety of the computer.

In fact, we will confirm the theorem from calculus by a simulation. In our simulation, we will consider how the ball moves in very short time intervals Δt. In a short time interval the velocity v is nearly constant, and we can compute the distance the ball moves as $\Delta s = v\Delta t$. In our program, we will simply set

```
const double DELTA_T = 0.01;
```

and update the position by

```
s = s + v * DELTA_T;
```

The velocity changes constantly—in fact, it is reduced by the gravitational force of the earth. In a short time interval, $\Delta v = -g\Delta t$, we must keep the velocity updated as

```
v = v - g * DELTA_T;
```

In the next iteration the new velocity is used to update the distance.

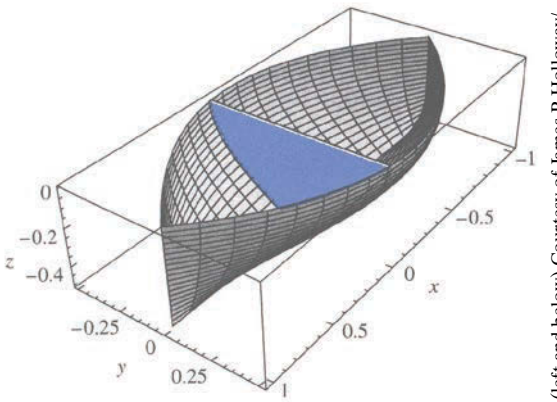
Now run the simulation until the cannonball falls back to the earth. Get the initial velocity as an input (100 m/s is a good value). Update the position and velocity 100 times per second, but print out the position only every full second. Also printout the values from the exact formula $s(t) = -\frac{1}{2}gt^2 + v_0 t$ for comparison.

Note: You may wonder whether there is a benefit to this simulation when an exact formula is available. Well, the formula from the calculus book is *not* exact. Actually, the gravitational force diminishes the farther the cannonball is away from the surface of the earth. This complicates the algebra sufficiently that it is not possible to give an exact formula for the actual motion, but the computer simulation can simply be extended to apply a variable gravitational force. For cannonballs, the calculus-book formula is actually good enough, but computers are necessary to compute accurate trajectories for higher-flying objects such as ballistic missiles.

▪▪▪ Science P6.16 A simple model for the hull of a ship is given by

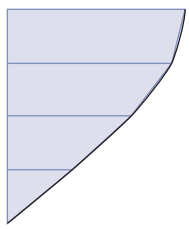
$$|y| = \frac{B}{2}\left[1 - \left(\frac{2x}{L}\right)^2\right]\left[1 - \left(\frac{z}{T}\right)^2\right]$$

where B is the beam, L is the length, and T is the draft. (*Note:* There are two values of y for each x and z because the hull is symmetric from starboard to port.)



(left and below) Courtesy of James P. Holloway/ John Wiley & Sons, Inc.

The cross-sectional area at a point x is called the "section" in nautical parlance. To compute it, let z go from 0 to $-T$ in n increments, each of size T/n. For each value of z, compute the value for y. Then sum the areas of trapezoidal strips. At right are the strips where $n = 4$.

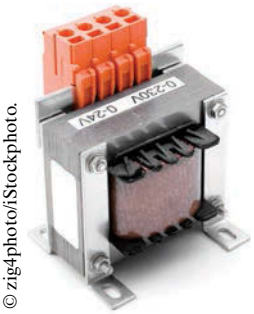


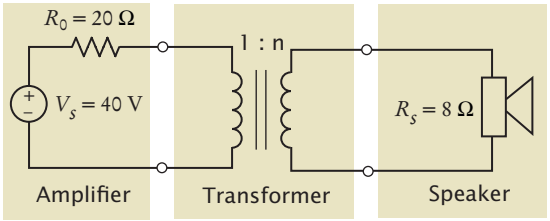
Write a program that reads in values for B, L, T, x, and n and then prints out the cross-sectional area at x.

▪ Science P6.17 Radioactive decay of radioactive materials can be modeled by the equation $A = A_0 e^{-t(\log 2/h)}$, where A is the amount of the material at time t, A_0 is the amount at time 0, and h is the half-life.

Technetium-99 is a radioisotope that is used in imaging of the brain. It has a half-life of 6 hours. Your program should display the relative amount A / A_0 in a patient body every hour for 24 hours after receiving a dose.

▪▪▪ Science P6.18 The photo at left shows an electric device called a "transformer". Transformers are often constructed by wrapping coils of wire around a ferrite core. The figure below illustrates a situation that occurs in various audio devices such as cell phones and music players. In this circuit, a transformer is used to connect a speaker to the output of an audio amplifier.





The symbol used to represent the transformer is intended to suggest two coils of wire. The parameter n of the transformer is called the "turns ratio" of the transformer. (The number of times that a wire is wrapped around the core to form a coil is called the number of turns in the coil. The turns ratio is literally the ratio of the number of turns in the two coils of wire.)

When designing the circuit, we are concerned primarily with the value of the power delivered to the speakers—that power causes the speakers to produce the sounds we want to hear. Suppose we were to connect the speakers directly to the amplifier without using the transformer. Some fraction of the power available from the amplifier would get to the speakers. The rest of the available power would be lost in the amplifier itself. The transformer is added to the circuit to increase the fraction of the amplifier power that is delivered to the speakers.

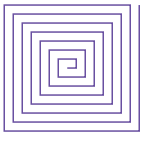
The power, P_s, delivered to the speakers is calculated using the formula

$$P_s = R_s \left(\frac{nV_s}{n^2 R_0 + R_s} \right)^2$$

Write a program that models the circuit shown and varies the turns ratio from 0.01 to 2 in 0.01 increments, then determines the value of the turns ratio that maximizes the power delivered to the speakers.

▪ Graphics P6.19 Write a graphical application that displays a checkerboard with 64 squares, alternating white and black.

▪▪▪ Graphics P6.20 Write a graphical application that draws a spiral, such as this one:



▪▪ Graphics P6.21 It is easy and fun to draw graphs of curves with the Java graphics library. Simply draw 100 line segments joining the points $(x, f(x))$ and $(x + d, f(x + d))$, where x ranges from $x_{\min}$ to $x_{\max}$ and $d = (x_{\max} - x_{\min})/100$.

Draw the curve $f(x) = 0.00005x^3 - 0.03x^2 + 4x + 200$, where x ranges from 0 to 400 in this fashion.

■■■ **Graphics P6.22** Draw a picture of the "four-leaved rose" whose equation in polar coordinates is $r = \cos(2\theta)$. Let θ go from 0 to 2π in 100 steps. Each time, compute r and then compute the (x, y) coordinates from the polar coordinates by using the formula

$$x = r \cdot \cos(\theta), y = r \cdot \sin(\theta)$$

ANSWERS TO SELF-CHECK QUESTIONS

1. 23 years.
2. 8 years.
3. Add a statement

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

   as the last statement in the `while` loop.
4. The program prints the same output. This is because the balance after 14 years is slightly below $20,000, and after 15 years, it is slightly above $20,000.
5. `2 4 8 16 32 64 128`

   Note that the value 128 is printed even though it is larger than 100.
6.
   ```
   n    output
   5
   4    4
   3    3
   2    2
   1    1
   0    0
   -1   -1
   ```
7.
   ```
   n    output
   1    1,
   2    1, 2,
   3    1, 2, 3,
   4
   ```

   There is a comma after the last value. Usually, commas are between values only.
8.
   ```
   a   n   r   i
   2   4   1   1
           2   2
           4   3
           8   4
          16   5
   ```

   The code computes a^n.
9.
   ```
   n    output
   1    1
   11   11
   21   21
   31   31
   41   41
   51   51
   61   61
   ...
   ```

   This is an infinite loop. `n` is never equal to 50.
10.
    ```
    count  temp
    1      123
    2      12.3
    3      1.23
    ```

    This yields the correct answer. The number 123 has 3 digits.

    ```
    count  temp
    1      100
    2      10.0
    ```

    This yields the wrong answer. The number 100 also has 3 digits. The loop condition should have been **`while (temp >= 10)`**.
11.
    ```
    int year = 1;
    while (year <= numberOfYears)
    {
       double interest = balance * RATE / 100;
       balance = balance + interest;
       year++;
    }
    ```
12. 11 numbers: 10 9 8 7 6 5 4 3 2 1 0
13.
    ```
    for (int i = 10; i <= 20; i = i + 2)
    {
       System.out.println(i);
    }
    ```
14.
    ```
    int sum = 0;
    for (int i = 1; i <= n; i++)
    {
       sum = sum + i;
    }
    ```
15.
    ```
    final int PERIODS = 5;
    for (int i = 1; i <= PERIODS; i++)
    {
       invest.waitYears(YEARS);
       System.out.printf(
          "The balance after %d years is %.2f\n",
          invest.getYears(), invest.getBalance());
    }
    ```
16.
    ```
    do
    {
       System.out.print(
          "Enter an integer between 0 and 100: ");
       value = in.nextInt();
    }
    while (value < 0 || value > 100);
    ```

17.
```
int value = 100;
while (value >= 100)
{
   System.out.print("Enter a value < 100: ");
   value = in.nextInt();
}
```
Here, the variable `value` had to be initialized with an artificial value to ensure that the loop is entered at least once.

18. Yes. The `do` loop

`do { body } while (condition);`

is equivalent to this `while` loop:

```
boolean first = true;
while (first || condition)
{
   body;
   first = false;
}
```

19.
```
int x;
int sum = 0;
do
{
   x = in.nextInt();
   sum = sum + x;
}
while (x != 0);
```

20.
```
int x = 0;
int previous;
do
{
   previous = x;
   x = in.nextInt();
   sum = sum + x;
}
while (x != 0 && previous != x);
```

21. `No data`

22. The first check ends the loop after the sentinel has been read. The second check ensures that the sentinel is not processed as an input value.

23. The `while` loop would never be entered. The user would never be prompted for input. Because `count` stays 0, the program would then print `"No data"`.

24. The `nextDouble` method also returns `false`. A more accurate prompt would have been: "Enter values, a key other than a digit to quit:" But that might be more confusing to the program user who would need to ponder which key to choose.

25. If the user doesn't provide any numeric input, the first call to `in.nextDouble()` will fail.

26. *Computing the average*

```
Enter scores, Q to quit: 90 80 90 100 80 Q
The average is 88
(Program exits)
```

27. *Simple conversion*

```
Your conversion question: How many in are 30 cm
30 cm = 11.81 in
(Program exits)
```
Only one value can be converted

Run program again for another question

Unknown unit

```
Your conversion question: How many inches are 30 cm?
Unknown unit: inches
Known units are in, ft, mi, mm, cm, m, km, oz, lb, g, kg, tsp, tbsp, pint, gal
(Program exits)
```

Program doesn't understand question syntax

```
Your conversion question: What is an ångström?
Please formulate your question as "How many (unit) are (value) (unit)?"
(Program exits)
```

28. *One score is not enough*

```
Enter scores, Q to quit: 90 Q
Error: At least two scores are required.
(Program exits)
```

29. It would not be possible to implement this interface using the Java features we have covered up to this point. There is no way for the program to know when the first set of inputs ends. (When you read numbers with `value = in.nextDouble()`, it is your choice whether to put them on a single line or multiple lines.)

30. *Comparing two interest rates*

```
First interest rate in percent: 5
Second interest rate in percent: 10
Years: 5
Year      5%          10%
-------------------------
0     10000.00    10000.00
1     10500.00    11000.00
2     11025.00    12100.00
3     11576.25    13310.00
4     12155.06    14641.00
5     12762.82    16105.10
```
This row clarifies that 1 means the end of the first year

31. The total is zero.

32.
```
double total = 0;
while (in.hasNextDouble())
{
```

```
   double input = in.nextDouble();
   if (input > 0) { total = total + input; }
}
```

33. `position` is `str.length()` and `ch` is unchanged from its initial value, `'?'`. Note that `ch` must be initialized with some value—otherwise the compiler will complain about a possibly uninitialized variable.

34. The loop will stop when a match is found, but you cannot access the match because neither `position` nor `ch` are defined outside the loop.

35. Start the loop at the end of string:

```
boolean found = false;
int i = str.length() - 1;
while (!found && i >= 0)
{
   char ch = str.charAt(i);
   if (ch == ' ') { found = true; }
   else { i--; }
}
```

36. The initial call to `in.nextDouble()` fails, terminating the program. One solution is to do all input in the loop and introduce a Boolean variable that checks whether the loop is entered for the first time.

```
double input = 0;
boolean first = true;
while (in.hasNextDouble())
{
   double previous = input;
   input = in.nextDouble();
   if (first) { first = false; }
   else if (input == previous)
   {
      System.out.println("Duplicate input");
   }
}
```

37. All values in the inner loop should be displayed on the same line.

38. Change lines 13, 18, and 30 to `for (int n = 0; n <= NMAX; n++)`. Change `NMAX` to 5.

39. 60: The outer loop is executed 10 times, and the inner loop 6 times.

40.
```
0123
1234
2345
```

41.
```
for (int i = 1; i <= 3; i++)
{
   for (int j = 1; j <= 4; j++)
   {
      System.out.print("[]");
   }
   System.out.println();
}
```

42. Compute `generator.nextInt(2)`, and use 0 for heads, 1 for tails, or the other way around.

43. Compute `generator.nextInt(4)` and associate the numbers 0 . . . 3 with the four suits. Then compute `generator.nextInt(13)` and associate the numbers 0 . . . 12 with Jack, Ace, 2 . . . 10, Queen, and King.

44. Construct two `Die` objects:

```
Die d1 = new Die(6);
Die d2 = new Die(6);
```

Then cast and print both of them:

```
System.out.println(
   d1.cast() + " " + d2.cast());
```

45. The call will produce a value between 2 and 12, but all values have the same probability. When throwing a pair of dice, the number 7 is six times as likely as the number 2. The correct formula is

```
int sum = generator.nextInt(6)
   + generator.nextInt(6) + 2;
```

46. `generator.nextDouble() * 100.0`

47. You should step over it because you are not interested in debugging the internals of the `println` method.

48. You should set a breakpoint. Stepping through loops can be tedious.

49. Unfortunately, most debuggers do not support going backwards. Instead, you must restart the program. Try setting breakpoints at the lines in which the variable is changed.

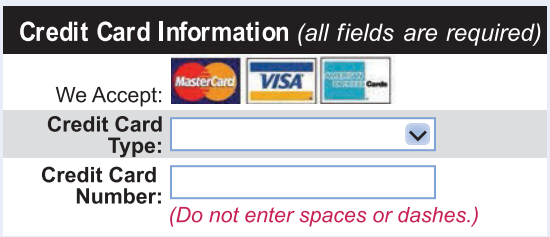
50. No, there is no need. You can just inspect the variables in the debugger.

51. For short programs, you certainly could. But when programs get longer, it would be very time-consuming to trace them manually.

WORKED EXAMPLE 6.1 Credit Card Processing

One of the minor annoyances of online shopping is that many Web sites require you to enter a credit card without spaces or dashes, which makes double-checking the number rather tedious. How hard can it be to remove dashes or spaces from a string? Not hard at all, as this worked example shows.

Problem Statement Your task is to remove all spaces or dashes from a string `creditCardNumber`. For example, if `creditCardNumber` is `"4123-5678-9012-3450"`, then you should set it to `"4123567890123450"`.



Step 1 Decide what work must be done *inside* the loop.

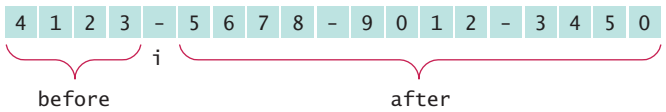
In the loop, we visit each character in turn. You can get the `i`th character as

```
char ch = creditCardNumber.charAt(i);
```

If it is not a dash or space, we move on to the next character. If it is a dash or space, we remove the offending character.

```
Repeat
   Set ch to the ith character of creditCardNumber.
   If ch is a space or dash
      Remove the character from creditCardNumber.
   Else
      Increment i.
```

You may wonder how to remove a character from a string in Java. Here is the procedure for removing the character at position `i`: Take the substrings that end before `i` and start after `i`, and concatenate them.




```
String before = creditCardNumber.substring(0, i);
String after = creditCardNumber.substring(i + 1);
creditCardNumber = before + after;
```

Note that we do *not* increment `i` after removing a character. For example, in the figure above, `i` was 4, and we removed the dash at position 4. The next time we enter the loop, we want to reexamine position 4 which now contains the character `5`.

Step 2 Specify the loop condition.

We stay in the loop while the index `i` is a valid position. That is,

```
i < creditCardNumber.length()
```

Step 3 Choose the loop type.

We don't know at the outset how often the loop is repeated. It depends on the number of dashes and spaces that we find. Therefore, we will choose a `while` loop. Why not a `do` loop? If we are given an empty string (because the user has not provided any credit card number at all), we do not want to enter the loop at all.

Step 4 Process the result after the loop has finished.

In this case, the result is simply the string.

Step 5 Trace the loop with typical examples.

The complete loop is

```
i = 0
While i < creditCardNumber.length()
   ch = the ith character of creditCardNumber.
   If ch is a space or dash
      Remove the character from creditCardNumber.
   Else
      Increment i.
```

It is a bit tedious to trace a string with 20 characters, so we will use a shorter example:

creditCardNumber	i	ch
4-56-7	0	4
4-56-7	1	-
456-7	1	5
456-7	2	6
456-7	3	-
4567	3	7

Step 6 Implement the loop in Java.

Here's the complete program:

worked_example_1/CCNumber.java

```
1  /**
2     This program removes spaces and dashes from a credit card number.
3  */
4  public class CCNumber
5  {
6     public static void main(String[] args)
7     {
8        String creditCardNumber = "4123-5678-9012-3450";
9
10       int i = 0;
11       while (i < creditCardNumber.length())
12       {
13          char ch = creditCardNumber.charAt(i);
14          if (ch == ' ' || ch == '-')
15          {
16             // Remove the character at position i
17
18             String before = creditCardNumber.substring(0, i);
19             String after = creditCardNumber.substring(i + 1);
```

```
20             creditCardNumber = before + after;
21          }
22          else
23          {
24             i++;
25          }
26       }
27
28       System.out.println(creditCardNumber);
29    }
30 }
```

WORKED EXAMPLE 6.2

Manipulating the Pixels in an Image

A digital image is made up of *pixels*. Each pixel is a tiny square of a given color. In this Worked Example, we will use a class `Picture` that has methods for loading an image and accessing its pixels.

Problem Statement Your task is to convert an image into its negative: turning white to black, cyan to red, and so on. The result is a negative image of the kind that old-fashioned film cameras used to produce.

Cay Horstmann.

The implementation of the `Picture` class uses the Java image library and is beyond the scope of this book, but here are the relevant parts of the public interface:

```
public class Picture
{
   . . .
   /**
      Gets the width of this picture.
      @return the width
   */
   public int getWidth() { . . . }

   /**
      Gets the height of this picture.
      @return the height
   */
   public int getHeight() { . . . }

   /**
      Loads a picture from a given source.
      @param source the image source. If the source starts
      with http://, it is a URL, otherwise, a filename.
   */
   public void load(String source) { . . . }

   /**
      Gets the color of a pixel.
      @param x the column index (between 0 and getWidth() - 1)
      @param y the row index (between 0 and getHeight() - 1)
      @return the color of the pixel at position (x, y)
   */
   public Color getColorAt(int x, int y) { . . . }

   /**
      Sets the color of a pixel.
      @param x the column index (between 0 and getWidth() - 1)
      @param y the row index (between 0 and getHeight() - 1)
      @param c the color for the pixel at position (x, y)
   */
   public void setColorAt(int x, int y, Color c) { . . . }

   . . .
```

```
}
```

Now consider the task of converting an image into its negative. The negative of a `Color` object is computed like this:

```
Color original = ...;
Color negative = new Color(255 - original.getRed(),
   255 - original.getGreen(),
   255 - original.getBlue());
```

We want to apply this operation to each pixel in the image.

To process all pixels, we can use one of the following two strategies:

```
For each row
   For each pixel in the row
      Process the pixel.
```

or

```
For each column
   For each pixel in the column
      Process the pixel.
```

Because our pixel class uses *x*/*y* coordinates to access a pixel, it turns out to be more natural to use the second strategy. (In Chapter 7, you will encounter two-dimensional arrays that are accessed with row/column coordinates. In that situation, use the first form.)

To traverse each column, the *x*-coordinate starts at `0`. Because there are `pic.getWidth()` columns, we use the loop

```
for (int x = 0; x < pic.getWidth(); x++)
```

Once a column has been fixed, we need to traverse all *y*-coordinates in that column, starting from `0`. There are `pic.getHeight()` rows, so our nested loops are

```
for (int x = 0; x < pic.getWidth(); x++)
{
   for (int y = 0; y < pic.getHeight(); y++)
   {
      Color original = pic.getColorAt(x, y);
      . . .
   }
}
```

The following program solves our image manipulation problem:

worked_example_2/Negative.java

```
1  import java.awt.Color;
2
3  public class Negative
4  {
5     public static void main(String[] args)
6     {
7        Picture pic = new Picture();
8        pic.load("queen-mary.png");
9        for (int x = 0; x < pic.getWidth(); x++)
10       {
11          for (int y = 0; y < pic.getHeight(); y++)
12          {
13             Color original = pic.getColorAt(x, y);
14             Color negative = new Color(255 - original.getRed(),
15                255 - original.getGreen(),
16                255 - original.getBlue());
17             pic.setColorAt(x, y, negative);
18          }
```

```
19          }
20       }
21    }
```

WORKED EXAMPLE 6.3 A Sample Debugging Session

This Worked Example presents a realistic example for running a debugger by examining a `Word` class whose primary purpose is to count the number of syllables in a word.

Problem Statement The `Word` class uses this rule for counting syllables:

> Each group of adjacent vowels (a, e, i, o, u, y) counts as one syllable (for example, the "ea" in "peach" contributes one syllable, but the "e . . . o" in "yellow" counts as two syllables). However, an "e" at the end of a word doesn't count as a syllable. Each word has at least one syllable, even if the previous rules give a count of `0`.

Also, when you construct a word from a string, any characters at the beginning or end of the string that aren't letters are stripped off. That is useful when you read the input using the `next` method of the `Scanner` class. Input strings can still contain quotation marks and punctuation marks, and we don't want them as part of the word.

Your task is to find and correct the errors in this program.

Here is the source code. There are a couple of bugs in this class.

worked_example_3/Word.java

```
1  /**
2     This class describes words in a document. There are a couple
3     of bugs in this class.
4  */
5  public class Word
6  {
7     private String text;
8
9     /**
10       Constructs a word by removing leading and trailing non-
11       letter characters, such as punctuation marks.
12       @param s the input string
13    */
14    public Word(String s)
15    {
16       int i = 0;
17       while (i < s.length() && !Character.isLetter(s.charAt(i)))
18       {
19          i++;
20       }
21       int j = s.length() - 1;
22       while (j > i && !Character.isLetter(s.charAt(j)))
23       {
24          j--;
25       }
26       text = s.substring(i, j);
27    }
28
29    /**
30       Returns the text of the word, after removal of the
31       leading and trailing non-letter characters.
32       @return the text of the word
33    */
34    public String getText()
35    {
36       return text;
37    }
38
```

```
39    /**
40       Counts the syllables in the word.
41       @return the syllable count
42    */
43    public int countSyllables()
44    {
45       int count = 0;
46       int end = text.length() - 1;
47       if (end < 0) { return 0; } // The empty string has no syllables
48
49       // An e at the end of the word doesn't count as a vowel
50       char ch = text.charAt(end);
51       if (ch == 'e' || ch == 'E') { end--; }
52
53       boolean insideVowelGroup = false;
54       for (int i = 0; i <= end; i++)
55       {
56          ch = text.charAt(i);
57          String vowels = "aeiouyAEIOUY";
58          if (vowels.indexOf(ch) >= 0)
59          {
60             // ch is a vowel
61             if (!insideVowelGroup)
62             {
63                // Start of new vowel group
64                count++;
65                insideVowelGroup = true;
66             }
67          }
68       }
69
70       // Every word has at least one syllable
71       if (count == 0) { count = 1; }
72
73       return count;
74    }
75 }
```

Here is a simple test class. Type in a sentence, and the syllable counts of all words are displayed.

worked_example_3/SyllableCounter.java

```
1  import java.util.Scanner;
2
3  /**
4     This program counts the syllables of all words in a sentence.
5  */
6  public class SyllableCounter
7  {
8     public static void main(String[] args)
9     {
10       Scanner in = new Scanner(System.in);
11
12       System.out.println("Enter a sentence ending in a period.");
13
14       String input;
15       do
16       {
17          input = in.next();
18          Word w = new Word(input);
```

```
19          int syllables = w.countSyllables();
20          System.out.println("Syllables in " + input + ": " + syllables);
21       }
22       while (!input.endsWith("."));
23    }
24 }
```

Supply this input:

```
Hello yellow peach.
```

Then the output is

```
Syllables in Hello: 1
Syllables in yellow: 1
Syllables in peach.: 1
```

That is not very promising.

First, set a breakpoint in the first line of the `countSyllables` method of the `Word` class, in line 43 of `Word.java`. Then start the program. The program will prompt you for the input. The program will stop at the breakpoint you just set.

First, the `countSyllables` method checks the last character of the word to see if it is a letter `'e'`. Let's just verify that this works correctly. Run the program to line 51 (see Figure 12).

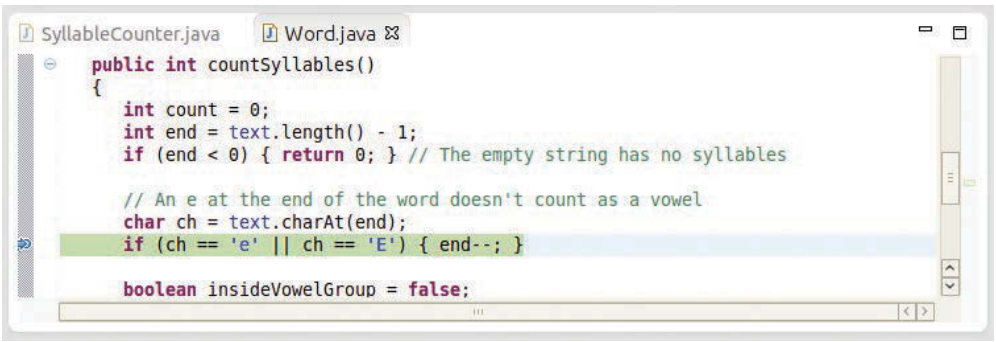


Figure 12 Debugging the `countSyllables` Method

Now inspect the variable `ch`. This particular debugger has a handy display of all current local and instance variables—see Figure 13. If yours doesn't, you may need to inspect `ch`

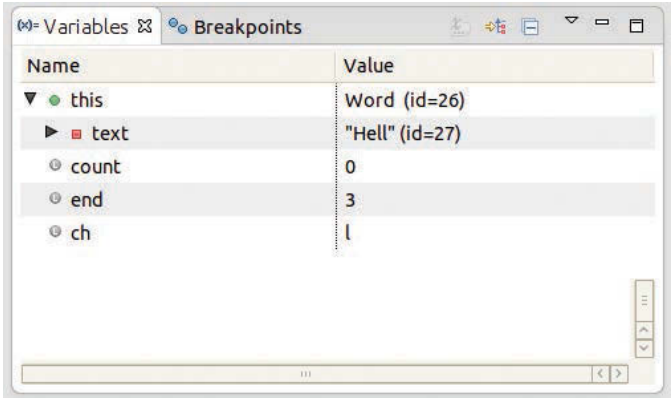


Figure 13
The Current Values of the Local and Instance Variables

manually. You can see that `ch` contains the value `'l'`. That is strange. Look at the source code. The `end` variable was set to `text.length() - 1`, the last position in the `text` string, and `ch` is the character at that position.

Looking further, you will find that `end` is set to 3, not 4, as you would expect. And `text` contains the string `"Hell"`, not `"Hello"`. Thus, it is no wonder that `countSyllables` returns the answer 1. We'll need to look elsewhere for the culprit. Apparently, the `Word` constructor contains an error.

Unfortunately, a debugger cannot go back in time. Thus, you must stop the debugger, set a breakpoint in the `Word` constructor, and restart the debugger. Supply the input once again. The debugger will stop at the beginning of the `Word` constructor. The constructor sets two variables `i` and `j`, skipping past any nonletters at the beginning and the end of the input string. Set a breakpoint past the end of the second loop (see Figure 14) so that you can inspect the values of `i` and `j`.

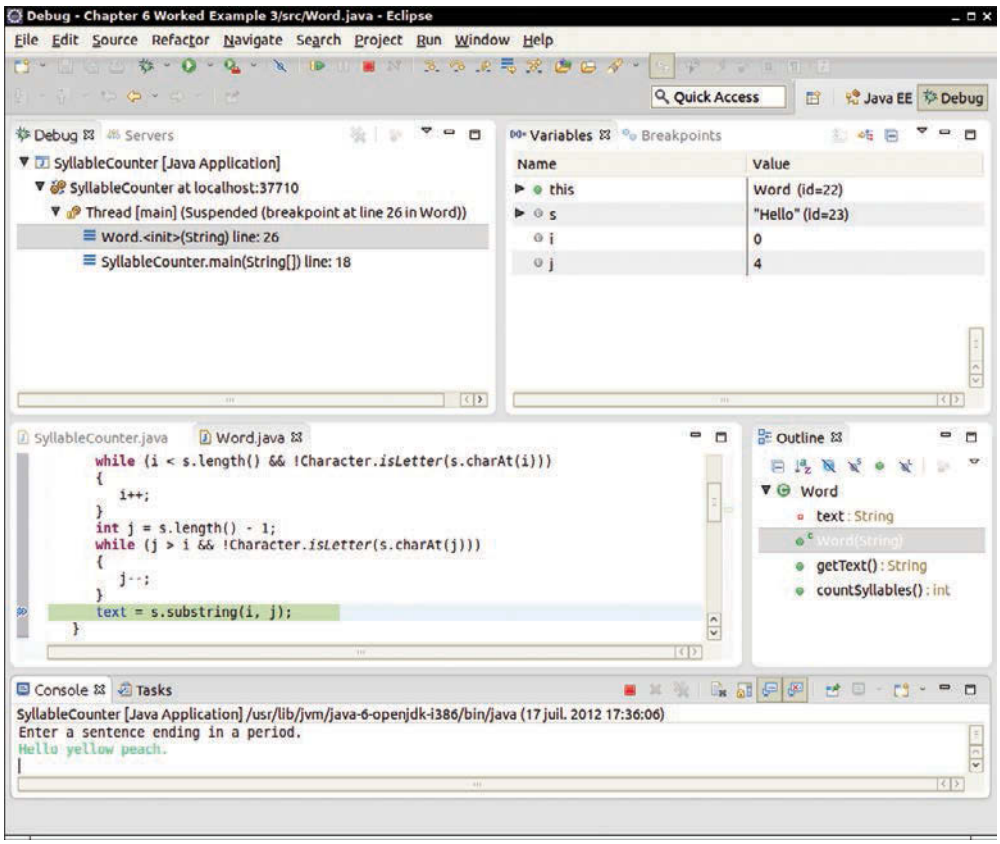


Figure 14 Debugging the `Word` Constructor

At this point, inspecting `i` and `j` shows that `i` is `0` and `j` is `4`. That makes sense—there were no punctuation marks to skip. So why is `text` being set to `"Hell"`? Recall that the `substring` method counts positions up to, but not including, the second parameter. Thus, the correct call should be

```
text = s.substring(i, j + 1);
```

This is a very typical off-by-one error.

Fix this error, recompile the program, and try the three test cases again. You will now get the output

```
Syllables in Hello: 1
Syllables in yellow: 1
Syllables in peach.: 1
```

As you can see, there still is a problem. Erase all breakpoints and set a breakpoint in the `countSyllables` method. Start the debugger and supply the input `"Hello."`. When the debugger stops at the breakpoint, start single stepping through the lines of the method. Here is the code of the loop that counts the syllables:

```
boolean insideVowelGroup = false;
for (int i = 0; i <= end; i++)
{
   ch = text.charAt(i);
   String vowels = "aeiouyAEIOUY";
   if (vowels.indexOf(ch) >= 0)
   {
      // ch is a vowel
      if (!insideVowelGroup)
      {
         // Start of new vowel group
         count++;
         insideVowelGroup = true;
      }
   }
}
```

In the first iteration through the loop, the debugger skips the `if` statement. That makes sense, because the first letter, `'H'`, isn't a vowel. In the second iteration, the debugger enters the `if` statement, as it should, because the second letter, `'e'`, is a vowel. The `insideVowelGroup` variable is set to `true`, and the vowel counter is incremented. In the third iteration, the `if` statement is again skipped, because the letter `'l'` is not a vowel. But in the fifth iteration, something weird happens. The letter `'o'` is a vowel, and the `if` statement is entered. But the second `if` statement is skipped, and `count` is not incremented again.

Why? The `insideVowelGroup` variable is still true, even though the first vowel group was finished when the consonant `'l'` was encountered. Reading a consonant should set `insideVowelGroup` back to `false`. This is a more subtle logic error, but not an uncommon one when designing a loop that keeps track of the processing state. To fix it, stop the debugger and add the following clause:

```
if (vowels.indexOf(ch) >= 0)
{
   . . .
}
else insideVowelGroup = false;
```

Now recompile and run the test once again. The output is:

```
Syllables in Hello: 2
Syllables in yellow: 2
Syllables in peach.: 1
```

Is the program now free from bugs? That is not a question the debugger can answer. Remember: Testing can show only the presence of bugs, not their absence.

CHAPTER 7

ARRAYS AND ARRAY LISTS

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CHAPTER GOALS

To collect elements using arrays and array lists

To use the enhanced for loop for traversing arrays and array lists

To learn common algorithms for processing arrays and array lists

To work with two-dimensional arrays

To understand the concept of regression testing

CHAPTER CONTENTS

In many programs, you need to collect large numbers of values. In Java, you use the array and array list constructs for this purpose. Arrays have a more concise syntax, whereas array lists can automatically grow to any desired size. In this chapter, you will learn about arrays, array lists, and common algorithms for processing them.

7.1 Arrays

We start this chapter by introducing the array data type. Arrays are the fundamental mechanism in Java for collecting multiple values. In the following sections, you will learn how to declare arrays and how to access array elements.

7.1.1 Declaring and Using Arrays

Suppose you write a program that reads a sequence of values and prints out the sequence, marking the largest value, like this:

```
32
54
67.5
29
35
80
115 <= largest value
44.5
100
65
```

You do not know which value to mark as the largest one until you have seen them all. After all, the last value might be the largest one. Therefore, the program must first store all values before it can print them.

Could you simply store each value in a separate variable? If you know that there are ten values, then you could store the values in ten variables `value1`, `value2`, `value3`, …, `value10`. However, such a sequence of variables is not very practical to use. You would have to write quite a bit of code ten times, once for each of the variables. In Java, an **array** is a much better choice for storing a sequence of values of the same type.

An array collects a sequence of values of the same type.

Here we create an array that can hold ten values of type `double`:

```
new double[10]
```

The number of elements (here, 10) is called the *length* of the array.

The `new` operator constructs the array. You will want to store the array in a variable so that you can access it later.

The type of an array variable is the type of the element to be stored, followed by `[]`. In this example, the type is `double[]`, because the element type is `double`.

Here is the declaration of an array variable of type `double[]` (see Figure 1):

```
double[] values; 1
```

When you declare an array variable, it is not yet initialized. You need to initialize the variable with the array:

```
double[] values = new double[10]; 2
```

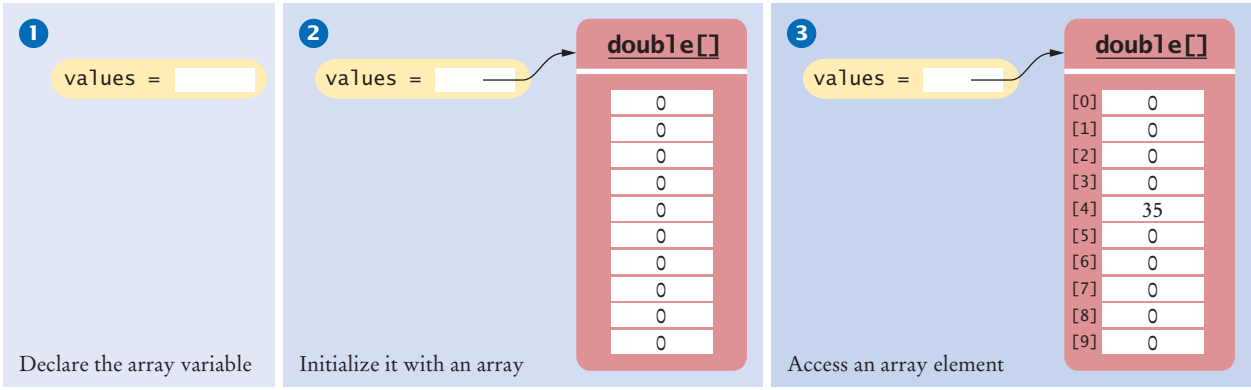


Figure 1 An Array of Size 10

Now `values` is initialized with an array of 10 numbers. By default, each number in the array is 0.

When you declare an array, you can specify the initial values. For example,

```
double[] moreValues = { 32, 54, 67.5, 29, 35, 80, 115, 44.5, 100, 65 };
```

When you supply initial values, you don't use the `new` operator. The compiler determines the length of the array by counting the initial values.

Individual elements in an array are accessed by an integer index `i`, using the notation *array*`[i]`.

To access a value in an array, you specify which "slot" you want to use. That is done with the `[]` operator:

```
values[4] = 35;
```

3

Now the number 4 slot of `values` is filled with 35 (see Figure 1). This "slot number" is called an *index*. Each slot in an array contains an *element*.

An array element can be used like any variable.

Because `values` is an array of `double` values, each element `values[i]` can be used like any variable of type `double`. For example, you can display the element with index 4 with the following command:

```
System.out.println(values[4]);
```

Syntax 7.1 Arrays

Syntax

To construct an array: `new` *typeName*`[`*length*`]`

To access an element: *arrayReference*`[`*index*`]`

```
double[] values = new double[10];
double[] moreValues = { 32, 54, 67.5, 29, 35 };
values[i] = 0;
```

Name of array variable

Type of array variable

Element type

Length

Use brackets to access an element.

List of initial values

The index must be ≥ 0 and < the length of the array.

See page 314.

Like a mailbox that is identified by a box number, an array element is identified by an index.

Before continuing, we must take care of an important detail of Java arrays. If you look carefully at Figure 1, you will find that the *fifth* element was filled when we changed `values[4]`. In Java, the elements of arrays are numbered *starting at 0*. That is, the legal elements for the `values` array are

`values[0]`, the first element
`values[1]`, the second element
`values[2]`, the third element
`values[3]`, the fourth element
`values[4]`, the fifth element
. . .
`values[9]`, the tenth element

In other words, the declaration

```
double[] values = new double[10];
```

creates an array with ten elements. In this array, an index can be any integer ranging from 0 to 9.

An array index must be at least zero and less than the size of the array.

You have to be careful that the index stays within the valid range. Trying to access an element that does not exist in the array is a serious error. For example, if `values` has ten elements, you are not allowed to access `values[20]`. Attempting to access an element whose index is not within the valid index range is called a **bounds error**. The compiler does not catch this type of error. When a bounds error occurs at run time, it causes a run-time exception.

A bounds error, which occurs if you supply an invalid array index, can cause your program to terminate.

Here is a very common bounds error:

```
double[] values = new double[10];
values[10] = value;
```

There is no `values[10]` in an array with ten elements—the index can range from 0 to 9.

To avoid bounds errors, you will want to know how many elements are in an array. The expression `values.length` yields the length of the `values` array. Note that there are no parentheses following `length`.

Table 1 Declaring Arrays

`int[] numbers = new int[10];`	An array of ten integers. All elements are initialized with zero.
`final int LENGTH = 10;` `int[] numbers = new int[LENGTH];`	It is a good idea to use a named constant instead of a "magic number".
`int length = in.nextInt();` `double[] data = new double[length];`	The length need not be a constant.
`int[] squares = { 0, 1, 4, 9, 16 };`	An array of five integers, with initial values.
`String[] friends = { "Emily", "Bob", "Cindy" };`	An array of three strings.
`double[] data = new int[10];`	**Error:** You cannot initialize a `double[]` variable with an array of type `int[]`.

Use the expression *array*.`length` to find the number of elements in an array.

The following code ensures that you only access the array when the index variable `i` is within the legal bounds:

```
if (0 <= i && i < values.length) { values[i] = value; }
```

Arrays suffer from a significant limitation: *their length is fixed*. If you start out with an array of 10 elements and later decide that you need to add additional elements, then you need to make a new array and copy all elements of the existing array into the new array. We will discuss this process in detail in Section 7.3.9.

To visit all elements of an array, use a variable for the index. Suppose `values` has ten elements and the integer variable `i` is set to 0, 1, 2, and so on, up to 9. Then the expression `values[i]` yields each element in turn. For example, this loop displays all elements in the `values` array:

```
for (int i = 0; i < 10; i++)
{
   System.out.println(values[i]);
}
```

Note that in the loop condition the index is *less than* 10 because there is no element corresponding to `values[10]`.

7.1.2 Array References

If you look closely at Figure 1, you will note that the variable `values` does not store any numbers. Instead, the array is stored elsewhere and the `values` variable holds a **reference** to the array. (The reference denotes the location of the array in memory.) You have already seen this behavior with objects in Section 2.8. When you access an object or array, you need not be concerned about the fact that Java uses references. This only becomes important when you copy a reference.

An array reference specifies the location of an array. Copying the reference yields a second reference to the same array.

When you copy an array variable into another, both variables refer to the same array (see Figure 2).

```
int[] scores = { 10, 9, 7, 4, 5 };
int[] values = scores; // Copying array reference
```

You can modify the array through either of the variables:

```
scores[3] = 10;
System.out.println(values[3]); // Prints 10
```

Section 7.3.9 shows how you can make a copy of the *contents* of the array.

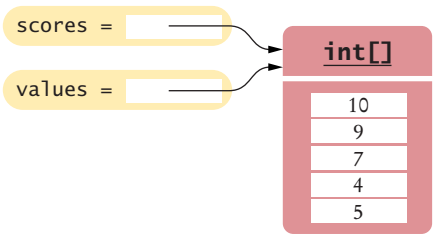


Figure 2
Two Array Variables Referencing the Same Array

7.1.3 Using Arrays with Methods

Arrays can occur as method arguments and return values.

Arrays can be method arguments and return values, just like any other values.

When you define a method with an array argument, you provide a parameter variable for the array. For example, the following method adds scores to a `Student` object:

```
public void addScores(int[] values)
{
   for (int i = 0; i < values.length; i++)
   {
      totalScore = totalScore + values[i];
   }
}
```

To call this method, you have to provide an array:

```
int[] scores = { 10, 9, 7, 10 };
fred.addScores(scores);
```

Conversely, a method can return an array. For example, a `Student` class can have a method

```
public int[] getScores()
```

that returns an array with all of the student's scores.

7.1.4 Partially Filled Arrays

With a partially filled array, you need to remember how many elements are filled.

An array cannot change size at run time. This is a problem when you don't know in advance how many elements you need. In that situation, you must come up with a good guess on the maximum number of elements that you need to store. For example, we may decide that we sometimes want to store more than ten elements, but never more than 100:

```
final int LENGTH = 100;
double[] values = new double[LENGTH];
```

In a typical program run, only a part of the array will be occupied by actual elements. We call such an array a **partially filled array**. You must keep a *companion variable* that counts how many elements are actually used. In Figure 3 we call the companion variable `currentSize`.

The following loop collects inputs and fills up the `values` array:

```
int currentSize = 0;
Scanner in = new Scanner(System.in);
while (in.hasNextDouble())
{
   if (currentSize < values.length)
   {
      values[currentSize] = in.nextDouble();
      currentSize++;
   }
}
```

With a partially filled array, keep a companion variable for the current size.

At the end of this loop, `currentSize` contains the actual number of elements in the array. Note that you have to stop accepting inputs if the `currentSize` companion variable reaches the array length.

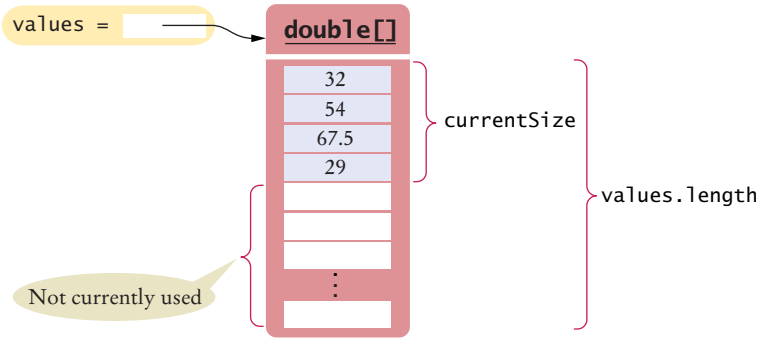


Figure 3 A Partially Filled Array

FULL CODE EXAMPLE

Go to wiley.com/go/bjeo6code to download a program that demonstrates array operations.

To process the gathered array elements, you again use the companion variable, not the array length. This loop prints the partially filled array:

```
for (int i = 0; i < currentSize; i++)
{
   System.out.println(values[i]);
}
```

1. Declare an array of integers containing the first five prime numbers.
2. Assume the array `primes` has been initialized as described in Self Check 1. What does it contain after executing the following loop?

   ```
   for (int i = 0; i < 2; i++)
   {
      primes[4 - i] = primes[i];
   }
   ```

3. Assume the array `primes` has been initialized as described in Self Check 1. What does it contain after executing the following loop?

   ```
   for (int i = 0; i < 5; i++)
   {
      primes[i]++;
   }
   ```

4. Given the declaration

   ```
   int[] values = new int[10];
   ```

   write statements to put the integer 10 into the elements of the array `values` with the lowest and the highest valid index.
5. Declare an array called `words` that can hold ten elements of type `String`.
6. Declare an array containing two strings, `"Yes"`, and `"No"`.
7. Can you produce the output on page 308 without storing the inputs in an array, by using an algorithm similar to the algorithm for finding the maximum in Section 6.7.5?
8. Declare a method of a class `Lottery` that returns a combination of `n` numbers. You don't need to implement the method.

Practice It Now you can try these exercises at the end of the chapter: R7.5, R7.6, R7.10, E7.1.

Common Error 7.1

Bounds Errors

Perhaps the most common error in using arrays is accessing a nonexistent element.

```
double[] values = new double[10];
values[10] = 5.4;
   // Error—values has 10 elements, and the index can range from 0 to 9
```

If your program accesses an array through an out-of-bounds index, there is no compiler error message. Instead, the program will generate an exception at run time.

Common Error 7.2

Uninitialized and Unfilled Arrays

A common error is to allocate an array variable, but not an actual array.

```
double[] values;
values[0] = 29.95; // Error—values not initialized
```

Array variables work exactly like object variables—they are only references to the actual array. To construct the actual array, you must use the `new` operator:

```
double[] values = new double[10];
```

Another common error is to allocate an array of objects and expect it to be filled with objects.

```
BankAccount[] accounts = new BankAccount[10]; // Contains ten null references
```

This array contains `null` references, not default bank accounts. You need to remember to fill the array, for example:

```
for (int i = 0; i < 10; i++)
{
   accounts[i] = new BankAccount();
}
```

Programming Tip 7.1

Use Arrays for Sequences of Related Items

Arrays are intended for storing sequences of values with the same meaning. For example, an array of test scores makes perfect sense:

```
int[] scores = new int[NUMBER_OF_SCORES];
```

But an array

```
int[] personalData = new int[3];
```

that holds a person's age, bank balance, and shoe size in positions 0, 1, and 2 is bad design. It would be tedious for the programmer to remember which of these data values is stored in which array location. In this situation, it is far better to use three separate variables.

Programming Tip 7.2

Make Parallel Arrays into Arrays of Objects

Programmers who are familiar with arrays, but unfamiliar with object-oriented programming, sometimes distribute information across separate arrays. Here is a typical example: A program needs to manage bank data, consisting of account numbers and balances. Don't store the account numbers and balances in separate arrays.

```
// Don't do this
int[] accountNumbers;
double[] balances;
```

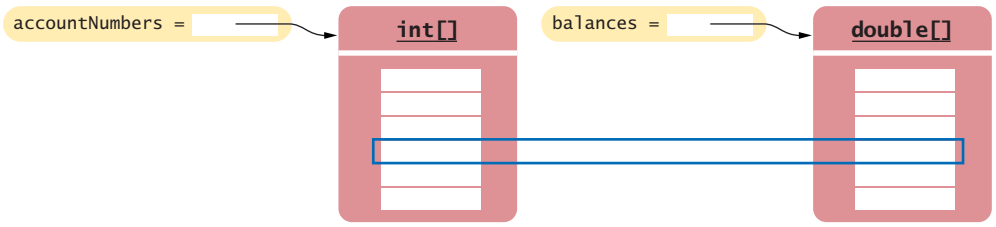


Figure 4 Avoid Parallel Arrays

Arrays such as these are called **parallel arrays** (see Figure 4). The `i`th slice (`accountNumbers[i]` and `balances[i]`) contains data that need to be processed together.

If you find yourself using two arrays that have the same length, ask yourself whether you couldn't replace them with a single array of a class type. Look at a slice and find the concept that it represents. Then make the concept into a class. In our example each slice contains an account number and a balance, describing a bank account. Therefore, it is an easy matter to use a single array of objects

Avoid parallel arrays by changing them into arrays of objects.

```
BankAccount[] accounts;
```

(See Figure 5.)

Why is this beneficial? Think ahead. Maybe your program will change and you will need to store the owner of the bank account as well. It is a simple matter to update the `BankAccount` class. It may well be quite complicated to add a new array and make sure that all methods that accessed the original two arrays now also correctly access the third one.

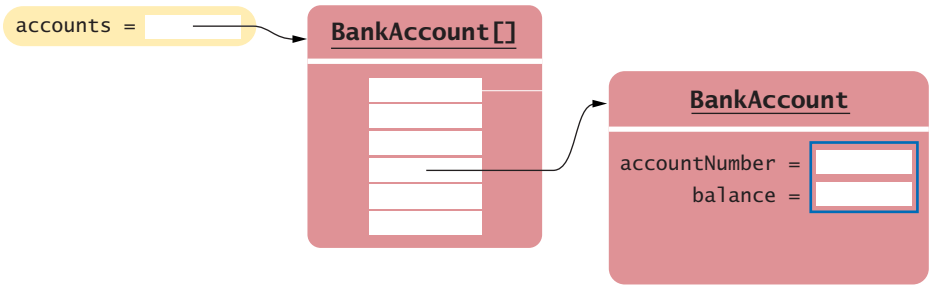


Figure 5 Reorganizing Parallel Arrays into an Array of Objects

Special Topic 7.1

Methods with a Variable Number of Arguments

It is possible to declare methods that receive a variable number of arguments. For example, we can write a method that can add an arbitrary number of scores to a student:

```
fred.addScores(10, 7); // This method call has two arguments
fred.addScores(1, 7, 2, 9); // Another call to the same method, now with four arguments
```

The method must be declared as

```
public void addScores(int... values)
```

The `int...` type indicates that the method can receive any number of `int` arguments. The `values` parameter variable is actually an `int[]` array that contains all arguments that were passed to the method.

The method implementation traverses the values array and processes the elements:

```
public void addScores(int... values)
{
   for (int i = 0; i < values.length; i++) // values is an int[]
   {
      totalScore = totalScore + values[i];
   }
}
```

Computing & Society 7.1 Computer Viruses

In November 1988, Robert Morris, a student at Cornell University, launched a so-called virus program that infected a significant fraction of computers connected to the Internet (which was much smaller then than it is now).

In order to attack a computer, a virus has to find a way to get its instructions executed. This particular program carried out a "buffer overrun" attack, providing an unexpectedly large input to a program on another machine. That program allocated an array of 512 characters, under the assumption that nobody would ever provide such a long input. Unfortunately, that program was written in the C programming language. C, unlike Java, does not check that an array index is less than the length of the array. If you write into an array using an index that is too large, you simply overwrite memory locations that belong to some other objects. C programmers are supposed to provide safety checks, but that had not happened in the program under attack. The virus program purposefully filled the 512-character array with 536 bytes. The excess 24 bytes overwrote a return address, which the attacker knew was stored just after the array. When the method that read the input was finished, it didn't return to its caller but to code supplied by the virus (see the figure). The virus was thus able to execute its code on a remote machine and infect it.

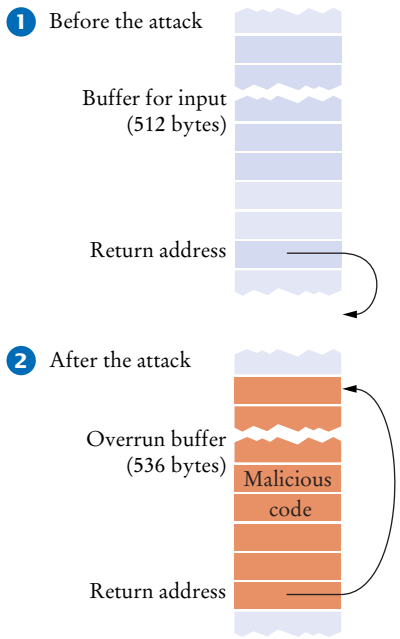
In Java, as in C, all programmers must be very careful not to overrun array boundaries. However, in Java, this error causes a run-time exception, and it never corrupts memory outside the array. This is one of the safety features of Java. One may well speculate what would possess the virus author to spend weeks designing a program that disabled thousands of computers. It appears that the break-in was fully intended by the author, but the disabling of the computers was a bug caused by continuous reinfection. Morris was sentenced to three years probation, 400 hours of community service, and a $10,000 fine.

In recent years, computer attacks have intensified and the motives have become more sinister. Instead of disabling computers, viruses often take permanent residence in the attacked computers. Criminal enterprises rent out the processing power of millions of hijacked computers for sending spam e-mail. Other viruses monitor every keystroke and send those that look like credit card numbers or banking passwords to their master.

Typically, a machine gets infected because a user executes code downloaded from the Internet, clicking on an icon or link that purports to be a game or video clip. Antivirus programs check all downloaded programs against an ever-growing list of known viruses.

When you use a computer for managing your finances, you need to be aware of the risk of infection. If a virus reads your banking password and empties your account, you will have a hard time convincing your financial institution that it wasn't your act, and you will most likely lose your money. Keep your operating system and antivirus program up to date, and don't click on suspicious links on a web page or in your e-mail inbox. Use banks that require "two-factor authentication" for major transactions, such as a callback on your cell phone.

Viruses are even used for military purposes. In 2010, a virus dubbed Stuxnet spread through Microsoft Windows and infected USB sticks. The virus looked for Siemens industrial computers and reprogrammed them in subtle ways. It appears that the virus was designed to damage the centrifuges of the Iranian nuclear enrichment operation. The computers controlling the centrifuges were not connected to the Internet, but they were configured with USB sticks, some of which were infected. Security researchers believe that the virus was developed by U.S. and Israeli intelligence agencies, and that it was successful in slowing down the Iranian nuclear program. Neither country has officially acknowledged or denied their role in the attacks.



A "Buffer Overrun" Attack

7.2 The Enhanced for Loop

You can use the enhanced for loop to visit all elements of an array.

Often, you need to visit all elements of an array. The *enhanced* `for` *loop* makes this process particularly easy to program.

Here is how you use the enhanced `for` loop to total up all elements in an array named `values`:

```
double[] values = . . .;
double total = 0;
for (double element : values)
{
   total = total + element;
}
```

The loop body is executed for each element in the array `values`. At the beginning of each loop iteration, the next element is assigned to the variable `element`. Then the loop body is executed. You should read this loop as "for each `element` in `values`".

This loop is equivalent to the following `for` loop with an explicit index variable:

```
for (int i = 0; i < values.length; i++)
{
   double element = values[i];
   total = total + element;
}
```

Note an important difference between the enhanced `for` loop and the basic `for` loop. In the enhanced `for` loop, the *element variable* is assigned `values[0]`, `values[1]`, and so on. In the basic `for` loop, the *index variable* `i` is assigned 0, 1, and so on.

Use the enhanced for loop if you do not need the index values in the loop body.

Keep in mind that the enhanced `for` loop has a very specific purpose: getting the elements of a collection, from the beginning to the end. It is not suitable for all array algorithms. In particular, the enhanced `for` loop does not allow you to modify the contents of an array. The following loop does not fill an array with zeroes:

```
for (double element : values)
{
   element = 0; // ERROR: this assignment does not modify array elements
}
```

When the loop is executed, the variable `element` is set to `values[0]`. Then `element` is set to 0, then to `values[1]`, then to 0, and so on. The `values` array is not modified. The remedy is simple: Use a basic `for` loop.

```
for (int i = 0; i < values.length; i++)
{
   values[i] = 0; // OK
}
```

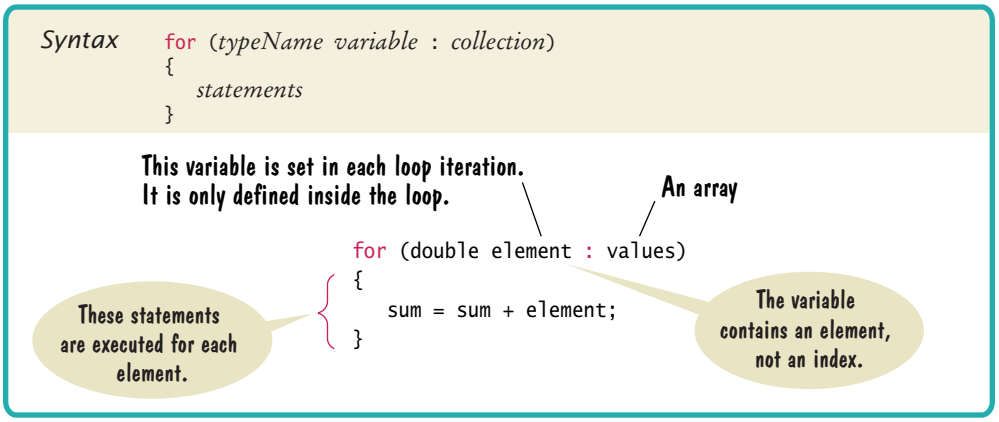
FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that demonstrates the enhanced for loop.

© Steve Cole/iStockphoto.

The enhanced `for` *loop is a convenient mechanism for traversing all elements in a collection.*

Syntax 7.2 The Enhanced for Loop



9. What does this enhanced for loop do?

```
int counter = 0;
for (double element : values)
{
   if (element == 0) { counter++; }
}
```

10. Write an enhanced for loop that prints all elements in the array values.
11. Write an enhanced for loop that multiplies all elements in a double[] array named factors, accumulating the result in a variable named product.
12. Why is the enhanced for loop not an appropriate shortcut for the following basic for loop?

```
for (int i = 0; i < values.length; i++) { values[i] = i * i; }
```

Practice It Now you can try these exercises at the end of the chapter: R7.11, R7.12, R7.13.

7.3 Common Array Algorithms

In the following sections, we discuss some of the most common algorithms for working with arrays. If you use a partially filled array, remember to replace values.length with the companion variable that represents the current size of the array.

7.3.1 Filling

This loop fills an array with squares (0, 1, 4, 9, 16, ...). Note that the element with index 0 contains 0^2, the element with index 1 contains 1^2, and so on.

```
for (int i = 0; i < values.length; i++)
{
   values[i] = i * i;
}
```

7.3.2 Sum and Average Value

You have already encountered this algorithm in Section 6.7.1. When the values are located in an array, the code looks much simpler:

```
double total = 0;
for (double element : values)
{
   total = total + element;
}
double average = 0;
if (values.length > 0) { average = total / values.length; }
```

7.3.3 Maximum and Minimum

Use the algorithm from Section 6.7.5 that keeps a variable for the largest element already encountered. Here is the implementation of that algorithm for an array:

```
double largest = values[0];
for (int i = 1; i < values.length; i++)
{
   if (values[i] > largest)
   {
      largest = values[i];
   }
}
```

Note that the loop starts at 1 because we initialize `largest` with `values[0]`.

To compute the smallest element, reverse the comparison.

These algorithms require that the array contain at least one element.

7.3.4 Element Separators

When separating elements, don't place a separator before the first element.

When you display the elements of an array, you usually want to separate them, often with commas or vertical lines, like this:

```
32 | 54 | 67.5 | 29 | 35
```

Note that there is one fewer separator than there are numbers. Print the separator before each element in the sequence *except the initial one* (with index `0`) like this:

```
for (int i = 0; i < values.length; i++)
{
   if (i > 0)
   {
      System.out.print(" | ");
   }
   System.out.print(values[i]);
}
```

To print five elements, you need four separators.

If you want comma separators, you can use the `Arrays.toString` method. (You'll need to import `java.util.Arrays`.) The expression

```
Arrays.toString(values)
```

returns a string describing the contents of the array `values` in the form

```
[32, 54, 67.5, 29, 35]
```

The elements are surrounded by a pair of brackets and separated by commas. This method can be convenient for debugging:

```
System.out.println("values=" + Arrays.toString(values));
```

7.3.5 Linear Search

To search for a specific element, visit the elements and stop when you encounter the match.

You often need to search for the position of a specific element in an array so that you can replace or remove it. Visit all elements until you have found a match or you have come to the end of the array. Here we search for the position of the first element in an array that is equal to 100:

```
int searchedValue = 100;
int pos = 0;
boolean found = false;
while (pos < values.length && !found)
{
   if (values[pos] == searchedValue)
   {
      found = true;
   }
   else
   {
      pos++;
   }
}
if (found) { System.out.println("Found at position: " + pos); }
else { System.out.println("Not found"); }
```

A linear search inspects elements in sequence until a match is found.

This algorithm is called **linear search** or *sequential search* because you inspect the elements in sequence. If the array is sorted, you can use the more efficient **binary search** algorithm. We discuss binary search in Chapter 14.

7.3.6 Removing an Element

Suppose you want to remove the element with index `pos` from the array `values`. As explained in Section 7.1.4, you need a companion variable for tracking the number of elements in the array. In this example, we use a companion variable called `currentSize`.

If the elements in the array are not in any particular order, simply overwrite the element to be removed with the *last* element of the array, then decrement the `currentSize` variable. (See Figure 6.)

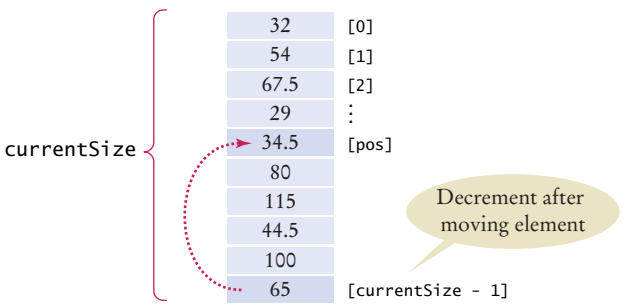


Figure 6
Removing an Element in an Unordered Array

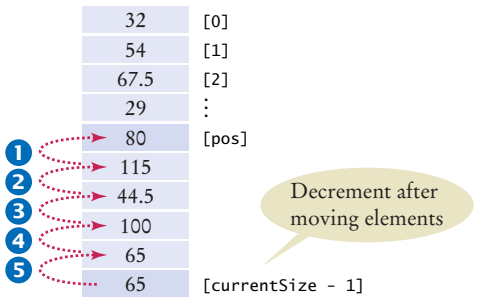


Figure 7
Removing an Element in an Ordered Array

```
values[pos] = values[currentSize - 1];
currentSize--;
```

The situation is more complex if the order of the elements matters. Then you must move all elements following the element to be removed to a lower index, and then decrement the variable holding the size of the array. (See Figure 7.)

```
for (int i = pos + 1; i < currentSize; i++)
{
   values[i - 1] = values[i];
}
currentSize--;
```

7.3.7 Inserting an Element

In this section, you will see how to insert an element into an array. Note that you need a companion variable for tracking the array size, as explained in Section 7.1.4.

If the order of the elements does not matter, you can simply insert new elements at the end, incrementing the variable tracking the size.

```
if (currentSize < values.length)
{
   currentSize++;
   values[currentSize - 1] = newElement;
}
```

It is more work to insert an element at a particular position in the middle of an array. First, move all elements after the insertion location to a higher index. Then insert the new element (see Figure 9).

Before inserting an element, move elements to the end of the array *starting with the last one.*

Note the order of the movement: When you remove an element, you first move the next element to a lower index, then the one after that, until you finally get to the end of the array. When you insert an element, you start at the end of the array, move that element to a higher index, then move the one before that, and so on until you finally get to the insertion location.

```
if (currentSize < values.length)
{
   currentSize++;
   for (int i = currentSize - 1; i > pos; i--)
   {
      values[i] = values[i - 1];
   }
   values[pos] = newElement;
}
```

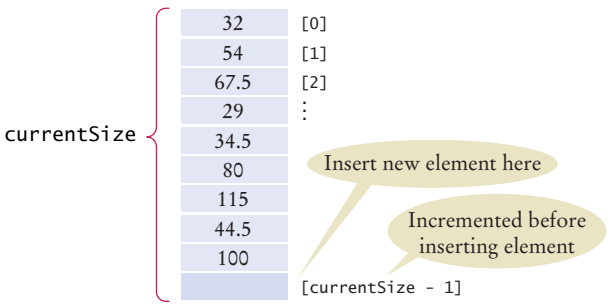


Figure 8
Inserting an Element in an Unordered Array

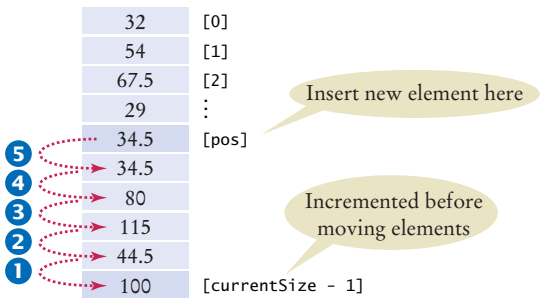
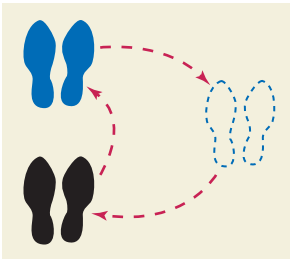


Figure 9
Inserting an Element in an Ordered Array

7.3.8 Swapping Elements



To swap two elements, you need a temporary variable.

You often need to swap elements of an array. For example, you can sort an array by repeatedly swapping elements that are not in order.

Consider the task of swapping the elements at positions `i` and `j` of an array `values`. We'd like to set `values[i]` to `values[j]`. But that overwrites the value that is currently stored in `values[i]`, so we want to save that first:

Use a temporary variable when swapping two elements.

```
double temp = values[i]; 2
values[i] = values[j]; 3
```

Now we can set `values[j]` to the saved value.

```
values[j] = temp; 4
```

Figure 10 shows the process.

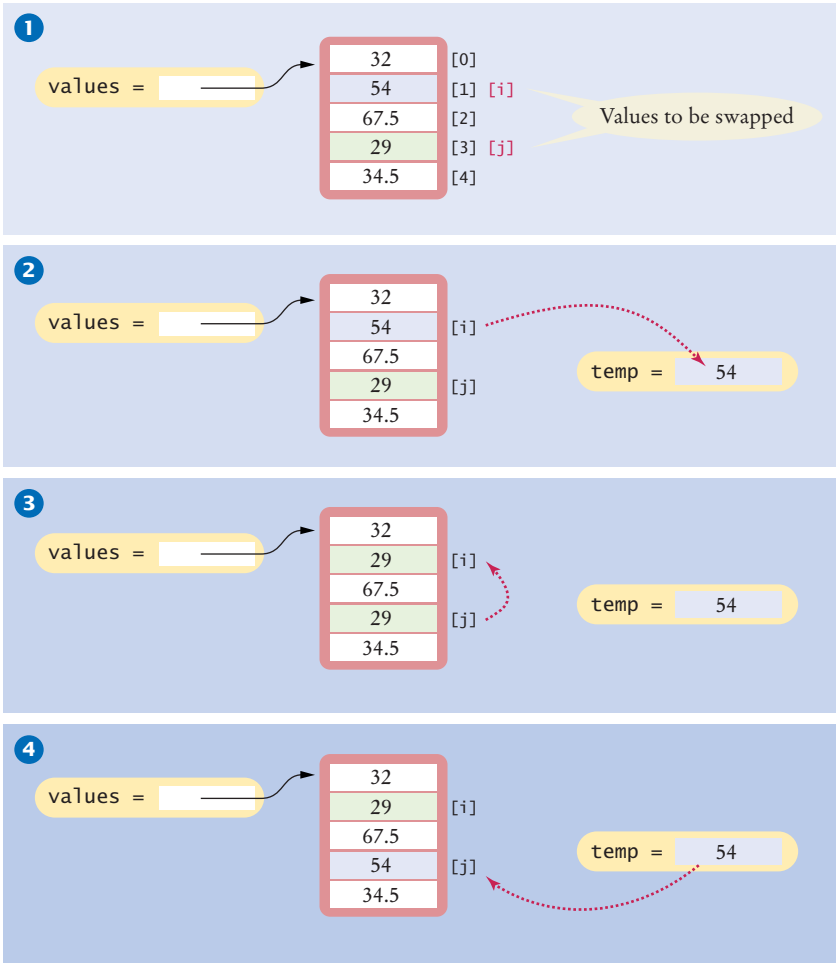


Figure 10 Swapping Array Elements

7.3.9 Copying Arrays

Array variables do not themselves hold array elements. They hold a reference to the actual array. If you copy the reference, you get another reference to the same array (see Figure 11):

```
double[] values = new double[6];
. . .  // Fill array
double[] prices = values; 1
```

Use the `Arrays.copyOf` method to copy the elements of an array into a new array.

If you want to make a true copy of an array, call the `Arrays.copyOf` method (as shown in Figure 11).

```
double[] prices = Arrays.copyOf(values, values.length); 2
```

The call `Arrays.copyOf(values, n)` allocates an array of length `n`, copies the first `n` elements of `values` (or the entire `values` array if `n > values.length`) into it, and returns the new array.

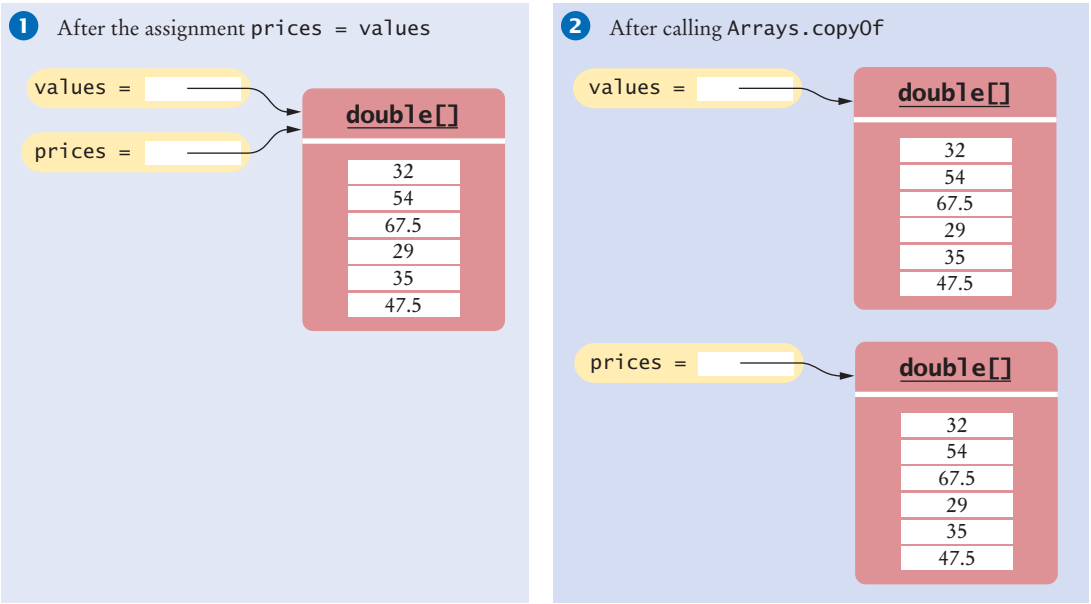


Figure 11 Copying an Array Reference versus Copying an Array

In order to use the `Arrays` class, you need to add the following statement to the top of your program:

```
import java.util.Arrays;
```

Another use for `Arrays.copyOf` is to grow an array that has run out of space. The following statements have the effect of doubling the length of an array (see Figure 12):

```
double[] newValues = Arrays.copyOf(values, 2 * values.length); 1
values = newValues; 2
```

The `copyOf` method was added in Java 6. If you use Java 5, replace

```
double[] newValues = Arrays.copyOf(values, n)
```

with

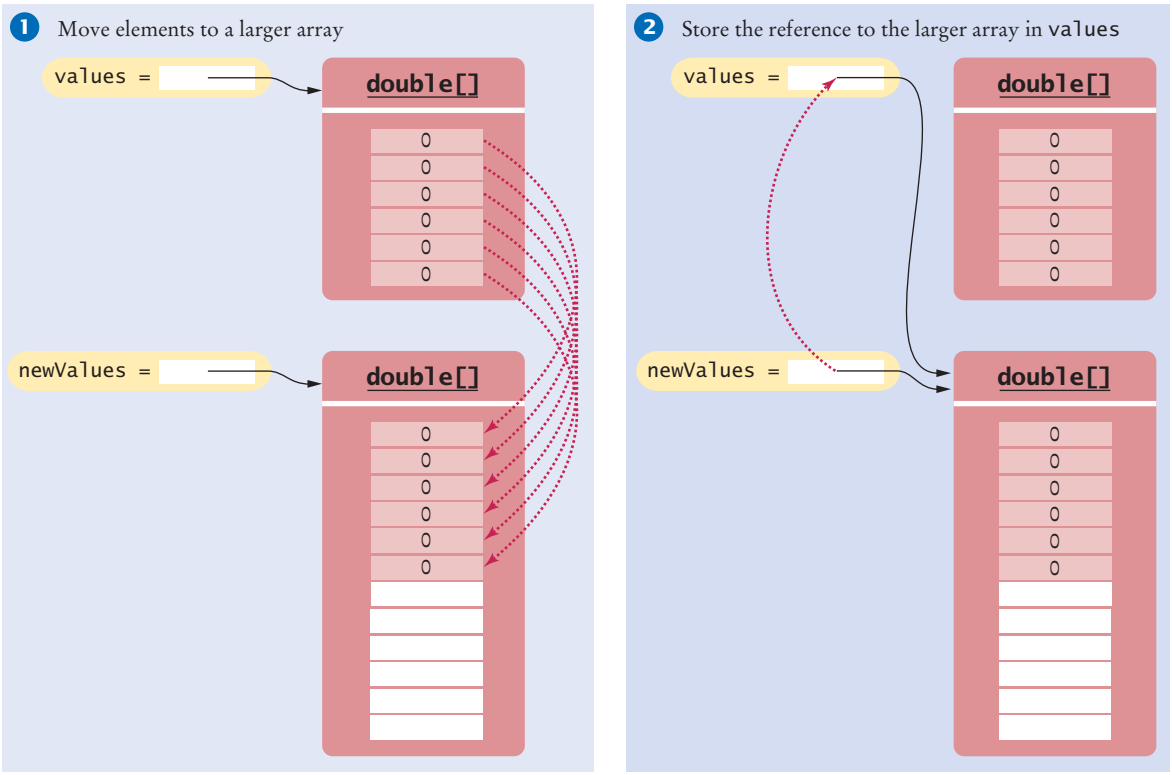


Figure 12 Growing an Array

```
double[] newValues = new double[n];
for (int i = 0; i < n && i < values.length; i++)
{
   newValues[i] = values[i];
}
```

7.3.10 Reading Input

If you know how many inputs the user will supply, it is simple to place them into an array:

```
double[] inputs = new double[NUMBER_OF_INPUTS];
for (i = 0; i < inputs.length; i++)
{
   inputs[i] = in.nextDouble();
}
```

However, this technique does not work if you need to read a sequence of arbitrary length. In that case, add the inputs to an array until the end of the input has been reached.

```
int currentSize = 0;
while (in.hasNextDouble() && currentSize < inputs.length)
{
   inputs[currentSize] = in.nextDouble();
   currentSize++;
}
```

Now inputs is a partially filled array, and the companion variable currentSize is set to the number of inputs.

However, this loop silently throws away inputs that don't fit into the array. A better approach is to grow the array to hold all inputs.

```
double[] inputs = new double[INITIAL_SIZE];
int currentSize = 0;
while (in.hasNextDouble())
{
   // Grow the array if it has been completely filled
   if (currentSize >= inputs.length)
   {
      inputs = Arrays.copyOf(inputs, 2 * inputs.length); // Grow the inputs array
   }

   inputs[currentSize] = in.nextDouble();
   currentSize++;
}
```

When you are done, you can discard any excess (unfilled) elements:

```
inputs = Arrays.copyOf(inputs, currentSize);
```

The following program puts these algorithms to work, solving the task that we set ourselves at the beginning of this chapter: to mark the largest value in an input sequence.

section_3/LargestInArray.java

```
1  import java.util.Scanner;
2
3  /**
4     This program reads a sequence of values and prints them, marking the largest value.
5  */
6  public class LargestInArray
7  {
8     public static void main(String[] args)
9     {
10       final int LENGTH = 100;
11       double[] values = new double[LENGTH];
12       int currentSize = 0;
13
14       // Read inputs
15
16       System.out.println("Please enter values, Q to quit:");
17       Scanner in = new Scanner(System.in);
18       while (in.hasNextDouble() && currentSize < values.length)
19       {
20          values[currentSize] = in.nextDouble();
21          currentSize++;
22       }
23
24       // Find the largest value
25
26       double largest = values[0];
27       for (int i = 1; i < currentSize; i++)
28       {
29          if (values[i] > largest)
30          {
31             largest = values[i];
32          }
33       }
```

```
34
35       // Print all values, marking the largest
36
37       for (int i = 0; i < currentSize; i++)
38       {
39          System.out.print(values[i]);
40          if (values[i] == largest)
41          {
42             System.out.print(" <== largest value");
43          }
44          System.out.println();
45       }
46    }
47 }
```

Program Run

```
Please enter values, Q to quit:
34.5 80 115 44.5 Q
34.5
80
115 <== largest value
44.5
```

13. Given these inputs, what is the output of the `LargestInArray` program?

    ```
    20 10 20 Q
    ```

14. Write a loop that counts how many elements in an array are equal to zero.

15. Consider the algorithm to find the largest element in an array. Why don't we initialize `largest` and `i` with zero, like this?

    ```
    double largest = 0;
    for (int i = 0; i < values.length; i++)
    {
       if (values[i] > largest)
       {
          largest = values[i];
       }
    }
    ```

16. When printing separators, we skipped the separator before the initial element. Rewrite the loop so that the separator is printed *after* each element, except for the last element.

17. What is wrong with these statements for printing an array with separators?

    ```
    System.out.print(values[0]);
    for (int i = 1; i < values.length; i++)
    {
       System.out.print(", " + values[i]);
    }
    ```

18. When finding the position of a match, we used a `while` loop, not a `for` loop. What is wrong with using this loop instead?

    ```
    for (pos = 0; pos < values.length && !found; pos++)
    {
       if (values[pos] > 100)
       {
          found = true;
       }
    }
    ```

19. When inserting an element into an array, we moved the elements with larger index values, starting at the end of the array. Why is it wrong to start at the insertion location, like this?

```
for (int i = pos; i < currentSize - 1; i++)
{
   values[i + 1] = values[i];
}
```

Practice It Now you can try these exercises at the end of the chapter: R7.16, R7.19, E7.7.

Common Error 7.3

Underestimating the Size of a Data Set

Programmers commonly underestimate the amount of input data that a user will pour into an unsuspecting program. Suppose you write a program to search for text in a file. You store each line in a string, and keep an array of strings. How big do you make the array? Surely nobody is going to challenge your program with an input that is more than 100 lines. Really? It is very easy to feed in the entire text of *Alice in Wonderland* or *War and Peace* (which are available on the Internet). All of a sudden, your program has to deal with tens or hundreds of thousands of lines. You either need to allow for large inputs or politely reject the excess input.

Special Topic 7.2

Sorting with the Java Library

Sorting an array efficiently is not an easy task. You will learn in Chapter 14 how to implement efficient sorting algorithms. Fortunately, the Java library provides an efficient `sort` method.

To sort an array `values`, call

```
Arrays.sort(values);
```

If the array is partially filled, call

```
Arrays.sort(values, 0, currentSize);
```

7.4 Problem Solving: Adapting Algorithms

By combining fundamental algorithms, you can solve complex programming tasks.

In Section 7.3, you were introduced to a number of fundamental array algorithms. These algorithms form the building blocks for many programs that process arrays. In general, it is a good problem-solving strategy to have a repertoire of fundamental algorithms that you can combine and adapt.

Consider this example problem: You are given the quiz scores of a student. You are to compute the final quiz score, which is the sum of all scores after dropping the lowest one. For example, if the scores are

```
8  7  8.5  9.5  7  4  10
```

then the final score is 50.

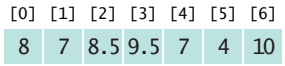
We do not have a ready-made algorithm for this situation. Instead, consider which algorithms may be related. These include:

- Calculating the sum (Section 7.3.2)
- Finding the minimum value (Section 7.3.3)
- Removing an element (Section 7.3.6)

We can formulate a plan of attack that combines these algorithms:

Find the minimum.
Remove it from the array.
Calculate the sum.

Let's try it out with our example. The minimum of



is 4. How do we remove it?

Now we have a problem. The removal algorithm in Section 7.3.6 locates the element to be removed by using the *position* of the element, not the value.

But we have another algorithm for that:

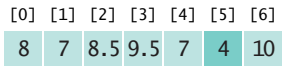
- Linear search (Section 7.3.5)

We need to fix our plan of attack:

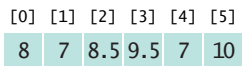
Find the minimum value.
Find its position.
Remove that position from the array.
Calculate the sum.

Will it work? Let's continue with our example.

We found a minimum value of 4. Linear search tells us that the value 4 occurs at position 5.



We remove it:



Finally, we compute the sum: 8 + 7 + 8.5 + 9.5 + 7 + 10 = 50.

This walkthrough demonstrates that our strategy works.

Can we do better? It seems a bit inefficient to find the minimum and then make another pass through the array to obtain its position.

You should be familiar with the implementation of fundamental algorithms so that you can adapt them.

We can adapt the algorithm for finding the minimum to yield the position of the minimum. Here is the original algorithm:

```
double smallest = values[0];
for (int i = 1; i < values.length; i++)
{
   if (values[i] < smallest)
   {
      smallest = values[i];
   }
```

```
}
```

When we find the smallest value, we also want to update the position:

```
if (values[i] < smallest)
{
   smallest = values[i];
   smallestPosition = i;
}
```

In fact, then there is no reason to keep track of the smallest value any longer. It is simply `values[smallestPosition]`. With this insight, we can adapt the algorithm as follows:

```
int smallestPosition = 0;
for (int i = 1; i < values.length; i++)
{
   if (values[i] < values[smallestPosition])
   {
      smallestPosition = i;
   }
}
```

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that uses the adapted algorithm for finding the minimum.

With this adaptation, our problem is solved with the following strategy:

Find the position of the minimum.
Remove it from the array.
Calculate the sum.

The next section shows you a technique for discovering a new algorithm when none of the fundamental algorithms can be adapted to a task.

SELF CHECK

20. Section 7.3.6 has two algorithms for removing an element. Which of the two should be used to solve the task described in this section?

21. It isn't actually necessary to *remove* the minimum in order to compute the total score. Describe an alternative.

22. How can you print the number of positive and negative values in a given array, using one or more of the algorithms in Section 6.7?

23. How can you print all positive values in an array, separated by commas?

24. Consider the following algorithm for collecting all matches in an array:

```
int matchesSize = 0;
for (int i = 0; i < values.length; i++)
{
   if (values[i] fulfills the condition)
   {
      matches[matchesSize] = values[i];
      matchesSize++;
   }
}
```

How can this algorithm help you with Self Check 23?

Practice It Now you can try these exercises at the end of the chapter: R7.25, R7.26.

HOW TO 7.1 Working with Arrays

In many data processing situations, you need to process a sequence of values. This How To walks you through the steps for storing input values in an array and carrying out computations with the array elements.

Problem Statement Consider again the problem from Section 7.4: A final quiz score is computed by adding all the scores, except for the lowest one. For example, if the scores are

```
8  7  8.5  9.5  7  5  10
```

then the final score is 50.

Thierry Dosogne/The Image Bank/Getty Images, Inc.

Step 1 Decompose your task into steps.

You will usually want to break down your task into multiple steps, such as

- Reading the data into an array.
- Processing the data in one or more steps.
- Displaying the results.

When deciding how to process the data, you should be familiar with the array algorithms in Section 7.3. Most processing tasks can be solved by using one or more of these algorithms.

In our sample problem, we will want to read the data. Then we will remove the minimum and compute the total. For example, if the input is `8 7 8.5 9.5 7 5 10`, we will remove the minimum of `5`, yielding `8 7 8.5 9.5 7 10`. The sum of those values is the final score of `50`.

Thus, we have identified three steps:

```
Read inputs.
Remove the minimum.
Calculate the sum.
```

Step 2 Determine which algorithm(s) you need.

Sometimes, a step corresponds to exactly one of the basic array algorithms in Section 7.3. That is the case with calculating the sum (Section 7.3.2) and reading the inputs (Section 7.3.10). At other times, you need to combine several algorithms. To remove the minimum value, you can find the minimum value (Section 7.3.3), find its position (Section 7.3.5), and remove the element at that position (Section 7.3.6).

We have now refined our plan as follows:

```
Read inputs.
Find the minimum.
Find its position.
Remove the minimum.
Calculate the sum.
```

This plan will work—see Section 7.4. But here is an alternate approach. It is easy to compute the sum and subtract the minimum. Then we don't have to find its position. The revised plan is

```
Read inputs.
Find the minimum.
Calculate the sum.
Subtract the minimum.
```

Step 3 Use classes and methods to structure the program.

Even though it may be possible to put all steps into the `main` method, this is rarely a good idea. It is better to carry out each processing step in a separate method. It is also a good idea to come up with a class that is responsible for collecting and processing the data.

In our example, let's provide a class `Student`. A student has an array of scores.

```
public class Student
{
   private double[] scores;
   private double scoresSize;
   . . .
   public Student(int capacity) { . . . }
   public boolean addScore(double score) { . . . }
   public double finalScore() { . . . }
}
```

A second class, `ScoreAnalyzer`, is responsible for reading the user input and displaying the result. Its `main` method simply calls the `Student` methods:

```
Student fred = new Student(100);
System.out.println("Please enter values, Q to quit:");
while (in.hasNextDouble())
{
   if (!fred.addScore(in.nextDouble()))
   {
      System.out.println("Too many scores.");
      return;
   }
}
System.out.println("Final score: " + fred.finalScore());
```

Now the `finalScore` method must do the heavy lifting. It too should not have to do all the work. Instead, we will supply helper methods

```
public double sum()
public double minimum()
```

These methods simply implement the algorithms in Sections 7.3.2 and 7.3.3.

Then the `finalScore` method becomes

```
public double finalScore()
{
   if (scoresSize == 0)
   {
      return 0;
   }
   else if (scoresSize == 1)
   {
      return scores[0];
   }
   else
   {
      return sum() - minimum();
   }
}
```

Step 4 Assemble and test the program.

Place your methods into a class. Review your code and check that you handle both normal and exceptional situations. What happens with an empty array? One that contains a single element? When no match is found? When there are multiple matches? Consider these boundary conditions and make sure that your program works correctly.

In our example, it is impossible to compute the minimum if the array is empty. In that case, we should terminate the program with an error message *before* attempting to call the `minimum` method.

What if the minimum value occurs more than once? That means that a student had more than one test with the same low score. We subtract only one of the occurrences of that low score, and that is the desired behavior.

The following table shows test cases and their expected output:

Test Case	Expected Output	Comment
`8 7 8.5 9.5 7 5 10`	50	See Step 1.
`8 7 7 9`	24	Only one instance of the low score should be removed.
`8`	0	After removing the low score, no score remains.
(no inputs)	**Error**	That is not a legal input.

The complete program is in the `how_to_1` folder of your companion code.

WORKED EXAMPLE 7.1 **Rolling the Dice**

Learn how to analyze a set of die tosses to see whether the die is "fair". Go to `wiley.com/go/bjeo6examples` and download the file for Worked Example 7.1.

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7.5 Problem Solving: Discovering Algorithms by Manipulating Physical Objects

In Section 7.4, you saw how to solve a problem by combining and adapting known algorithms. But what do you do when none of the standard algorithms is sufficient for your task? In this section, you will learn a technique for discovering algorithms by manipulating physical objects.

Consider the following task: You are given an array whose size is an even number, and you are to switch the first and the second half. For example, if the array contains the eight numbers

then you should change it to

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Manipulating physical objects can give you ideas for discovering algorithms.

Many students find it quite challenging to come up with an algorithm. They may know that a loop is required, and they may realize that elements should be inserted (Section 7.3.7) or swapped (Section 7.3.8), but they do not have sufficient intuition to draw diagrams, describe an algorithm, or write down pseudocode.

Use a sequence of coins, playing cards, or toys to visualize an array of values.

One useful technique for discovering an algorithm is to manipulate physical objects. Start by lining up some objects to denote an array. Coins, playing cards, or small toys are good choices.

Here we arrange eight coins:

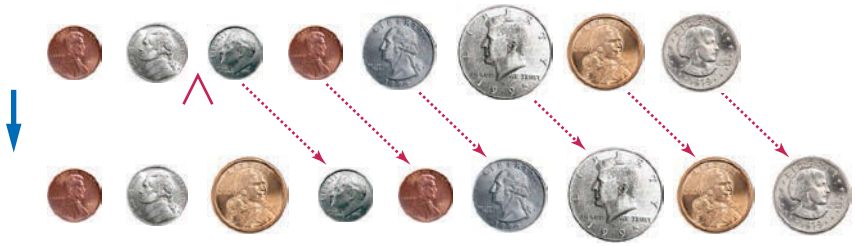
Now let's step back and see what we can do to change the order of the coins.

We can remove a coin (Section 7.3.6):

Visualizing the removal of an array element

We can insert a coin (Section 7.3.7):

Visualizing the insertion of an array element



Or we can swap two coins (Section 7.3.8).

Visualizing the swapping of two array elements

Go ahead—line up some coins and try out these three operations right now so that you get a feel for them.

Now how does that help us with our problem, switching the first and the second half of the array?

Let's put the first coin into place, by swapping it with the fifth coin. However, as Java programmers, we will say that we swap the coins in positions 0 and 4:

Next, we swap the coins in positions 1 and 5:

Two more swaps, and we are done:

Now an algorithm is becoming apparent:

```
i = 0
j = ... (we'll think about that in a minute)
While (don't know yet)
   Swap elements at positions i and j
   i++
   j++
```

Where does the variable j start? When we have eight coins, the coin at position zero is moved to position 4. In general, it is moved to the middle of the array, or to position **size / 2**.

And how many iterations do we make? We need to swap all coins in the first half. That is, we need to swap **size / 2** coins.

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a program that implements the algorithm that switches the first and second halves of an array.

The pseudocode is

```
i = 0
j = size / 2
While (i < size / 2)
   Swap elements at positions i and j
   i++
   j++
```

It is a good idea to make a walkthrough of the pseudocode (see Section 6.2). You can use paper clips to denote the positions of the variables **i** and **j**. If the walkthrough is successful, then we know that there was no "off-by-one" error in the pseudocode. Self Check 25 asks you to carry out the walkthrough, and Exercise E7.8 asks you to translate the pseudocode to Java. Exercise R7.27 suggests a different algorithm for switching the two halves of an array, by repeatedly removing and inserting coins.

You can use paper clips as position markers or counters.

Many people find that the manipulation of physical objects is less intimidating than drawing diagrams or mentally envisioning algorithms. Give it a try when you need to design a new algorithm!

SELF CHECK

25. Walk through the algorithm that we developed in this section, using two paper clips to indicate the positions for **i** and **j**. Explain why there are no bounds errors in the pseudocode.

26. Take out some coins and simulate the following pseudocode, using two paper clips to indicate the positions for **i** and **j**.

```
i = 0
j = size - 1
While (i < j)
   Swap elements at positions i and j
   i++
   j--
```

What does the algorithm do?

27. Consider the task of rearranging all elements in an array so that the even numbers come first. Otherwise, the order doesn't matter. For example, the array

```
1 4 14 2 1 3 5 6 23
```

could be rearranged to

```
4 2 14 6 1 5 3 23 1
```

Using coins and paperclips, discover an algorithm that solves this task by swapping elements, then describe it in pseudocode.

28. Discover an algorithm for the task of Self Check 27 that uses removal and insertion of elements instead of swapping.

29. Consider the algorithm in Section 6.7.5 that finds the largest element in a sequence of inputs—*not* the largest element in an array. Why is this algorithm better visualized by picking playing cards from a deck rather than arranging toy soldiers in a sequence?

Practice It Now you can try these exercises at the end of the chapter: R7.27, R7.28, E7.8.

7.6 Two-Dimensional Arrays

It often happens that you want to store collections of values that have a two-dimensional layout. Such data sets commonly occur in financial and scientific applications. An arrangement consisting of rows and columns of values is called a **two-dimensional array**, or a *matrix*.

Let's explore how to store the example data shown in Figure 13: the medal counts of the figure skating competitions at the 2014 Winter Olympics.

	Gold	Silver	Bronze
Canada	0	3	0
Italy	0	0	1
Germany	0	0	1
Japan	1	0	0
Kazakhstan	0	0	1
Russia	3	1	1
South Korea	0	1	0
United States	1	0	1

Figure 13 Figure Skating Medal Counts

7.6.1 Declaring Two-Dimensional Arrays

Use a two-dimensional array to store tabular data.

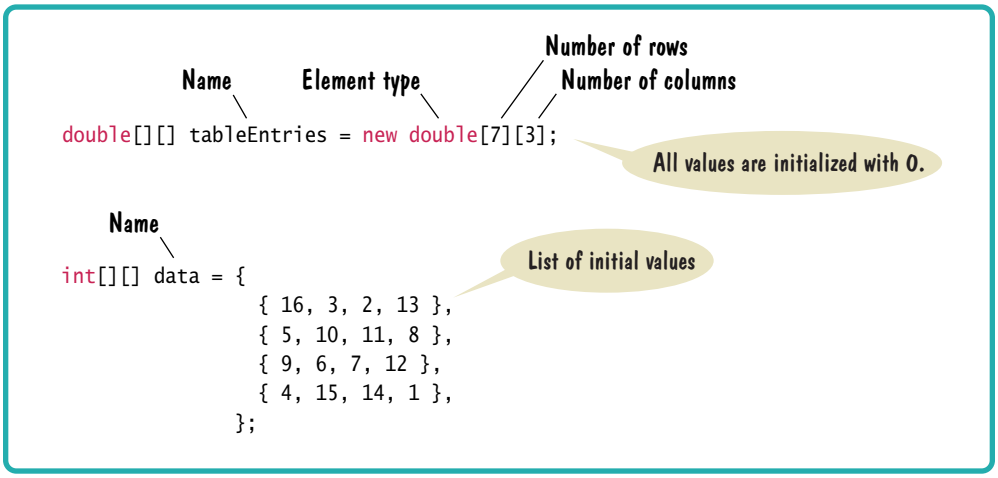
In Java, you obtain a two-dimensional array by supplying the number of rows and columns. For example, `new int[7][3]` is an array with seven rows and three columns. You store a reference to such an array in a variable of type `int[][]`. Here is a complete declaration of a two-dimensional array, suitable for holding our medal count data:

```
final int COUNTRIES = 8;
final int MEDALS = 3;
int[][] counts = new int[COUNTRIES][MEDALS];
```

Alternatively, you can declare and initialize the array by grouping each row:

```
int[][] counts =
   {
      { 0, 3, 0 },
      { 0, 0, 1 },
      { 0, 0, 1 },
      { 1, 0, 0 },
      { 0, 0, 1 },
      { 3, 1, 1 },
      { 0, 1, 0 }
      { 1, 0, 1 }
   };
```

Syntax 7.3 Two-Dimensional Array Declaration



As with one-dimensional arrays, you cannot change the size of a two-dimensional array once it has been declared.

7.6.2 Accessing Elements

Individual elements in a two-dimensional array are accessed by using two index values, *array*[i][j].

To access a particular element in the two-dimensional array, you need to specify two index values in separate brackets to select the row and column, respectively (see Figure 14):

```
int medalCount = counts[3][1];
```

To access all elements in a two-dimensional array, you use nested loops. For example, the following loop prints all elements of `counts`:

```
for (int i = 0; i < COUNTRIES; i++)
{
   // Process the ith row
   for (int j = 0; j < MEDALS; j++)
   {
      // Process the jth column in the ith row
      System.out.printf("%8d", counts[i][j]);
   }
   System.out.println(); // Start a new line at the end of the row
}
```

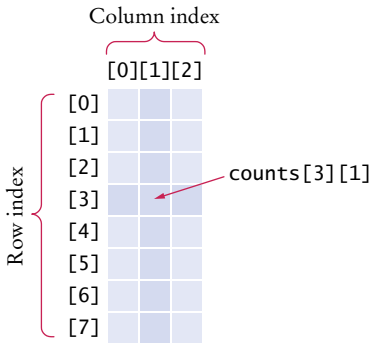


Figure 14
Accessing an Element in a Two-Dimensional Array

In these loops, the number of rows and columns were given as constants. Alternatively, you can use the following expressions:

- `counts.length` is the number of rows.
- `counts[0].length` is the number of columns. (See Special Topic 7.3 for an explanation of this expression.)

With these expressions, the nested loops become

```
for (int i = 0; i < counts.length; i++)
{
   for (int j = 0; j < counts[0].length; j++)
   {
      System.out.printf("%8d", counts[i][j]);
   }
   System.out.println();
}
```

7.6.3 Locating Neighboring Elements

Some programs that work with two-dimensional arrays need to locate the elements that are adjacent to an element. This task is particularly common in games. Figure 15 shows how to compute the index values of the neighbors of an element.

For example, the neighbors of `counts[3][1]` to the left and right are `counts[3][0]` and `counts[3][2]`. The neighbors to the top and bottom are `counts[2][1]` and `counts[4][1]`.

You need to be careful about computing neighbors at the boundary of the array. For example, `counts[0][1]` has no neighbor to the top. Consider the task of computing the sum of the neighbors to the top and bottom of the element `count[i][j]`. You need to check whether the element is located at the top or bottom of the array:

```
int total = 0;
if (i > 0) { total = total + counts[i - 1][j]; }
if (i < ROWS - 1) { total = total + counts[i + 1][j]; }
```

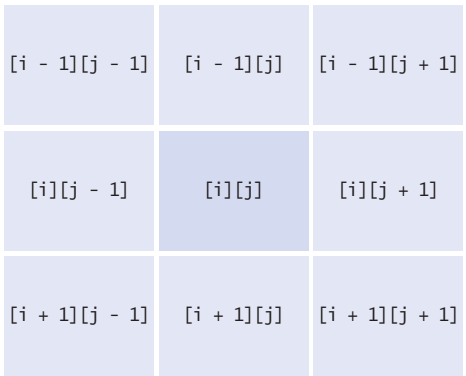


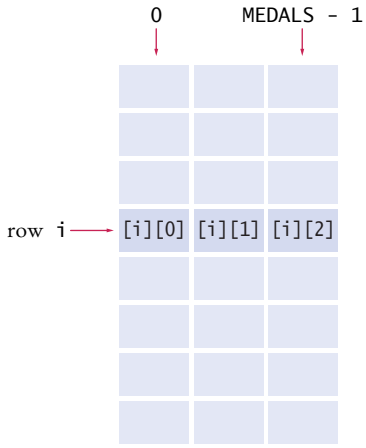
Figure 15
Neighboring Locations in a Two-Dimensional Array

7.6.4 Accessing Rows and Columns

You often need to access all elements in a row or column, for example to compute the sum of the elements or the largest element in a row or column.

In our sample array, the row totals give us the total number of medals won by a particular country.

Finding the correct index values is a bit tricky, and it is a good idea to make a quick sketch. To compute the total of row `i`, we need to visit the following elements:

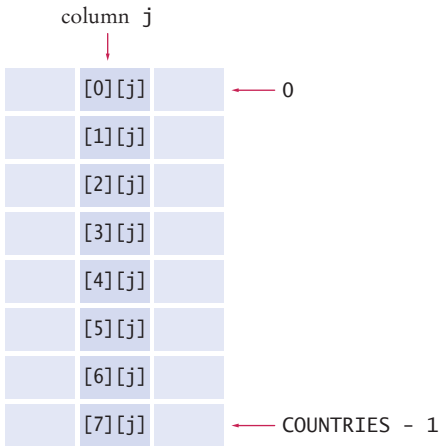


As you can see, we need to compute the sum of `counts[i][j]`, where `j` ranges from `0` to `MEDALS - 1`. The following loop computes the total:

```
int total = 0;
for (int j = 0; j < MEDALS; j++)
{
   total = total + counts[i][j];
}
```

Computing column totals is similar. Form the sum of `counts[i][j]`, where `i` ranges from `0` to `COUNTRIES - 1`.

```
int total = 0;
for (int i = 0; i < COUNTRIES; i++)
{
   total = total + counts[i][j];
}
```



Working with two-dimensional arrays is illustrated in the following program. The program prints out the medal counts and the row totals.

section_6/Medals.java

```
/**
   This program prints a table of medal winner counts with row totals.
*/
public class Medals
{
   public static void main(String[] args)
   {
      final int COUNTRIES = 8;
      final int MEDALS = 3;

      String[] countries =
         {
            "Canada",
            "Italy",
            "Germany",
            “Japan”,
            "Kazakhstan",
            "Russia",
            "South Korea",
            "United States"
         };

      int[][] counts =
         {
            { 0, 3, 0 },
            { 0, 0, 1 },
            { 0, 0, 1 },
            { 1, 0, 0 },
            { 0, 0, 1 },
            { 3, 1, 1 },
            { 0, 1, 0 },
            { 1, 0, 1 }
         };

      System.out.println("        Country    Gold  Silver  Bronze   Total");

      // Print countries, counts, and row totals
      for (int i = 0; i < COUNTRIES; i++)
      {
         // Process the ith row
         System.out.printf("%15s", countries[i]);

         int total = 0;

         // Print each row element and update the row total
         for (int j = 0; j < MEDALS; j++)
         {
            System.out.printf("%8d", counts[i][j]);
            total = total + counts[i][j];
         }

         // Display the row total and print a new line
         System.out.printf("%8d\n", total);
      }
   }
}
```

Program Run

```
        Country    Gold  Silver  Bronze   Total
         Canada       0       3       0       3
          Italy       0       0       1       1
        Germany       0       0       1       1
          Japan       1       0       0       1
     Kazakhstan       0       0       1       1
         Russia       3       1       1       5
    South Korea       0       1       0       1
  United States       1       0       1       2
```

30. What results do you get if you total the columns in our sample medals data?

31. Consider an 8×8 array for a board game:

```
int[][] board = new int[8][8];
```

Using two nested loops, initialize the board so that zeroes and ones alternate, as on a checkerboard:

```
0 1 0 1 0 1 0 1
1 0 1 0 1 0 1 0
0 1 0 1 0 1 0 1
. . .
1 0 1 0 1 0 1 0
```

Hint: Check whether `i + j` is even.

32. Declare a two-dimensional array for representing a tic-tac-toe board. The board has three rows and columns and contains strings `"x"`, `"o"`, and `" "`.

33. Write an assignment statement to place an `"x"` in the upper-right corner of the tic-tac-toe board in Self Check 32.

34. Which elements are on the diagonal joining the upper-left and the lower-right corners of the tic-tac-toe board in Self Check 32?

Practice It Now you can try these exercises at the end of the chapter: R7.29, E7.16, E7.17.

WORKED EXAMPLE 7.2 **A World Population Table**

Learn how to print world population data in a table with row and column headers, and with totals for each of the data columns. Go to `wiley.com/go/bjeo6examples` and download the file for Worked Example 7.2.

Special Topic 7.3

Two-Dimensional Arrays with Variable Row Lengths

When you declare a two-dimensional array with the command

```
int[][] a = new int[3][3];
```

you get a 3×3 matrix that can store 9 elements:

```
a[0][0] a[0][1] a[0][2]
a[1][0] a[1][1] a[1][2]
a[2][0] a[2][1] a[2][2]
```

In this matrix, all rows have the same length.

In Java it is possible to declare arrays in which the row length varies. For example, you can store an array that has a triangular shape, such as:

```
b[0][0]
b[1][0] b[1][1]
b[2][0] b[2][1] b[2][2]
```

To allocate such an array, you must work harder. First, you allocate space to hold three rows. Indicate that you will manually set each row by leaving the second array index empty:

```
double[][] b = new double[3][];
```

Then allocate each row separately (see Figure 16):

```
for (int i = 0; i < b.length; i++)
{
   b[i] = new double[i + 1];
}
```

You can access each array element as `b[i][j]`. The expression `b[i]` selects the `i`th row, and the `[j]` operator selects the `j`th element in that row.

Note that the number of rows is `b.length`, and the length of the `i`th row is `b[i].length`. For example, the following pair of loops prints a ragged array:

```
for (int i = 0; i < b.length; i++)
{
   for (int j = 0; j < b[i].length; j++)
   {
      System.out.print(b[i][j]);
   }
   System.out.println();
}
```

Alternatively, you can use two enhanced `for` loops:

```
for (double[] row : b)
{
   for (double element : row)
   {
      System.out.print(element);
   }
   System.out.println();
}
```

Naturally, such "ragged" arrays are not very common.

Java implements plain two-dimensional arrays in exactly the same way as ragged arrays: as arrays of one-dimensional arrays. The expression `new int[3][3]` automatically allocates an array of three rows, and three arrays for the rows' contents.

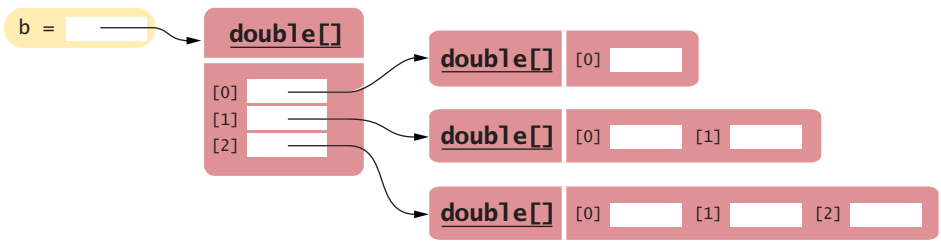


Figure 16 A Triangular Array

Special Topic 7.4

Multidimensional Arrays

You can declare arrays with more than two dimensions. For example, here is a three-dimensional array:

```
int[][][] rubiksCube = new int[3][3][3];
```

Each array element is specified by three index values:

```
rubiksCube[i][j][k]
```

7.7 Array Lists

An array list stores a sequence of values whose size can change.

When you write a program that collects inputs, you don't always know how many inputs you will have. In such a situation, an **array list** offers two significant advantages:

- Array lists can grow and shrink as needed.
- The `ArrayList` class supplies methods for common tasks, such as inserting and removing elements.

In the following sections, you will learn how to work with array lists.

An array list expands to hold as many elements as needed.

Syntax 7.4 Array Lists

Syntax

To construct an array list: `new ArrayList<`*typeName*`>()`

To access an element: *arraylistReference*`.get(index)`
arraylistReference`.set(index, value)`

Variable type — Variable name — An array list object of size 0

```
ArrayList<String> friends = new ArrayList<String>();
```

```
friends.add("Cindy");
String name = friends.get(i);
friends.set(i, "Harry");
```

The add method appends an element to the array list, increasing its size.

Use the get and set methods to access an element.

The index must be ≥ 0 and < friends.size().

7.7.1 Declaring and Using Array Lists

The following statement declares an array list of strings:

```
ArrayList<String> names = new ArrayList<String>();
```

The ArrayList class is a generic class: ArrayList<*Type*> collects elements of the specified type.

The `ArrayList` class is contained in the `java.util` package. In order to use array lists in your program, you need to use the statement `import java.util.ArrayList`.

The type `ArrayList<String>` denotes an array list of `String` elements. The angle brackets around the `String` type tell you that `String` is a **type parameter**. You can replace `String` with any other class and get a different array list type. For that reason, `ArrayList` is called a **generic class**. However, you cannot use primitive types as type parameters—there is no `ArrayList<int>` or `ArrayList<double>`. Section 7.7.4 shows how you can collect numbers in an array list.

It is a common error to forget the initialization:

```
ArrayList<String> names;
names.add("Harry"); // Error—names not initialized
```

Here is the proper initialization:

```
ArrayList<String> names = new ArrayList<String>();
```

Note the `()` after `new ArrayList<String>` on the right-hand side of the initialization. It indicates that the **constructor** of the `ArrayList<String>` class is being called.

When the `ArrayList<String>` is first constructed, it has size `0`. You use the `add` method to add an element to the end of the array list.

```
names.add("Emily"); // Now names has size 1 and element "Emily"
names.add("Bob"); // Now names has size 2 and elements "Emily", "Bob"
names.add("Cindy"); // names has size 3 and elements "Emily", "Bob", and "Cindy"
```

Use the size method to obtain the current size of an array list.

The size increases after each call to `add` (see Figure 17). The `size` method yields the current size of the array list.

To obtain an array list element, use the `get` method, not the `[]` operator. As with arrays, index values start at `0`. For example, `names.get(2)` retrieves the name with index 2, the third element in the array list:

Use the get and set methods to access an array list element at a given index.

```
String name = names.get(2);
```

As with arrays, it is an error to access a nonexistent element. A very common bounds error is to use the following:

```
int i = names.size();
name = names.get(i);  // Error
```

The last valid index is `names.size() - 1`.

To set an array list element to a new value, use the `set` method:

```
names.set(2, "Carolyn");
```

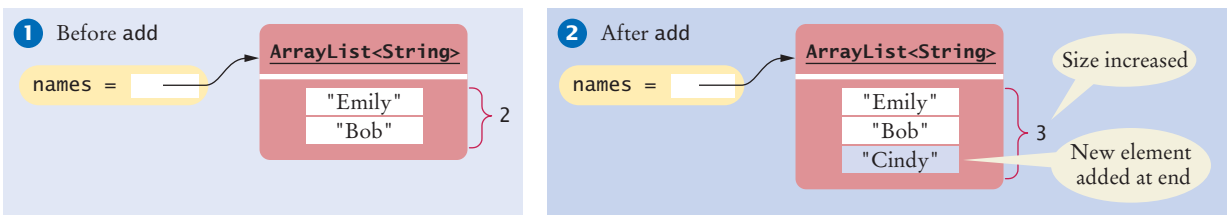


Figure 17 Adding an Array List Element with `add`

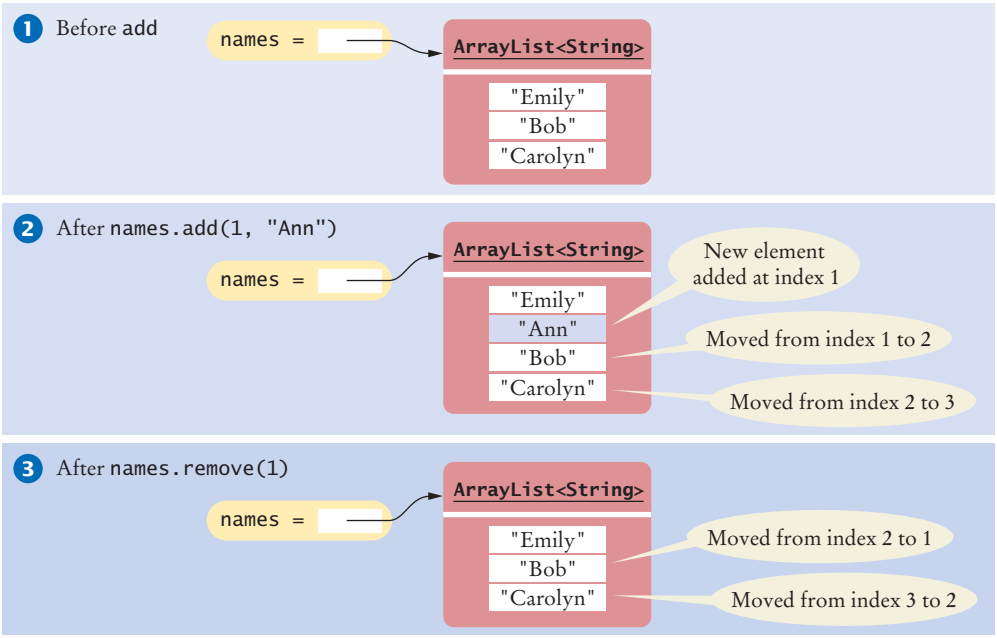


Figure 18 Adding and Removing Elements in the Middle of an Array List

An array list has methods for adding and removing elements in the middle.

Use the add and remove methods to add and remove array list elements.

This call sets position 2 of the `names` array list to `"Carolyn"`, overwriting whatever value was there before.

The `set` method overwrites existing values. It is different from the `add` method, which adds a new element to the array list.

You can insert an element in the middle of an array list. For example, the call `names.add(1, "Ann")` adds a new element at position 1 and moves all elements with index 1 or larger by one position. After each call to the `add` method, the size of the array list increases by 1 (see Figure 18).

Conversely, the `remove` method removes the element at a given position, moves all elements after the removed element down by one position, and reduces the size of the array list by 1. Part 3 of Figure 18 illustrates the result of `names.remove(1)`.

With an array list, it is very easy to get a quick printout. Simply pass the array list to the `println` method:

```
System.out.println(names); // Prints [Emily, Bob, Carolyn]
```

7.7.2 Using the Enhanced for Loop with Array Lists

You can use the enhanced `for` loop to visit all elements of an array list. For example, the following loop prints all names:

```
ArrayList<String> names = . . . ;
for (String name : names)
{
   System.out.println(name);
}
```

This loop is equivalent to the following basic `for` loop:

```
for (int i = 0; i < names.size(); i++)
{
```

```
      String name = names.get(i);
      System.out.println(name);
   }
```

7.7.3 Copying Array Lists

As with arrays, you need to remember that array list variables hold references. Copying the reference yields two references to the same array list (see Figure 19).

```
ArrayList<String> friends = names;
friends.add("Harry");
```

Now both `names` and `friends` reference the same array list to which the string `"Harry"` was added.

If you want to make a copy of an array list, construct the copy and pass the original list into the constructor:

```
ArrayList<String> newNames = new ArrayList<String>(names);
```

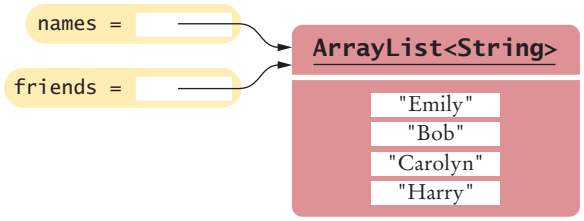


Figure 19
Copying an Array List Reference

Table 2 Working with Array Lists

`ArrayList<String> names = new ArrayList<String>();`	Constructs an empty array list that can hold strings.
`names.add("Ann");` `names.add("Cindy");`	Adds elements to the end of the array list.
`System.out.println(names);`	Prints `[Ann, Cindy]`.
`names.add(1, "Bob");`	Inserts an element at index 1. `names` is now `[Ann, Bob, Cindy]`.
`names.remove(0);`	Removes the element at index 0. `names` is now `[Bob, Cindy]`.
`names.set(0, "Bill");`	Replaces an element with a different value. `names` is now `[Bill, Cindy]`.
`String name = names.get(i);`	Gets an element.
`String last = names.get(names.size() - 1);`	Gets the last element.

`ArrayList<Integer> squares = new ArrayList<Integer>();`
`for (int i = 0; i < 10; i++)`
`{`
`  squares.add(i * i);`
`}`
	Constructs an array list holding the first ten squares.

7.7.4 Wrappers and Auto-boxing

Like truffles that must be in a wrapper to be sold, a number must be placed in a wrapper to be stored in an array list.

In Java, you cannot directly insert primitive type values—numbers, characters, or `boolean` values—into array lists. For example, you cannot form an `ArrayList<double>`. Instead, you must use one of the **wrapper classes** shown in the following table.

Primitive Type	Wrapper Class
`byte`	`Byte`
`boolean`	`Boolean`
`char`	`Character`
`double`	`Double`
`float`	`Float`
`int`	`Integer`
`long`	`Long`
`short`	`Short`

To collect numbers in array lists, you must use wrapper classes.

For example, to collect `double` values in an array list, you use an `ArrayList<Double>`. Note that the wrapper class names start with uppercase letters, and that two of them differ from the names of the corresponding primitive type: `Integer` and `Character`.

Conversion between primitive types and the corresponding wrapper classes is automatic. This process is called **auto-boxing** (even though *auto-wrapping* would have been more consistent).

For example, if you assign a `double` value to a `Double` variable, the number is automatically "put into a box" (see Figure 20).

```
Double wrapper = 29.95;
```

Conversely, wrapper values are automatically "unboxed" to primitive types:

```
double x = wrapper;
```

Because boxing and unboxing is automatic, you don't need to think about it. Simply remember to use the wrapper type when you declare array lists of numbers. From then on, use the primitive type and rely on auto-boxing.

```
ArrayList<Double> values = new ArrayList<Double>();
values.add(29.95);
double x = values.get(0);
```

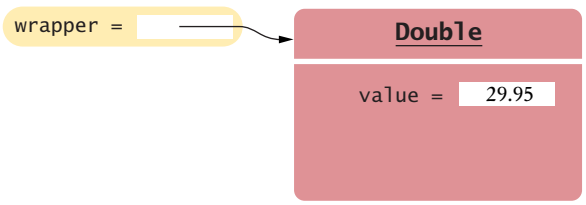


Figure 20 A Wrapper Class Variable

7.7.5 Using Array Algorithms with Array Lists

The array algorithms in Section 7.3 can be converted to array lists simply by using the array list methods instead of the array syntax (see Table 3 on page 350). For example, this code snippet finds the largest element in an array:

```
double largest = values[0];
for (int i = 1; i < values.length; i++)
{
   if (values[i] > largest)
   {
      largest = values[i];
   }
}
```

Here is the same algorithm, now using an array list:

```
double largest = values.get(0);
for (int i = 1; i < values.size(); i++)
{
   if (values.get(i) > largest)
   {
      largest = values.get(i);
   }
}
```

7.7.6 Storing Input Values in an Array List

When you collect an unknown number of inputs, array lists are *much* easier to use than arrays. Simply read inputs and add them to an array list:

```
ArrayList<Double> inputs = new ArrayList<Double>();
while (in.hasNextDouble())
{
   inputs.add(in.nextDouble());
}
```

7.7.7 Removing Matches

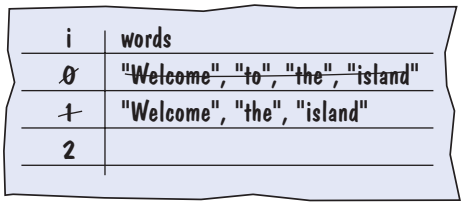
It is easy to remove elements from an array list, by calling the `remove` method. A common processing task is to remove all elements that match a particular condition. Suppose, for example, that we want to remove all strings of length < 4 from an array list.

Of course, you traverse the array list and look for matching elements:

```
ArrayList<String> words = . . .;
for (int i = 0; i < words.size(); i++)
{
   String word = words.get(i);
   if (word.length() < 4)
   {
      Remove the element at index i.
   }
}
```

But there is a subtle problem. After you remove the element, the `for` loop increments `i`, skipping past the *next* element.

Consider this concrete example, where `words` contains the strings `"Welcome"`, `"to"`, `"the"`, `"island!"`. When `i` is 1, we remove the word `"to"` at index 1. Then `i` is incremented to 2, and the word `"the"`, which is now at position 1, is never examined.



We should not increment the index when removing a word. The appropriate pseudocode is

```
If the element at index i matches the condition
   Remove the element.
Else
   Increment i.
```

Because we don't always increment the index, a `for` loop is not appropriate for this algorithm. Instead, use a `while` loop:

```
int i = 0;
while (i < words.size())
{
   String word = words.get(i);
   if (word.length() < 4)
   {
      words.remove(i);
   }
   else
   {
      i++;
   }
}
```

7.7.8 Choosing Between Array Lists and Arrays

For most programming tasks, array lists are easier to use than arrays. Array lists can grow and shrink. On the other hand, arrays have a nicer syntax for element access and initialization.

Which of the two should you choose? Here are some recommendations.

- If the size of a collection never changes, use an array.
- If you collect a long sequence of primitive type values and you are concerned about efficiency, use an array.
- Otherwise, use an array list.

The following program shows how to mark the largest value in a sequence of values stored in an array list. Note how the program is an improvement over the array version on page 325. This program can process input sequences of arbitrary length.

FULL CODE EXAMPLE

Go to `wiley.com/go/bjeo6code` to download a version of the Student class that uses an array list.

Table 3 Comparing Array and Array List Operations

Operation	Arrays	Array Lists
Get an element.	`x = values[4];`	`x = values.get(4);`
Replace an element.	`values[4] = 35;`	`values.set(4, 35);`
Number of elements.	`values.length`	`values.size()`
Number of filled elements.	`currentSize` (companion variable, see Section 7.1.4)	`values.size()`
Remove an element.	See Section 7.3.6.	`values.remove(4);`
Add an element, growing the collection.	See Section 7.3.7.	`values.add(35);`
Initializing a collection.	`int[] values = { 1, 4, 9 };`	No initializer list syntax; call `add` three times.

section_7/LargestInArrayList.java

```
1  import java.util.ArrayList;
2  import java.util.Scanner;
3
4  /**
5     This program reads a sequence of values and prints them, marking the largest value.
6  */
7  public class LargestInArrayList
8  {
9     public static void main(String[] args)
10    {
11       ArrayList<Double> values = new ArrayList<Double>();
12
13       // Read inputs
14
15       System.out.println("Please enter values, Q to quit:");
16       Scanner in = new Scanner(System.in);
17       while (in.hasNextDouble())
18       {
19          values.add(in.nextDouble());
20       }
21
22       // Find the largest value
23
24       double largest = values.get(0);
25       for (int i = 1; i < values.size(); i++)
26       {
27          if (values.get(i) > largest)
28          {
29             largest = values.get(i);
30          }
31       }
32
33       // Print all values, marking the largest
34
35       for (double element : values)
36       {
```

```
37            System.out.print(element);
38            if (element == largest)
39            {
40               System.out.print(" <== largest value");
41            }
42            System.out.println();
43         }
44      }
45   }
```

Program Run

```
Please enter values, Q to quit:
35 80 115 44.5 Q
35
80
115 <== largest value
44.5
```

35. Declare an array list of integers called `primes` that contains the first five prime numbers (2, 3, 5, 7, and 11).

36. Given the array list `primes` declared in Self Check 35, write a loop to print its elements in reverse order, starting with the last element.

37. What does the array list `names` contain after the following statements?

```
ArrayList<String> names = new ArrayList<String>;
names.add("Bob");
names.add(0, "Ann");
names.remove(1);
names.add("Cal");
```

38. What is wrong with this code snippet?

```
ArrayList<String> names;
names.add(Bob);
```

39. Consider this method that appends the elements of one array list to another:

```
public void append(ArrayList<String> target, ArrayList<String> source)
{
   for (int i = 0; i < source.size(); i++)
   {
      target.add(source.get(i));
   }
}
```

What are the contents of `names1` and `names2` after these statements?

```
ArrayList<String> names1 = new ArrayList<String>();
names1.add("Emily");
names1.add("Bob");
names1.add("Cindy");
ArrayList<String> names2 = new ArrayList<String>();
names2.add("Dave");
append(names1, names2);
```

40. Suppose you want to store the names of the weekdays. Should you use an array list or an array of seven strings?

41. The `ch07/section_7` directory of your source code contains an alternate implementation of the problem solution in How To 7.1 on page 330. Compare the array and array list implementations. What is the primary advantage of the latter?

Practice It Now you can try these exercises at the end of the chapter: R7.14, R7.33, E7.17, E7.20.

Common Error 7.4

Length and Size

Unfortunately, the Java syntax for determining the number of elements in an array, an array list, and a string is not at all consistent. It is a common error to confuse these. You just have to remember the correct syntax for every data type.

Data Type	Number of Elements
Array	`a.length`
Array list	`a.size()`
String	`a.length()`

Special Topic 7.5

The Diamond Syntax

There is a convenient syntax enhancement for declaring array lists and other generic classes. In a statement that declares and constructs an array list, you need not repeat the type parameter in the constructor. That is, you can write

```
ArrayList<String> names = new ArrayList<>();
```

instead of

```
ArrayList<String> names = new ArrayList<String>();
```

This shortcut is called the "diamond syntax" because the empty brackets <> look like a diamond shape.

For now, we will use the explicit syntax and include the type parameters with constructors. In later chapters, we will switch to the diamond syntax.

7.8 Regression Testing

A test suite is a set of tests for repeated testing.

It is a common and useful practice to make a new test whenever you find a program bug. You can use that test to verify that your bug fix really works. Don't throw the test away; feed it to the next version after that and all subsequent versions. Such a collection of test cases is called a **test suite**.

You will be surprised how often a bug that you fixed will reappear in a future version. This is a phenomenon known as *cycling*. Sometimes you don't quite understand the reason for a bug and apply a quick fix that appears to work. Later, you apply a different quick fix that solves a second problem but makes the first problem appear again. Of course, it is always best to think through what really causes a bug and fix the root cause instead of doing a sequence of "Band-Aid" solutions. If you don't succeed in doing that, however, you at least want to have an honest appraisal of how well the program works. By keeping all old test cases around and testing them against every new version, you get that feedback. The process of checking each version of a program against a test suite is called **regression testing**.

How do you organize a suite of tests? An easy technique is to produce multiple tester classes, such as `ScoreTester1`, `ScoreTester2`, and so on, where each program runs with a separate set of test data. For example, here is a tester for the `Student` class:

```
public class ScoreTester1
{
```

Regression testing involves repeating previously run tests to ensure that known failures of prior versions do not appear in new versions of the software.

```
      public static void main(String[] args)
      {
         Student fred = new Student(100);
         fred.addScore(10);
         fred.addScore(20);
         fred.addScore(5);
         System.out.println("Final score: " + fred.finalScore());
         System.out.println("Expected: 30");
      }
   }
```

Another useful approach is to provide a generic tester, and feed it inputs from multiple files, as in the following.

section_8/ScoreTester.java

```
1  import java.util.Scanner;
2
3  public class ScoreTester
4  {
5     public static void main(String[] args)
6     {
7        Scanner in = new Scanner(System.in);
8        double expected = in.nextDouble();
9        Student fred = new Student(100);
10       while (in.hasNextDouble())
11       {
12          if (!fred.addScore(in.nextDouble()))
13          {
14             System.out.println("Too many scores.");
15             return;
16          }
17       }
18       System.out.println("Final score: " + fred.finalScore());
19       System.out.println("Expected: " + expected);
20    }
21 }
```

The program reads the expected result and the scores. By running the program with different inputs, we can test different scenarios.

Of course, it would be tedious to type in the input values by hand every time the test is executed. It is much better to save the inputs in a file, such as the following:

section_8/input1.txt

```
30
10
20
5
```

When running the program from a shell window, one can link the input file to the input of a program, as if all the characters in the file had actually been typed by a user. Type the following command into a shell window:

```
java ScoreTester < input1.txt
```

The program is executed, but it no longer reads input from the keyboard. Instead, the `System.in` object (and the `Scanner` that reads from `System.in`) gets the input from the file `input1.txt`. We discussed this process, called input **redirection**, in Special Topic 6.2.

The output is still displayed in the console window:

Program Run

```
Final score: 30
Expected: 30
```

You can also redirect output. To capture the program's output in a file, use the command

```
java ScoreTester < input1.txt > output1.txt
```

This is useful for archiving test cases.

42. Suppose you modified the code for a method. Why do you want to repeat tests that already passed with the previous version of the code?
43. Suppose a customer of your program finds an error. What action should you take beyond fixing the error?
44. Why doesn't the `ScoreTester` program contain prompts for the inputs?

Practice It Now you can try these exercises at the end of the chapter: R7.35, R7.36.

Programming Tip 7.3

Batch Files and Shell Scripts

If you need to perform the same tasks repeatedly on the command line, then it is worth learning about the automation features offered by your operating system.

Under Windows, you use batch files to execute a number of commands automatically. For example, suppose you need to test a program by running three testers:

```
java ScoreTester1
java ScoreTester < input1.txt
java ScoreTester < input2.txt
```

Then you find a bug, fix it, and run the tests again. Now you need to type the three commands once more. There has to be a better way. Under Windows, put the commands in a text file and call it `test.bat`:

File test.bat

```
1  java ScoreTester1
2  java ScoreTester < input1.txt
3  java ScoreTester < input2.txt
```

Then you just type

```
test.bat
```

and the three commands in the batch file execute automatically.

Batch files are a feature of the operating system, not of Java. On Linux, Mac OS, and UNIX, shell scripts are used for the same purpose. In this simple example, you can execute the commands by typing

```
sh test.bat
```

There are many uses for batch files and shell scripts, and it is well worth it to learn more about their advanced features, such as parameters and loops.

Computing & Society 7.2 The Therac-25 Incidents

The Therac-25 is a computerized device to deliver radiation treatment to cancer patients (see the figure). Between June 1985 and January 1987, several of these machines delivered serious overdoses to at least six patients, killing some of them and seriously maiming the others.

The machines were controlled by a computer program. Bugs in the program were directly responsible for the overdoses. According to Leveson and Turner ("An Investigation of the Therac-25 Accidents," *IEEE Computer*, July 1993, pp. 18–41), the program was written by a single programmer, who had since left the manufacturing company producing the device and could not be located. None of the company employees interviewed could say anything about the educational level or qualifications of the programmer.

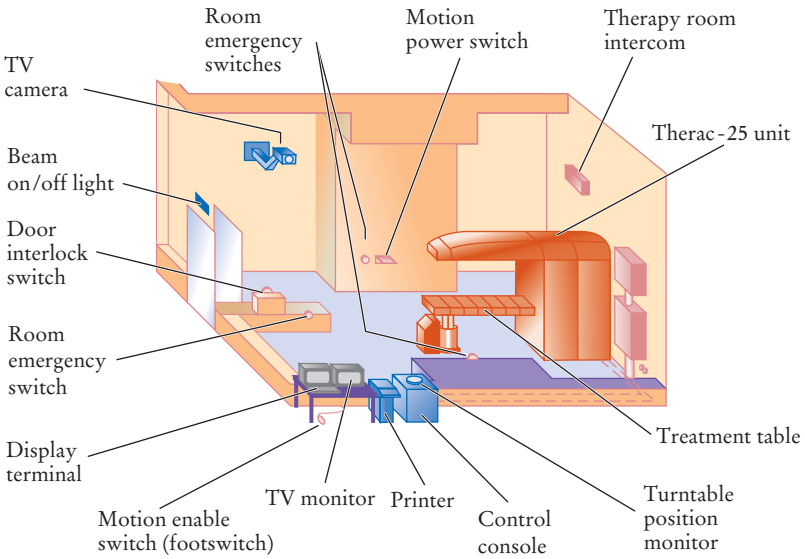
The investigation by the federal Food and Drug Administration (FDA) found that the program was poorly documented and that there was neither a specification document nor a formal test plan. (This should make you think. Do you have a formal test plan for your programs?)

The overdoses were caused by the amateurish design of the software that had to control different devices concurrently, namely the keyboard, the display, the printer, and of course the radiation device itself. Synchronization and data sharing between the tasks were done in an ad hoc way, even though safe multitasking techniques were known at the time. Had the programmer enjoyed a formal education that involved these techniques, or taken the effort to study the literature, a safer machine could have been built. Such a machine would have probably involved a commercial multitasking system, which might have required a more expensive computer.

The same flaws were present in the software controlling the predecessor model, the Therac-20, but that machine had hardware interlocks that mechanically prevented overdoses. The hardware safety devices were removed in the Therac-25 and replaced by checks in the software, presumably to save cost.

Frank Houston of the FDA wrote in 1985, "A significant amount of software for life-critical systems comes from small firms, especially in the medical device industry; firms that fit the profile of those resistant to or uninformed of the principles of either system safety or software engineering."

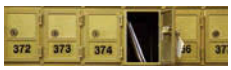
Who is to blame? The programmer? The manager who not only failed to ensure that the programmer was up to the task but also didn't insist on comprehensive testing? The hospitals that installed the device, or the FDA, for not reviewing the design process? Unfortunately, even today there are no firm standards for what constitutes a safe software design process.



Typical Therac-25 Facility

CHAPTER SUMMARY

Use arrays for collecting values.



- An array collects a sequence of values of the same type.
- Individual elements in an array are accessed by an integer index `i`, using the notation *array*`[i]`.
- An array element can be used like any variable.
- An array index must be at least zero and less than the size of the array.

- A bounds error, which occurs if you supply an invalid array index, can cause your program to terminate.
- Use the expression *array*.`length` to find the number of elements in an array.
- An array reference specifies the location of an array. Copying the reference yields a second reference to the same array.
- Arrays can occur as method arguments and return values.
- With a partially filled array, keep a companion variable for the current size.
- Avoid parallel arrays by changing them into arrays of objects.

Know when to use the enhanced `for` loop.

- You can use the enhanced `for` loop to visit all elements of an array.
- Use the enhanced `for` loop if you do not need the index values in the loop body.

Know and use common array algorithms.

- When separating elements, don't place a separator before the first element.
- A linear search inspects elements in sequence until a match is found.
- Before inserting an element, move elements to the end of the array *starting with the last one*.
- Use a temporary variable when swapping two elements.
- Use the `Arrays.copyOf` method to copy the elements of an array into a new array.

Combine and adapt algorithms for solving a programming problem.

- By combining fundamental algorithms, you can solve complex programming tasks.
- You should be familiar with the implementation of fundamental algorithms so that you can adapt them.

Discover algorithms by manipulating physical objects.

- Use a sequence of coins, playing cards, or toys to visualize an array of values.
- You can use paper clips as position markers or counters.

Use two-dimensional arrays for data that is arranged in rows and columns.

- Use a two-dimensional array to store tabular data.
- Individual elements in a two-dimensional array are accessed by using two index values, *array*`[i][j]`.

Use array lists for managing collections whose size can change.

- An array list stores a sequence of values whose size can change.
- The `ArrayList` class is a generic class: `ArrayList<`*Type*`>` collects elements of the specified type.
- Use the `size` method to obtain the current size of an array list.

- Use the `get` and `set` methods to access an array list element at a given index.
- Use the `add` and `remove` methods to add and remove array list elements.
- To collect numbers in array lists, you must use wrapper classes.

Describe the process of regression testing.

- A test suite is a set of tests for repeated testing.
- Regression testing involves repeating previously run tests to ensure that known failures of prior versions do not appear in new versions of the software.

STANDARD LIBRARY ITEMS INTRODUCED IN THIS CHAPTER

```
java.lang.Boolean
java.lang.Double
java.lang.Integer
java.util.Arrays
   copyOf
   toString
```

```
java.util.ArrayList<E>
   add
   get
   remove
   set
   size
```

REVIEW EXERCISES

■■ **R7.1** Carry out the following tasks with an array:

a. Allocate an array `a` of ten integers.

b. Put the number 17 as the initial element of the array.

c. Put the number 29 as the last element of the array.

d. Fill the remaining elements with –1.

e. Add 1 to each element of the array.

f. Print all elements of the array, one per line.

g. Print all elements of the array in a single line, separated by commas.

■ **R7.2** What is an index of an array? What are the legal index values? What is a bounds error?

■ **R7.3** Write a program that contains a bounds error. Run the program. What happens on your computer?

■ **R7.4** Write a loop that reads ten numbers and a second loop that displays them in the opposite order from which they were entered.

■■ **R7.5** Write code that fills an array `values` with each set of numbers below.

a. 1 2 3 4 5 6 7 8 9 10

b. 0 2 4 6 8 10 12 14 16 18 20

c. 1 4 9 16 25 36 49 64 81 100

d. 0 0 0 0 0 0 0 0 0 0

e. 1 4 9 16 9 7 4 9 11

f. 0 1 0 1 0 1 0 1 0 1

g. 0 1 2 3 4 0 1 2 3 4

■■ R7.6 Consider the following array:

```
int[] a = { 1, 2, 3, 4, 5, 4, 3, 2, 1, 0 };
```

What is the value of `total` after the following loops complete?

a.
```
int total = 0;
for (int i = 0; i < 10; i++) { total = total + a[i]; }
```

b.
```
int total = 0;
for (int i = 0; i < 10; i = i + 2) { total = total + a[i]; }
```

c.
```
int total = 0;
for (int i = 1; i < 10; i = i + 2) { total = total + a[i]; }
```

d.
```
int total = 0;
for (int i = 2; i <= 10; i++) { total = total + a[i]; }
```

e.
```
int total = 0;
for (int i = 1; i < 10; i = 2 * i) { total = total + a[i]; }
```

f.
```
int total = 0;
for (int i = 9; i >= 0; i--) { total = total + a[i]; }
```

g.
```
int total = 0;
for (int i = 9; i >= 0; i = i - 2) { total = total + a[i]; }
```

h.
```
int total = 0;
for (int i = 0; i < 10; i++) { total = a[i] - total; }
```

■■ R7.7 Consider the following array:

```
int[] a = { 1, 2, 3, 4, 5, 4, 3, 2, 1, 0 };
```

What are the contents of the array `a` after the following loops complete?

a.
```
for (int i = 1; i < 10; i++) { a[i] = a[i - 1]; }
```

b.
```
for (int i = 9; i > 0; i--) { a[i] = a[i - 1]; }
```

c.
```
for (int i = 0; i < 9; i++) { a[i] = a[i + 1]; }
```

d.
```
for (int i = 8; i >= 0; i--) { a[i] = a[i + 1]; }
```

e.
```
for (int i = 1; i < 10; i++) { a[i] = a[i] + a[i - 1]; }
```

f.
```
for (int i = 1; i < 10; i = i + 2) { a[i] = 0; }
```

g.
```
for (int i = 0; i < 5; i++) { a[i + 5] = a[i]; }
```

h.
```
for (int i = 1; i < 5; i++) { a[i] = a[9 - i]; }
```

■■■ R7.8 Write a loop that fills an array `values` with ten random numbers between 1 and 100. Write code for two nested loops that fill `values` with ten *different* random numbers between 1 and 100.

■■ R7.9 Write Java code for a loop that simultaneously computes both the maximum and minimum of an array.

■ R7.10 What is wrong with each of the following code segments?

a.
```
int[] values = new int[10];
for (int i = 1; i <= 10; i++)
{
   values[i] = i * i;
}
```

b.
```
int[] values;
for (int i = 0; i < values.length; i++)
{
   values[i] = i * i;
}
```

■■ **R7.11** Write enhanced `for` loops for the following tasks.

a. Printing all elements of an array in a single row, separated by spaces.

b. Computing the maximum of all elements in an array.

c. Counting how many elements in an array are negative.

■■ **R7.12** Rewrite the following loops without using the enhanced `for` loop construct. Here, `values` is an array of floating-point numbers.

a.
```
for (double x : values) { total = total + x; }
```

b.
```
for (double x : values) { if (x == target) { return true; } }
```

c.
```
int i = 0;
for (double x : values) { values[i] = 2 * x; i++; }
```

■■ **R7.13** Rewrite the following loops using the enhanced `for` loop construct. Here, `values` is an array of floating-point numbers.

a.
```
for (int i = 0; i < values.length; i++) { total = total + values[i]; }
```

b.
```
for (int i = 1; i < values.length; i++) { total = total + values[i]; }
```

c.
```
for (int i = 0; i < values.length; i++)
{
   if (values[i] == target) { return i; }
}
```

■ **R7.14** What is wrong with each of the following code segments?

a.
```
ArrayList<int> values = new ArrayList<int>();
```

b.
```
ArrayList<Integer> values = new ArrayList();
```

c.
```
ArrayList<Integer> values = new ArrayList<Integer>;
```

d.
```
ArrayList<Integer> values = new ArrayList<Integer>();
for (int i = 1; i <= 10; i++)
{
   values.set(i - 1, i * i);
}
```

e.
```
ArrayList<Integer> values;
for (int i = 1; i <= 10; i++)
{
   values.add(i * i);
}
```

■■ **R7.15** For the operations on partially filled arrays below, provide the header of a method. Do not implement the methods.

a. Sort the elements in decreasing order.

b. Print all elements, separated by a given string.

c. Count how many elements are less than a given value.

d. Remove all elements that are less than a given value.

e. Place all elements that are less than a given value in another array.

■ **R7.16** Trace the flow of the loop in Section 7.3.4 with the given example. Show two columns, one with the value of `i` and one with the output.

■ **R7.17** Consider the following loop for collecting all elements that match a condition; in this case, that the element is larger than 100.

```
ArrayList<Double> matches = new ArrayList<Double>();
for (double element : values)
{
```

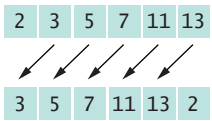
```
      if (element > 100)
      {
         matches.add(element);
      }
   }
```

Trace the flow of the loop, where `values` contains the elements 110 90 100 120 80. Show two columns, for `element` and `matches`.

■ **R7.18** Trace the flow of the loop in Section 7.3.5, where `values` contains the elements 80 90 100 120 110. Show two columns, for `pos` and `found`. Repeat the trace when `values` contains the elements 80 90 120 70.

■■ **R7.19** Trace the algorithm for removing an element described in Section 7.3.6. Use an array `values` with elements 110 90 100 120 80, and remove the element at index 2.

■■ **R7.20** Give pseudocode for an algorithm that rotates the elements of an array by one position, moving the initial element to the end of the array, as shown at right.



■■ **R7.21** Give pseudocode for an algorithm that removes all negative values from an array, preserving the order of the remaining elements.

■■ **R7.22** Suppose `values` is a *sorted* array of integers. Give pseudocode that describes how a new value can be inserted so that the resulting array stays sorted.

■■■ **R7.23** A *run* is a sequence of adjacent repeated values. Give pseudocode for computing the length of the longest run in an array. For example, the longest run in the array with elements

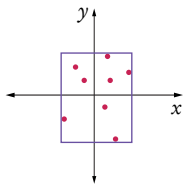
```
1 2 5 5 3 1 2 4 3 2 2 2 2 3 6 5 5 6 3 1
```

has length 4.

■■■ **R7.24** What is wrong with the following method that aims to fill an array with random numbers?

```
public void makeCombination(int[] values, int n)
{
   Random generator = new Random();
   int[] numbers = new int[values.length];
   for (int i = 0; i < numbers.length; i++)
   {
      numbers[i] = generator.nextInt(n);
   }
   values = numbers;
}
```

■■ **R7.25** You are given two arrays denoting x- and y-coordinates of a set of points in a plane. For plotting the point set, we need to know the x- and y-coordinates of the smallest rectangle containing the points. How can you obtain these values from the fundamental algorithms in Section 7.3?



■ **R7.26** Solve the quiz score problem described in Section 7.4 by sorting the array first. How do you need to modify the algorithm for computing the total?

■■ **R7.27** Solve the task described in Section 7.5 using an algorithm that removes and inserts elements instead of switching them. Write the pseudocode for the algorithm, assuming that methods for removal and insertion exist. Act out the algorithm with a

sequence of coins and explain why it is less efficient than the swapping algorithm developed in Section 7.5.

■■ **R7.28** Develop an algorithm for finding the most frequently occurring value in an array of numbers. Use a sequence of coins. Place paper clips below each coin that count how many other coins of the same value are in the sequence. Give the pseudocode for an algorithm that yields the correct answer, and describe how using the coins and paper clips helped you find the algorithm.

■■ **R7.29** Write Java statements for performing the following tasks with an array declared as

```
int[][] values = new int[ROWS][COLUMNS];
```

- Fill all entries with `0`.
- Fill elements alternately with `0`s and `1`s in a checkerboard pattern.
- Fill only the elements in the top and bottom rows with zeroes.
- Compute the sum of all elements.
- Print the array in tabular form.

■■ **R7.30** Write pseudocode for an algorithm that fills the first and last columns as well as the first and last rows of a two-dimensional array of integers with –1.

■ **R7.31** Section 7.7.7 shows that you must be careful about updating the index value when you remove elements from an array list. Show how you can avoid this problem by traversing the array list backwards.

■■ **R7.32** True or false?

a. All elements of an array are of the same type.
b. Arrays cannot contain strings as elements.
c. Two-dimensional arrays always have the same number of rows and columns.
d. Elements of different columns in a two-dimensional array can have different types.
e. A method cannot return a two-dimensional array.
f. A method cannot change the length of an array argument.
g. A method cannot change the number of columns of an argument that is a two-dimensional array.

■■ **R7.33** How do you perform the following tasks with array lists in Java?

a. Test that two array lists contain the same elements in the same order.
b. Copy one array list to another.
c. Fill an array list with zeroes, overwriting all elements in it.
d. Remove all elements from an array list.

■ **R7.34** True or false?

a. All elements of an array list are of the same type.
b. Array list index values must be integers.
c. Array lists cannot contain strings as elements.
d. Array lists can change their size, getting larger or smaller.
e. A method cannot return an array list.
f. A method cannot change the size of an array list argument.

■ **Testing R7.35** Define the terms regression testing and test suite.

■■ **Testing R7.36** What is the debugging phenomenon known as *cycling*? What can you do to avoid it?

PRACTICE EXERCISES

■■ **E7.1** Write a program that initializes an array with ten random integers and then prints four lines of output, containing

- Every element at an even index.
- Every even element.
- All elements in reverse order.
- Only the first and last element.

■ **E7.2** Modify the `LargestInArray.java` program in Section 7.3 to mark both the smallest and the largest elements.

■■ **E7.3** Write a method `sumWithoutSmallest` that computes the sum of an array of values, except for the smallest one, in a single loop. In the loop, update the sum and the smallest value. After the loop, return the difference.

■ **E7.4** Add a method `removeMin` to the `Student` class of Section 7.4 that removes the minimum score without calling other methods.

■■ **E7.5** Compute the *alternating sum* of all elements in an array. For example, if your program reads the input

1 4 9 16 9 7 4 9 11

then it computes

$$1 - 4 + 9 - 16 + 9 - 7 + 4 - 9 + 11 = -2$$

■ **E7.6** Write a method that reverses the sequence of elements in an array. For example, if you call the method with the array

1 4 9 16 9 7 4 9 11

then the array is changed to

11 9 4 7 9 16 9 4 1

■■■ **E7.7** Write a program that produces ten random permutations of the numbers 1 to 10. To generate a random permutation, you need to fill an array with the numbers 1 to 10 so that no two entries of the array have the same contents. You could do it by brute force, generating random values until you have a value that is not yet in the array. But that is inefficient. Instead, follow this algorithm:

```
Make a second array and fill it with the numbers 1 to 10.
Repeat 10 times
   Pick a random element from the second array.
   Remove it and append it to the permutation array.
```

■ **E7.8** Write a method that implements the algorithm developed in Section 7.5.

■■ **E7.9** Write a class `DataSet` that stores a number of values of type `double`. Provide a constructor

```
public DataSet(int maximumNumberOfValues)
```

and a method

```
public void add(double value)
```

that adds a value, provided there is still room.

Provide methods to compute the sum, average, maximum, and minimum value.

■■ **E7.10** Write array methods that carry out the following tasks for an array of integers by completing the `ArrayMethods` class below. For each method, provide a test program.

```
public class ArrayMethods
{
   private int[] values;
   public ArrayMethods(int[] initialValues) { values = initialValues; }
   public void swapFirstAndLast() { . . . }
   public void shiftRight() { . . . }
   . . .
}
```

a. Swap the first and last elements in the array.

b. Shift all elements to the right by one and move the last element into the first position. For example, 1 4 9 16 25 would be transformed into 25 1 4 9 16.

c. Replace all even elements with `0`.

d. Replace each element except the first and last by the larger of its two neighbors.

e. Remove the middle element if the array length is odd, or the middle two elements if the length is even.

f. Move all even elements to the front, otherwise preserving the order of the elements.

g. Return the second-largest element in the array.

h. Return true if the array is currently sorted in increasing order.

i. Return true if the array contains two adjacent duplicate elements.

j. Return true if the array contains duplicate elements (which need not be adjacent).

■■ **E7.11** Consider the following class:

```
public class Sequence
{
   private int[] values;
   public Sequence(int size) { values = new int[size]; }
   public void set(int i, int n) { values[i] = n; }
   public int get(int i) { return values[i]; }
   public int size() { return values.length; }
}
```

Add a method

```
public boolean equals(Sequence other)
```

that checks whether two sequences have the same values in the same order.

■■ **E7.12** Add a method

```
public boolean sameValues(Sequence other)
```

to the `Sequence` class of Exercise E7.11 that checks whether two sequences have the same values in some order, ignoring duplicates. For example, the two sequences

1 4 9 16 9 7 4 9 11

and

11 11 7 9 16 4 1

would be considered identical. You will probably need one or more helper methods.

■■■ **E7.13** Add a method

```
public boolean isPermutationOf(Sequence other)
```

to the `Sequence` class of Exercise E7.11 that checks whether two sequences have the same values in some order, with the same multiplicities. For example,

1 4 9 16 9 7 4 9 11

is a permutation of

11 1 4 9 16 9 7 4 9

but

1 4 9 16 9 7 4 9 11

is not a permutation of

11 11 7 9 16 4 1 4 9

You will probably need one or more helper methods.

■■ **E7.14** Add a method

```
public Sequence sum(Sequence other)
```

to the `Sequence` class of Exercise E7.11 that yields the sum of this sequence and another. If the sequences don't have the same length, assume that the missing elements are zero. For example, the sum of

1 4 9 16 9 7 4 9 11

and

11 11 7 9 16 4 1

is the sequence

12 15 16 25 25 11 5 9 11

■■ **E7.15** Write a program that generates a sequence of 20 random values between 0 and 99 in an array, prints the sequence, sorts it, and prints the sorted sequence. Use the `sort` method from the standard Java library.

■■ **E7.16** Add a method to the `Table` class below that computes the average of the neighbors of a table element in the eight directions shown in Figure 15:

```
public double neighborAverage(int row, int column)
```

However, if the element is located at the boundary of the array, include only the neighbors that are in the table. For example, if `row` and `column` are both 0, there are only three neighbors.

```
public class Table
{
    private int[][] values;
    public Table(int rows, int columns) { values = new int[rows][columns]; }
    public void set(int i, int j, int n) { values[i][j] = n; }
}
```

■■ **E7.17** Given the `Table` class of Exercise E7.16 , add a method that returns the sum of the `i`th row (if horizontal is `true`) or column (if horizontal is `false`):

```
public double sum(int i, boolean horizontal)
```

■■ **E7.18** Write a program that reads a sequence of input values and displays a bar chart of the values, using asterisks, like this:

```
**********************
*****************************************
****************************
*************************
**************
```

You may assume that all values are positive. First figure out the maximum value. That value's bar should be drawn with 40 asterisks. Shorter bars should use proportionally fewer asterisks.

■■■ **E7.19** Repeat Exercise E7.17, but make the bars vertical, with the tallest bar twenty asterisks high.

```
    *
    *
    *
    *
    *
    *
   **
  ***
  ***
 ****
 ****
 ****
 ****
*****
*****
*****
*****
*****
*****
*****
```

■■■ **E7.20** Improve the program of Exercise E7.17 to work correctly when the data set contains negative values.

■■ **E7.21** Improve the program of Exercise E7.17 by adding captions for each bar. Prompt the user for the captions and data values. The output should look like this:

```
       Egypt **********
      France ****************************************
       Japan ***************************
     Uruguay *************************
Switzerland **************
```

■ **E7.22** Consider the following class:

```
public class Sequence
{
    private ArrayList<Integer> values;
    public Sequence() { values = new ArrayList<Integer>(); }
    public void add(int n) { values.add(n); }
    public String toString() { return values.toString(); }
}
```

Add a method

```
public Sequence append(Sequence other)
```

that creates a new sequence, appending this and the other sequence, without modifying either sequence. For example, if `a` is

1 4 9 16

and `b` is the sequence

9 7 4 9 11

then the call `a.append(b)` returns the sequence

1 4 9 16 9 7 4 9 11

without modifying `a` or `b`.

■■ **E7.23** Add a method

```
public Sequence merge(Sequence other)
```

to the `Sequence` class of Exercise E7.21 that merges two sequences, alternating elements from both sequences. If one sequence is shorter than the other, then alternate

as long as you can and then append the remaining elements from the longer sequence. For example, if `a` is

1 4 9 16

and `b` is

9 7 4 9 11

then `a.merge(b)` returns the sequence

1 9 4 7 9 4 16 9 11

without modifying `a` or `b`.

■■ **E7.24** Add a method

```
public Sequence mergeSorted(Sequence other)
```

to the `Sequence` class of Exercise E7.21 that merges two sorted sequences, producing a new sorted sequence. Keep an index into each sequence, indicating how much of it has been processed already. Each time, append the smallest unprocessed value from either sequence, then advance the index. For example, if `a` is

1 4 9 16

and `b` is

4 7 9 9 11

then `a.mergeSorted(b)` returns the sequence

1 4 4 7 9 9 9 11 16

If `a` or `b` is not sorted, merge the longest prefixes of `a` and `b` that are sorted.

PROGRAMMING PROJECTS

■■ **P7.1** A *run* is a sequence of adjacent repeated values. Write a program that generates a sequence of 20 random die tosses in an array and that prints the die values, marking the runs by including them in parentheses, like this:

```
1 2 (5 5) 3 1 2 4 3 (2 2 2) 3 6 (5 5) 6 3 1
```

Use the following pseudocode:

```
Set a boolean variable inRun to false.
For each valid index i in the array
   If inRun
      If values[i] is different from the preceding value
         Print ).
         inRun = false.
   If not inRun
      If values[i] is the same as the following value
         Print (.
         inRun = true.
   Print values[i].
If inRun, print ).
```

■■ **P7.2** Write a program that generates a sequence of 20 random die tosses in an array and that prints the die values, marking only the longest run, like this:

```
1 2 5 5 3 1 2 4 3 (2 2 2) 3 6 5 5 6 3 1
```

If there is more than one run of maximum length, mark the first one.

■■ **P7.3** It is a well-researched fact that men in a restroom generally prefer to maximize their distance from already occupied stalls, by occupying the middle of the longest sequence of unoccupied places.

For example, consider the situation where ten stalls are empty.

```
_ _ _ _ _ _ _ _ _ _
```

The first visitor will occupy a middle position:

```
_ _ _ _ _ X _ _ _ _
```

The next visitor will be in the middle of the empty area at the left.

```
_ _ X _ _ X _ _ _ _
```

Write a program that reads the number of stalls and then prints out diagrams in the format given above when the stalls become filled, one at a time. *Hint:* Use an array of `boolean` values to indicate whether a stall is occupied.

■■■ **P7.4** In this assignment, you will model the game of *Bulgarian Solitaire*. The game starts with 45 cards. (They need not be playing cards. Unmarked index cards work just as well.) Randomly divide them into some number of piles of random size. For example, you might start with piles of size 20, 5, 1, 9, and 10. In each round, you take one card from each pile, forming a new pile with these cards. For example, the sample starting configuration would be transformed into piles of size 19, 4, 8, 9, and 5. The solitaire is over when the piles have size 1, 2, 3, 4, 5, 6, 7, 8, and 9, in some order. (It can be shown that you always end up with such a configuration.)

In your program, produce a random starting configuration and print it. Then keep applying the solitaire step and print the result. Stop when the solitaire final configuration is reached.

■■■ **P7.5** *Magic squares*. An $n \times n$ matrix that is filled with the numbers $1, 2, 3, \ldots, n^2$ is a magic square if the sum of the elements in each row, in each column, and in the two diagonals is the same value.

16	3	2	13
5	10	11	8
9	6	7	12
4	15	14	1

Write a program that reads in 16 values from the keyboard and tests whether they form a magic square when put into a 4×4 array.

You need to test two features:

1. Does each of the numbers 1, 2, ..., 16 occur in the user input?
2. When the numbers are put into a square, are the sums of the rows, columns, and diagonals equal to each other?

■■■ **P7.6** Implement the following algorithm to construct magic $n \times n$ squares; it works only if n is odd.

```
Set row = n - 1, column = n / 2.
For k = 1 ... n * n
   Place k at [row][column].
   Increment row and column.
   If the row or column is n, replace it with 0.
   If the element at [row][column] has already been filled
      Set row and column to their previous values.
      Decrement row.
```

11	18	25	2	9
10	12	19	21	3
4	6	13	20	22
23	5	7	14	16
17	24	1	8	15

Here is the 5×5 square that you get if you follow this method:

Write a program whose input is the number n and whose output is the magic square of order n if n is odd.

■■ **P7.7** A theater seating chart is implemented as a two-dimensional array of ticket prices, like this:

```
10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10
10 10 20 20 20 20 20 20 10 10
10 10 20 20 20 20 20 20 10 10
10 10 20 20 20 20 20 20 10 10
20 20 30 30 40 40 30 30 20 20
20 30 30 40 50 50 40 30 30 20
30 40 50 50 50 50 50 50 40 30
```

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Write a program that prompts users to pick either a seat or a price. Mark sold seats by changing the price to 0. When a user specifies a seat, make sure it is available. When a user specifies a price, find any seat with that price.

■■■ **P7.8** Write a program that plays tic-tac-toe. The tic-tac-toe game is played on a 3×3 grid as in the photo at right. The game is played by two players, who take turns. The first player marks moves with a circle, the second with a cross. The player who has formed a horizontal, vertical, or diagonal sequence of three marks wins. Your program should draw the game board, ask the user for the coordinates of the next mark, change the players after every successful move, and pronounce the winner.

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■■■ **P7.9** In this assignment, you will implement a simulation of a popular casino game usually called video poker. The card deck contains 52 cards, 13 of each suit. At the beginning of the game, the deck is shuffled. You need to devise a fair method for shuffling. (It does not have to be efficient.) The player pays a token for each game. Then the top five cards of the deck are presented to the player. The player can reject none, some, or all of the cards. The rejected cards are replaced from the top of the deck. Now the hand is scored. Your program should pronounce it to be one of the following:

- No pair—The lowest hand, containing five separate cards that do not match up to create any of the hands below.
- One pair—Two cards of the same value, for example two queens. Payout: 1
- Two pairs—Two pairs, for example two queens and two 5's. Payout: 2
- Three of a kind—Three cards of the same value, for example three queens. Payout: 3
- Straight—Five cards with consecutive values, not necessarily of the same suit, such as 4, 5, 6, 7, and 8. The ace can either precede a 2 or follow a king. Payout: 4
- Flush—Five cards, not necessarily in order, of the same suit. Payout: 5
- Full House—Three of a kind and a pair, for example three queens and two 5's. Payout: 6
- Four of a Kind—Four cards of the same value, such as four queens. Payout: 25
- Straight Flush—A straight and a flush: Five cards with consecutive values of the same suit. Payout: 50
- Royal Flush—The best possible hand in poker. A 10, jack, queen, king, and ace, all of the same suit. Payout: 250

■■■ **P7.10** *The Game of Life* is a well-known mathematical game that gives rise to amazingly complex behavior, although it can be specified by a few simple rules. (It is not actually a game in the traditional sense, with players competing for a win.) Here are the rules. The game is played on a rectangular board. Each square can be either empty or occupied. At the beginning, you can specify empty and occupied cells in some way; then the game runs automatically. In each *generation*, the next generation is computed. A new cell is born on an empty square if it is surrounded by exactly three occupied neighbor cells. A cell dies of overcrowding if it is surrounded by four or more neighbors, and it dies of loneliness if it is surrounded by zero or one neighbor. A neighbor is an occupant of an adjacent square to the left, right, top, or bottom or in a diagonal direction. Figure 21 shows a cell and its neighbor cells.

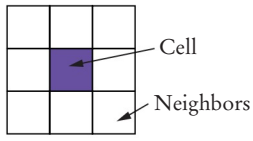

Figure 21
Neighborhood of a Cell

Many configurations show interesting behavior when subjected to these rules. Figure 22 shows a *glider*, observed over five generations. After four generations, it is transformed into the identical shape, but located one square to the right and below.

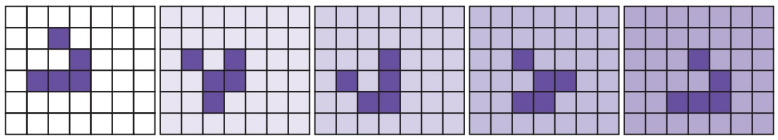

Figure 22 Glider

One of the more amazing configurations is the glider gun: a complex collection of cells that, after 30 moves, turns back into itself and a glider (see Figure 23).

Program the game to eliminate the drudgery of computing successive generations by hand. Use a two-dimensional array to store the rectangular configuration. Write a program that shows successive generations of the game. Ask the user to specify the original configuration, by typing in a configuration of spaces and o characters.

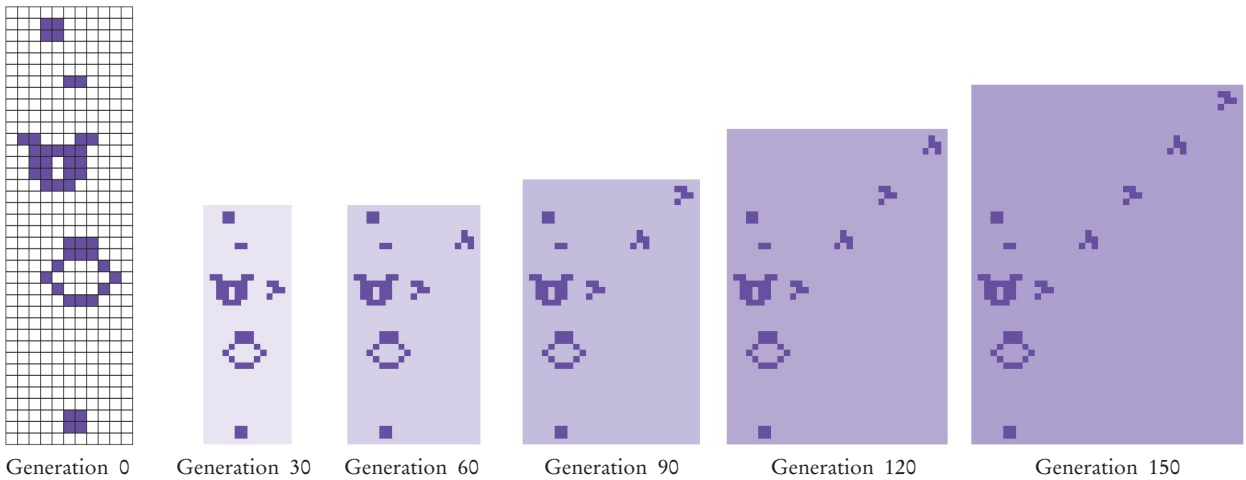

Figure 23 Glider Gun

■■ Business P7.11 A pet shop wants to give a discount to its clients if they buy one or more pets and at least five other items. The discount is equal to 20 percent of the cost of the other items, but not the pets.


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Use a class `Item` to describe an item, with any needed methods and a constructor

```
public Item(double price, boolean isPet, int quantity)
```

An invoice holds a collection of `Item` objects; use an array or array list to store them. In the `Invoice` class, implement methods

```
public void add(Item anItem)
public double getDiscount()
```

Write a program that prompts a cashier to enter each price and quantity, and then a `Y` for a pet or `N` for another item. Use a price of –1 as a sentinel. In the loop, call the `add` method; after the loop, call the `getDiscount` method and display the returned value.

■■ Business P7.12 A supermarket wants to reward its best customer of each day, showing the customer's name on a screen in the supermarket. For that purpose, the store keeps an `ArrayList<Customer>`. In the `Store` class, implement methods

```
public void addSale(String customerName, double amount)
public String nameOfBestCustomer()
```

to record the sale and return the name of the customer with the largest sale.

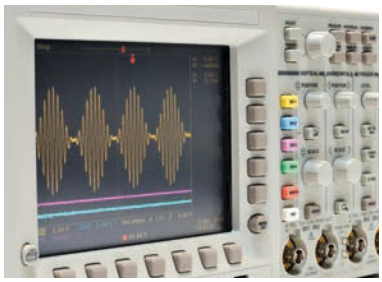
Write a program that prompts the cashier to enter all prices and names, adds them to a `Store` object, and displays the best customer's name. Use a price of `0` as a sentinel.

■■■ Business P7.13 Improve the program of Exercise P7.12 so that it displays the top customers, that is, the `topN` customers with the largest sales, where `topN` is a value that the user of the program supplies. Implement a method

```
public ArrayList<String> nameOfBestCustomers(int topN)
```

If there were fewer than `topN` customers, include all of them.

■■ Science P7.14 Sounds can be represented by an array of "sample values" that describe the intensity of the sound at a point in time. The program in `ch07/sound` of your companion code reads a sound file (in WAV format), processes the sample values, and shows the result. Your task is to process the sound by introducing an echo. For each sound value, add the value from 0.2 seconds ago. Scale the result so that no value is larger than 32767.


© GordonHeeley/iStockphoto.

■■■ Science P7.15 You are given a two-dimensional array of values that give the height of a terrain at different points in a square. Write a constructor

```
public Terrain(double[][] heights)
```

and a method

```
public void printFloodMap(double waterLevel)
```

that prints out a flood map, showing which of the points in the terrain would be flooded if the water level was the given value.

In the flood map, print a * for each flooded point and a space for each point that is not flooded.

Here is a sample map:

```
* * * *         * *
* * * * *     * * *
* * * *         * *
* * *         * * *
* * * *   *   * * *
* * * * * * * * * *
* *     * * *
*       * * * *   *
              * *
            * * *
```

Then write a program that reads one hundred terrain height values and shows how the terrain gets flooded when the water level increases in ten steps from the lowest point in the terrain to the highest.

■■ Science P7.16 Sample values from an experiment often need to be smoothed out. One simple approach is to replace each value in an array with the average of the value and its two neighboring values (or one neighboring value if it is at either end of the array). Given a class `Data` with instance fields

```
private double[] values;
private double valuesSize;
```

implement a method

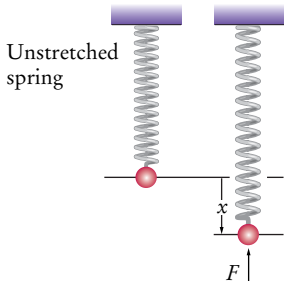
```
public void smooth()
```

that carries out this operation. You should not create another array in your solution.

■■■ Science P7.17 Write a program that models the movement of an object with mass m that is attached to an oscillating spring. When a spring is displaced from its equilibrium position by an amount x, Hooke's law states that the restoring force is

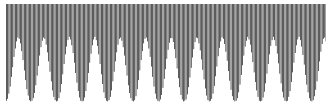
$$F = -kx$$

where k is a constant that depends on the spring. (Use 10 N /m for this simulation.)

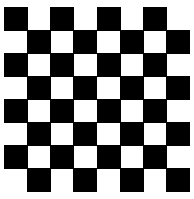


Start with a given displacement x (say, 0.5 meter). Set the initial velocity v to 0. Compute the acceleration a from Newton's law ($F = ma$) and Hooke's law, using a mass of 1 kg. Use a small time interval $\Delta t = 0.01$ second. Update the velocity—it changes by $a\Delta t$. Update the displacement—it changes by $v\Delta t$.

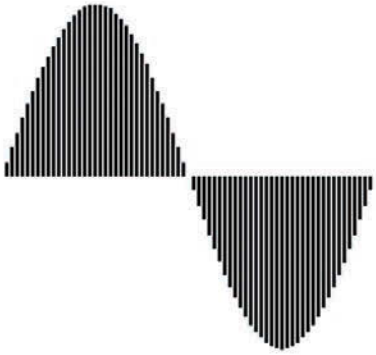
Every ten iterations, plot the spring displacement as a bar, where 1 pixel represents 1 cm, as shown here.



■■ Graphics P7.18 Generate the image of a checkerboard.



■ **Graphics P7.19** Generate the image of a sine wave. Draw a line of pixels for every five degrees.



■ **Graphics P7.20** Implement a class `Cloud` that contains an array list of `Point2D.Double` objects. Support methods

```
public void add(Point2D.Double aPoint)
public void draw(Graphics2D g2)
```

Draw each point as a tiny circle. Write a graphical application that draws a cloud of 100 random points.

■■ **Graphics P7.21** Implement a class `Polygon` that contains an array list of `Point2D.Double` objects. Support methods

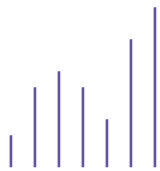
```
public void add(Point2D.Double aPoint)
public void draw(Graphics2D g2)
```

Draw the polygon by joining adjacent points with a line, and then closing it up by joining the end and start points. Write a graphical application that draws a square and a pentagon using two `Polygon` objects.

■ **Graphics P7.22** Write a class `Chart` with methods

```
public void add(int value)
public void draw(Graphics2D g2)
```

that displays a stick chart of the added values, like this:



You may assume that the values are pixel positions.

■■ **Graphics P7.23** Write a class `BarChart` with methods

```
public void add(double value)
public void draw(Graphics2D g2)
```

that displays a bar chart of the added values. You may assume that all added values are positive. Stretch the bars so that they fill the entire area of the screen. You must figure out the maximum of the values, then scale each bar.

■■■ **Graphics P7.24** Improve the `BarChart` class of Exercise P7.23 to work correctly when the data contains negative values.

■■ **Graphics P7.25** Write a class `PieChart` with methods

```
public void add(double value)
public void draw(Graphics2D g2)
```

that displays a pie chart of the added values. Assume that all data values are positive.

ANSWERS TO SELF-CHECK QUESTIONS

1. `int[] primes = { 2, 3, 5, 7, 11 };`
2. `2, 3, 5, 3, 2`
3. `3, 4, 6, 8, 12`
4. `values[0] = 10;`
   `values[9] = 10;` or better:
   `values[values.length - 1] = 10;`
5. `String[] words = new String[10];`
6. `String[] words = { "Yes", "No" };`
7. No. Because you don't store the values, you need to print them when you read them. But you don't know where to add the `<=` until you have seen all values.
8.
```
public class Lottery
{
   public int[] getCombination(int n) { . . . }
   . . .
}
```
9. It counts how many elements of `values` are zero.
10.
```
for (double x : values)
{
   System.out.println(x);
}
```
11.
```
double product = 1;
for (double f : factors)
{
   product = product * f;
}
```
12. The loop writes a value into `values[i]`. The enhanced `for` loop does not have the index variable `i`.
13.
```
20 <== largest value
10
20 <== largest value
```
14.
```
int count = 0;
for (double x : values)
{
   if (x == 0) { count++; }
}
```
15. If all elements of `values` are negative, then the result is incorrectly computed as `0`.
16.
```
for (int i = 0; i < values.length; i++)
{
   System.out.print(values[i]);
   if (i < values.length - 1)
   {
      System.out.print(" | ");
   }
}
```
    Now you know why we set up the loop the other way.
17. If the array has no elements, then the program terminates with an exception.
18. If there is a match, then `pos` is incremented before the loop exits.
19. This loop sets all elements to `values[pos]`.
20. Use the first algorithm. The order of elements does not matter when computing the sum.
21. **Find the minimum value.**
    Calculate the sum.
    Subtract the minimum value.
22. Use the algorithm for counting matches (Section 6.7.2) twice, once for counting the positive values and once for counting the negative values.
23. You need to modify the algorithm in Section 7.3.4.
```
boolean first = true;
for (int i = 0; i < values.length; i++)
{
   if (values[i] > 0))
   {
      if (first) { first = false; }
      else { System.out.print(", "); }
   }
   System.out.print(values[i]);
}
```
    Note that you can no longer use `i > 0` as the criterion for printing a separator.
24. Use the algorithm to collect all positive elements in an array, then use the algorithm in Section 7.3.4 to print the array of matches.
25. The paperclip for **i** assumes positions 0, 1, 2, 3. When **i** is incremented to 4, the condition **i < size / 2** becomes false, and the loop ends. Similarly, the paperclip for **j** assumes positions 4, 5, 6, 7, which are the valid positions for the second half of the array.

26. It reverses the elements in the array.

27. Here is one solution. The basic idea is to move all odd elements to the end. Put one paper clip at the beginning of the array and one at the end. If the element at the first paper clip is odd, swap it with the one at the other paper clip and move that paper clip to the left. Otherwise, move the first paper clip to the right. Stop when the two paper clips meet. Here is the pseudocode:

```
i = 0
j = size - 1
While (i < j)
   If (a[i] is odd)
      Swap elements at positions i and j.
      j--
   Else
      i++
```

28. Here is one solution. The idea is to remove all odd elements and move them to the end. The trick is to know when to stop. Nothing is gained by moving odd elements into the area that already contains moved elements, so we want to mark that area with another paper clip.

```
i = 0
moved = size
While (i < moved)
   If (a[i] is odd)
      Remove the element at position i and add it
         at the end.
      moved--
```

29. When you read inputs, you get to see values one at a time, and you can't peek ahead. Picking cards one at a time from a deck of cards simulates this process better than looking at a sequence of items, all of which are revealed.

30. You get the total number of gold, silver, and bronze medals in the competition. In our example, there are four of each.

31.
```
for (int i = 0; i < 8; i++)
{
   for (int j = 0; j < 8; j++)
   {
      board[i][j] = (i + j) % 2;
   }
}
```

32. `String[][] board = new String[3][3];`

33. `board[0][2] = "x";`

34. `board[0][0]`, `board[1][1]`, `board[2][2]`

35.
```
ArrayList<Integer> primes =
   new ArrayList<Integer>();
primes.add(2);
primes.add(3);
primes.add(5);
primes.add(7);
primes.add(11);
```

36.
```
for (int i = primes.size() - 1; i >= 0; i--)
{
   System.out.println(primes.get(i));
}
```

37. `"Ann"`, `"Cal"`

38. The `names` variable has not been initialized.

39. `names1` contains `"Emily"`, `"Bob"`, `"Cindy"`, `"Dave"`; `names2` contains `"Dave"`

40. Because the number of weekdays doesn't change, there is no disadvantage to using an array, and it is easier to initialize:

```
String[] weekdayNames = { "Monday", "Tuesday",
   "Wednesday", "Thursday", "Friday",
   "Saturday", "Sunday" };
```

41. Reading inputs into an array list is much easier.

42. It is possible to introduce errors when modifying code.

43. Add a test case to the test suite that verifies that the error is fixed.

44. There is no human user who would see the prompts because input is provided from a file.

WORKED EXAMPLE 7.1

Rolling the Dice

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Problem Statement Your task is to analyze whether a die is fair by counting how often the values 1, 2, ..., 6 appear. Your input is a sequence of die toss values, and you should print a table with the frequencies of each die value.

Step 1 Decompose your task into steps.

Our first try at decomposition simply echoes the problem statement:

```
Read the die values.
Count how often the values 1, 2, ..., 6 appear.
Print the counts.
```

But let's think about the task a little more. This decomposition suggests that we first read and store all die values. Do we really need to store them? After all, we only want to know how often each face value appears. If we keep an array of counters, we can discard each input after incrementing the counter.

This refinement yields the following outline:

```
For each input value
   Increment the corresponding counter.
Print the counters.
```

Step 2 Determine which algorithm(s) you need.

We don't have a ready-made algorithm for reading inputs and incrementing a counter, but it is straightforward to develop one. Suppose we read an input into `value`. This is an integer between 1 and 6. If we have an array `counters` of length 6, then we simply call

```
counters[value - 1]++;
```

Alternatively, we can use an array of seven integers, "wasting" the element `counters[0]`. That trick makes it easier to update the counters. When reading an input value, we simply execute

```
counters[value]++; // value is between 1 and 6
```

That is, we create the array as

```
counters = new int[sides + 1];
```

Why introduce a `sides` variable? Suppose you later changed your mind and wanted to investigate 12-sided dice:

© Ryan Ruffatti/iStockphoto.

Then the program can simply be changed by setting `sides` to 12.

The only remaining task is to print the counts. A typical output might look like this:

```
1:    3
2:    3
3:    2
4:    2
5:    2
6:    0
```

We haven't seen an algorithm for this exact output format. It is similar to the basic loop for printing all elements:

```
for (int element : counters)
{
   System.out.println(element);
}
```

However, that loop is not appropriate for two reasons. First, it displays the unused `0` entry. The "enhanced" `for` loop is no longer suitable if we want to skip that entry. We need a traditional `for` loop instead:

```
for (int i = 1; i < counters.length; i++)
{
   System.out.println(counters[i]);
}
```

This loop prints the counter values, but it doesn't quite match the sample output. We also want the corresponding face values:

```
for (int i = 1; i < counters.length; i++)
{
   System.out.printf("%2d: %4d\n", i, counters[i]);
}
```

Step 3 Use methods to structure your program.

We will provide a method for each step:

- `void countInputs()`
- `void printCounters()`

The `main` method calls these methods:

```
public class DiceAnalyzer
{
   public static void main(String[] args)
   {
      final int SIDES = 6;
      Dice dice = new Dice(SIDES);
      dice.countInputs();
      dice.printCounters();
   }
}
```

The `countInputs` method reads all inputs and increments the matching counters. The `printCounters` method prints the value of the faces and counters, as already described.

Step 4 Assemble and test the program.

The listing at the end of this section shows the complete program. There is one notable feature that we have not previously discussed. When updating a counter

```
counters[value]++;
```

we want to be sure that the user did not provide a wrong input which would cause an array bounds error. Therefore, we reject inputs < 1 or > `sides`.

The following table shows test cases and their expected output. To save space, we only show the counters in the output.

Test Case	Expected Output	Comment
1 2 3 4 5 6	1 1 1 1 1 1	Each number occurs once.
1 2 3	1 1 1 0 0 0	Numbers that don't appear should have counts of zero.
1 2 3 1 2 3 4	2 2 2 1 0 0	The counters should reflect how often each input occurs.
(No input)	0 0 0 0 0 0	This is a legal input; all counters are zero.
0 1 2 3 4 5 6 7	**Error**	Each input should be between 1 and 6.

Here's the complete program:

worked_example_1/Dice.java

```
1  import java.util.Scanner;
2
3  /**
4     This program reads a sequence of die toss values and prints how many times
5     each value occurred.
6  */
7  public class Dice
8  {
9     private int[] counters;
10
11    public Dice(int sides)
12    {
13       counters = new int[SIDES + 1]; // counters[0] is not used
14    }
15
16    public void countInputs()
17    {
18       System.out.println("Please enter values, Q to quit:");
19       Scanner in = new Scanner(System.in);
20       while (in.hasNextInt())
21       {
22          int value = in.nextInt();
23
24          // Increment the counter for the input value
25
26          if (1 <= value && value <= counters.length)
27          {
28             counters[value]++;
29          }
30          else
31          {
32             System.out.println(value + " is not a valid input.");
33          }
34       }
35    }
36
```

```
37    public void printCounters()
38    {
39       for (int i = 1; i < counters.length; i++)
40       {
41          System.out.printf("%2d: %4d\n", i, counters[i]);
42       }
43    }
44 }
```

worked_example_1/DiceAnalyzer

```
45 public class DiceAnalyzer
46 {
47    public static void main(String[] args)
48    {
49       final int SIDES = 6;
50       Dice dice = new Dice(SIDES);
51       dice.countInputs();
52       dice.printcounters();
53    }
54 }
```

Program Run

```
Please enter values, Q to quit:
1 2 3 1 2 3 4 Q
1:    2
2:    2
3:    2
4:    1
5:    0
6:    0
```

WORKED EXAMPLE 7.2 A World Population Table

Problem Statement You are to print the following population data in tabular format and add column totals that show the total world population in the given years.

Population Per Continent (in millions)							
Year	1750	1800	1850	1900	1950	2000	2050
Africa	106	107	111	133	221	767	1766
Asia	502	635	809	947	1402	3634	5268
Australia	2	2	2	6	13	30	46
Europe	163	203	276	408	547	729	628
North America	2	7	26	82	172	307	392
South America	16	24	38	74	167	511	809

Step 1 First, we break down the task into steps:

Initialize the table data.
Print the table.
Compute and print the column totals.

Step 2 Initialize the table as a sequence of rows:

```
int[][] populations =
   {
      { 106, 107, 111, 133, 221, 767, 1766 },
      { 502, 635, 809, 947, 1402, 3634, 5268 },
      { 2, 2, 2, 6, 13, 30, 46 },
      { 163, 203, 276, 408, 547, 729, 628 },
      { 2, 7, 26, 82, 172, 307, 392 },
      { 16, 24, 38, 74, 167, 511, 809 }
   };
```

Step 3 To print the row headers, we also need a one-dimensional array of the continent names. Note that it has the same number of rows as our table.

```
String[] continents =
   {
      "Africa",
      "Asia",
      "Australia",
      "Europe",
      "North America",
      "South America"
   };
```

To print a row, we first print the continent name, then all columns. This is achieved with two nested loops. The outer loop prints each row:

```
// Print population data
for (int i = 0; i < ROWS; i++)
{
   // Print the ith row
   . . .
   System.out.println(); // Start a new line at the end of the row
}
```

To print a row, we first print the row header, then all columns:

```
System.out.printf("%20s", continents[i]);
for (int j = 0; j < COLUMNS; j++)
{
   System.out.printf("%5d", populations[i][j]);
}
```

Step 4 To print the column sums, we use the algorithm that was described in Section 7.6.4. We carry out that computation once for each column.

```
for (int j = 0; j < COLUMNS; j++)
{
   int total = 0;
   for (int i = 0; i < ROWS; i++)
   {
      total = total + populations[i][j];
   }
   System.out.printf("%5d", total);
}
```

Here is the complete program:

worked_example_2/WorldPopulation.java

```
1  /**
2     This program prints a table showing the world population growth over 300 years.
3  */
4  public class WorldPopulation
5  {
6     public static void main(String[] args)
7     {
8        final int ROWS = 6;
9        final int COLUMNS = 7;
10
11       int[][] populations =
12          {
13             { 106, 107, 111, 133, 221, 767, 1766 },
14             { 502, 635, 809, 947, 1402, 3634, 5268 },
15             { 2, 2, 2, 6, 13, 30, 46 },
16             { 163, 203, 276, 408, 547, 729, 628 },
17             { 2, 7, 26, 82, 172, 307, 392 },
18             { 16, 24, 38, 74, 167, 511, 809 }
19          };
20
21       String[] continents =
22          {
23             "Africa",
24             "Asia",
25             "Australia",
26             "Europe",
```

```
27             "North America",
28             "South America"
29          };
30
31       System.out.println("               Year 1750 1800 1850 1900 1950 2000 2050");
32
33       // Print population data
34
35       for (int i = 0; i < ROWS; i++)
36       {
37          // Print the ith row
38          System.out.printf("%20s", continents[i]);
39          for (int j = 0; j < COLUMNS; j++)
40          {
41             System.out.printf("%5d", populations[i][j]);
42          }
43          System.out.println(); // Start a new line at the end of the row
44       }
45
46       // Print column totals
47
48       System.out.print("               World");
49       for (int j = 0; j < COLUMNS; j++)
50       {
51          int total = 0;
52          for (int i = 0; i < ROWS; i++)
53          {
54             total = total + populations[i][j];
55          }
56          System.out.printf("%5d", total);
57       }
58       System.out.println();
59    }
60 }
```

Program Run

```
                Year 1750 1800 1850 1900 1950 2000 2050
              Africa  106  107  111  133  221  767 1766
                Asia  502  635  809  947 1402 3634 5268
           Australia    2    2    2    6   13   30   46
              Europe  163  203  276  408  547  729  628
       North America    2    7   26   82  172  307  392
       South America   16   24   38   74  167  511  809
               World  791  978 1262 1650 2522 5978 8909
```