

Starting Out With C++

From Control Structures Through Objects

BRIEF VERSION

EIGHTH EDITION

Tony Gaddis

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From Control Structures through Objects

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Preface

Welcome to the Brief Version of *Starting Out with C++: From Control Structures through Objects, 8th edition.* This book is intended for use in a one or two-semester C++ programming sequence, or an accelerated one-semester course. Students new to programming, as well as those with prior course work in other languages, will find this text beneficial. The fundamentals of programming are covered for the novice, while the details, pitfalls, and nuances of the C++ language are explored in-depth for both the beginner and more experienced student. The book is written with clear, easy-to-understand language, and it covers all the necessary topics for an introductory programming course. This text is rich in example programs that are concise, practical, and real-world oriented, ensuring that the student not only learns how to implement the features and constructs of C++, but why and when to use them.

Changes in the Eighth Edition

C++11 is the latest standard version of the C++ language. In previous years, while the standard was being developed, it was known as C++0x. In August 2011, it was approved by the International Standards Organization (ISO), and the name of the standard was officially changed to C++11. Most of the popular compilers now support the C++11 standard.

The new C++11 standard was the primary motivation behind this edition. Although this edition introduces many of the new language features, a C++11 compiler is not strictly required to use the book. As you progress through the book, you will see C++11 icons in the margins, next to the new features that are introduced. Programs appearing in sections that are not marked with this icon will still compile using an older compiler.

Here is a summary of the new C++11 topics that are introduced in this edition:

- The auto key word is introduced as a way to simplify complex variable definitions. The auto key word causes the compiler to infer a variable's data type from its initialization value.
- The long long int and unsigned long long int data types, and the LL literal suffix are introduced.
- Chapter 5 shows how to pass a string object directly to a file stream object's open member function, without the need to call the c_str() member function. (A discussion of the c_str() function still exists for anyone using a legacy compiler.)

- The range-based for loop is introduced in Chapter 7. This new looping mechanism automatically iterates over each element of an array, vector, or other collection, without the need of a counter variable or a subscript.
- Chapter 7 shows how a vector can be initialized with an initialization list.
- The nullptr key word is introduced as the standard way of representing a null pointer.
- Smart pointers are introduced in Chapter 9, with an example of dynamic memory allocation using unique ptr.
- Chapter 10 discusses the new, overloaded to_string functions for converting numeric values to string objects.
- The string class's new back() and front() member functions are included in Chapter 10's overview of the string class.
- Strongly typed enums are discussed in Chapter 11.
- Chapter 13 shows how to use the smart pointer unique_ptr to dynamically allocate an object.
- Chapter 15 discusses the override key word and demonstrates how it can help prevent subtle overriding errors. The final key word is discussed as a way of preventing a virtual member function from being overridden.

In addition to the C++11 topics, the following general improvements were made:

- Several new programming problems have been added to the text, and many of the existing programming problems have been modified to make them unique from previous editions.
- The discussion of early, historic computers in Chapter 1 is expanded.
- The discussion of literal values in Chapter 2 is improved.
- The introduction of the char data type in Chapter 2 is reorganized to use character literals in variable assignments before using ASCII values in variable assignments.
- The discussion of random numbers in Chapter 3 is expanded and improved, with the addition of a new *In the Spotlight* section.
- A new *Focus on Object-Oriented Programming* section has been added to Chapter 13, showing how to write a class that simulates dice.
- A new *Focus on Object-Oriented Programming* section has been added to Chapter 14, showing an object-oriented program that simulates the game of Cho-Han. The program uses objects for the dealer, two players, and a pair of dice.

Organization of the Text

This text teaches C++ in a step-by-step fashion. Each chapter covers a major set of topics and builds knowledge as the student progresses through the book. Although the chapters can be easily taught in their existing sequence, some flexibility is provided. The diagram shown in Figure P-1 suggests possible sequences of instruction.





Chapter 1 covers fundamental hardware, software, and programming concepts. You may choose to skip this chapter if the class has already mastered those topics. Chapters 2 through 7 cover basic C++ syntax, data types, expressions, selection structures, repetition structures, functions, and arrays. Each of these chapters builds on the previous chapter and should be covered in the order presented.

After Chapter 7 has been covered, you may proceed to Chapter 8, or jump to either Chapter 9 or Chapter 12. (If you jump to Chapter 12 at this point, you will need to postpone sections 12.7, 12.8, and 12.10 until Chapters 9 and 11 have been covered.)

After Chapter 9 has been covered, either of Chapters 10 or 11 may be covered. After Chapter 11, you may cover Chapters 13 through 15 in sequence.

This text's approach starts with a firm foundation in structured, procedural programming before delving fully into object-oriented programming.

Brief Overview of Each Chapter

Chapter 1: Introduction to Computers and Programming

This chapter provides an introduction to the field of computer science and covers the fundamentals of programming, problem solving, and software design. The components of programs, such as key words, variables, operators, and punctuation are covered. The tools of the trade, such as pseudocode, flow charts, and hierarchy charts are also presented.

Chapter 2: Introduction to C++

This chapter gets the student started in C++ by introducing data types, identifiers, variable declarations, constants, comments, program output, simple arithmetic operations, and C-strings. Programming style conventions are introduced and good programming style is modeled here, as it is throughout the text. An optional section explains the difference between ANSI standard and pre-standard C++ programs.

Chapter 3: Expressions and Interactivity

In this chapter the student learns to write programs that input and handle numeric, character, and string data. The use of arithmetic operators and the creation of mathematical expressions are covered in greater detail, with emphasis on operator precedence. Debugging is introduced, with a section on hand tracing a program. Sections are also included on simple output formatting, on data type conversion and type casting, and on using library functions that work with numbers.

Chapter 4: Making Decisions

Here the student learns about relational operators, relational expressions and how to control the flow of a program with the if, if/else, and if/else if statements. The conditional operator and the switch statement are also covered. Crucial applications of these constructs are covered, such as menu-driven programs and the validation of input.

Chapter 5: Loops and Files

This chapter covers repetition control structures. The while loop, do-while loop, and for loop are taught, along with common uses for these devices. Counters, accumulators, running totals, sentinels, and other application-related topics are discussed. Sequential file I/O is also introduced. The student learns to read and write text files, and use loops to process the data in a file.

Chapter 6: Functions

In this chapter the student learns how and why to modularize programs, using both void and value returning functions. Argument passing is covered, with emphasis on when arguments should be passed by value versus when they need to be passed by reference. Scope of variables is covered, and sections are provided on local versus global variables and on static local variables. Overloaded functions are also introduced and demonstrated.

Chapter 7: Arrays

In this chapter the student learns to create and work with single and multidimensional arrays. Many examples of array processing are provided including examples illustrating how to find the sum, average, highest, and lowest values in an array and how to sum the rows, columns, and all elements of a two-dimensional array. Programming techniques using parallel arrays are also demonstrated, and the student is shown how to use a data file as an input source to populate an array. STL vectors are introduced and compared to arrays.

Chapter 8: Sorting and Searching Arrays

Here the student learns the basics of sorting arrays and searching for data stored in them. The chapter covers the Bubble Sort, Selection Sort, Linear Search, and Binary Search algorithms. There is also a section on sorting and searching STL vector objects.

Chapter 9: Pointers

This chapter explains how to use pointers. Pointers are compared to and contrasted with reference variables. Other topics include pointer arithmetic, initialization of pointers, relational comparison of pointers, pointers and arrays, pointers and functions, dynamic memory allocation, and more.

Chapter 10: Characters, C-strings, and More About the string Class

This chapter discusses various ways to process text at a detailed level. Library functions for testing and manipulating characters are introduced. C-strings are discussed, and the technique of storing C-strings in char arrays is covered. An extensive discussion of the string class methods is also given.

Chapter 11: Structured Data

The student is introduced to abstract data types and taught how to create them using structures, unions, and enumerated data types. Discussions and examples include using pointers to structures, passing structures to functions, and returning structures from functions.

Chapter 12: Advanced File Operations

This chapter covers sequential access, random access, text, and binary files. The various modes for opening files are discussed, as well as the many methods for reading and writing file contents. Advanced output formatting is also covered.

Chapter 13: Introduction to Classes

The student now shifts focus to the object-oriented paradigm. This chapter covers the fundamental concepts of classes. Member variables and functions are discussed. The student learns about private and public access specifications, and reasons to use each. The topics of constructors, overloaded constructors, and destructors are also presented. The chapter presents a section modeling classes with UML and how to find the classes in a particular problem.

Chapter 14: More About Classes

This chapter continues the study of classes. Static members, friends, memberwise assignment, and copy constructors are discussed. The chapter also includes in-depth sections on operator overloading, object conversion, and object aggregation. There is also a section on class collaborations and the use of CRC cards.

Chapter 15: Inheritance, Polymorphism, and Virtual Functions

The study of classes continues in this chapter with the subjects of inheritance, polymorphism, and virtual member functions. The topics covered include base and derived class constructors and destructors, virtual member functions, base class pointers, static and dynamic binding, multiple inheritance, and class hierarchies.

Appendix A: Getting Started with Alice

This appendix gives a quick introduction to Alice. Alice is free software that can be used to teach fundamental programming concepts using 3D graphics.

Appendix B: ASCII Character Set

A list of the ASCII and Extended ASCII characters and their codes.

Appendix C: Operator Precedence and Associativity

A chart showing the C++ operators and their precedence.

The following appendices are available online at www.pearsonglobaleditions.com/gaddis.

Appendix D: Introduction to Flowcharting

A brief introduction to flowcharting. This tutorial discusses sequence, selection, case, repetition, and module structures.

Appendix E: Using UML in Class Design

This appendix shows the student how to use the Unified Modeling Language to design classes. Notation for showing access specification, data types, parameters, return values, overloaded functions, composition, and inheritance are included.

Appendix F: Namespaces

This appendix explains namespaces and their purpose. Examples showing how to define a namespace and access its members are given.

Appendix G: Passing Command Line Arguments

Teaches the student how to write a C++ program that accepts arguments from the command line. This appendix will be useful to students working in a command line environment, such as Unix, Linux, or the Windows command prompt.

Appendix H: Header File and Library Function Reference

This appendix provides a reference for the C++ library functions and header files discussed in the book.

Appendix I: Binary Numbers and Bitwise Operations

A guide to the C++ bitwise operators, as well as a tutorial on the internal storage of integers.

Appendix J: Multi-Source File Programs

Provides a tutorial on creating programs that consist of multiple source files. Function header files, class specification files, and class implementation files are discussed.

Appendix K: Stream Member Functions for Formatting

Covers stream member functions for formatting such as setf.

Appendix L: Answers to Checkpoints

Students may test their own progress by comparing their answers to the checkpoint exercises against this appendix. The answers to all Checkpoints are included.

Appendix M: Solutions to Odd-Numbered Review Questions

Another tool that students can use to gauge their progress.

Features of the Text

	Concept Statements	Each major section of the text starts with a concept statement. This statement summarizes the ideas of the section.
	Example Programs	The text has hundreds of complete example programs, each designed to highlight the topic currently being studied. In most cases, these are practical, real-world examples. Source code for these programs is provided so that students can run the programs themselves.
~	Program Output	After each example program there is a sample of its screen output. This immediately shows the student how the program should function.
	In the Spotlight	Each of these sections provides a programming problem and a detailed, step-by-step analysis showing the student how to solve it.
	VideoNotes	A series of online videos, developed specifically for this book, is available for viewing at www.pearsonglobaleditions.com/gaddis. Icons appear throughout the text alerting the student to videos about specific topics.
	Checkpoints	Checkpoints are questions placed throughout each chapter as a self-test study aid. Answers for all Checkpoint questions can be downloaded from the book's Companion Web site at www. pearsonglobaleditions.com/gaddis. This allows students to check how well they have learned a new topic.
	Notes	Notes appear at appropriate places throughout the text. They are short explanations of interesting or often misunderstood points relevant to the topic at hand.

!	Warnings	Warnings are notes that caution the student about certain C++ features, programming techniques, or practices that can lead to malfunctioning programs or lost data.
	Case Studies	Case studies that simulate real-world applications appear in many chapters throughout the text. These case studies are de- signed to highlight the major topics of the chapter in which they appear.
	Review Questions and Exercises	Each chapter presents a thorough and diverse set of review questions, such as fill-in-the-blank and short answer, that check the student's mastery of the basic material presented in the chap- ter. These are followed by exercises requiring problem solving and analysis, such as the <i>Algorithm Workbench</i> , <i>Predict the Out- put</i> , and <i>Find the Errors</i> sections. Answers to the odd-numbered review questions and review exercises can be downloaded from the book's Companion Web site at www.pearsonglobaleditions. com/gaddis.
	Programming Challenges	Each chapter offers a pool of programming exercises designed to solidify the student's knowledge of the topics currently being studied. In most cases the assignments present real-world prob- lems to be solved. When applicable, these exercises include input validation rules.
	Group Projects	There are several group programming projects throughout the text, intended to be constructed by a team of students. One student might build the program's user interface, while another student writes the mathematical code, and another designs and implements a class the program uses. This process is similar to the way many professional programs are written and encourages team work within the classroom.
	Software Development Project: Serendipity Booksellers	Available for download from the book's Companion Web site at www.pearsonglobaleditions.com/gaddis. This is an ongoing project that instructors can optionally assign to teams of students. It systematically develops a "real-world" software package: a point-of-sale program for the fictitious Serendipity Booksellers organization. The Serendipity assignment for each chapter adds more functionality to the software, using constructs and tech- niques covered in that chapter. When complete, the program will act as a cash register, manage an inventory database, and produce a variety of reports.
	C++ Quick Reference Guide	For easy access, a quick reference guide to the C++ language is printed on the last two pages of Appendix C in the book.
1	C++11	Throughout the text, new C++11 language features are introduced. Look for the C++11 icon to find these new features.

Supplements

Student Online Resources

Many student resources are available for this book from the publisher. The following items are available on the Gaddis Series Companion Web site at www.pearsonglobaleditions.com/gaddis:

- The source code for each example program in the book
- Access to the book's companion VideoNotes
- A full set of appendices, including answers to the Checkpoint questions and answers to the odd-numbered review questions
- A collection of valuable Case Studies
- The complete Serendipity Booksellers Project

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MyProgrammingLab helps students fully grasp the logic, semantics, and syntax of programming. Through practice exercises and immediate, personalized feedback, MyProgrammingLab improves the programming competence of beginning students who often struggle with the basic concepts and paradigms of popular high-level programming languages.

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

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The following supplements are available to qualified instructors only:

- Answers to all Review Questions in the text
- Solutions for all Programming Challenges in the text
- PowerPoint presentation slides for every chapter
- Computerized test bank
- Answers to all Student Lab Manual questions
- Solutions for all Student Lab Manual programs

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Textbook Web site

Student and instructor resources, including links to download Microsoft[®] Visual Studio Express and other popular IDEs, for all the books in the Gaddis *Starting Out With* series can be accessed at the following URL:

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Which Gaddis C++ book is right for you?

The Starting Out with C++ Series includes three books, one of which is sure to fit your course:

- Starting Out with C++: From Control Structures through Objects
- Starting Out with C++: Early Objects

appendices dealing with linked lists and recursion.

• Starting Out with C++: Brief Version

The following chart will help you determine which book is right for your course.

 FROM CONTROL STRUCTURES THROUGH OBJECTS BRIEF VERSION 	EARLY OBJECTS
LATE INTRODUCTION OF OBJECTS Classes are introduced in Chapter 13 of the stan- dard text and Chapter 11 of the brief text, after control structures, functions, arrays, and pointers. Advanced OOP topics, such as inheritance and polymorphism, are covered in the following two chapters.	EARLIER INTRODUCTION OF OBJECTS Classes are introduced in Chapter 7, after control structures and functions, but before arrays and pointers. Their use is then integrated into the remainder of the text. Advanced OOP topics, such as inheritance and polymorphism, are covered in Chapters 11 and 15.
INTRODUCTION OF DATA STRUCTURES AND RECURSION Linked lists, stacks and queues, and binary trees are introduced in the final chapters of the standard text. Recursion is covered after stacks and queues, but before binary trees. These topics are not covered in the brief text, though it does have	INTRODUCTION OF DATA STRUCTURES AND RECURSION Linked lists, stacks and queues, and binary trees are introduced in the final chapters of the text, after the chapter on recursion.

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28 Preface

I would like to thank my family for their love and support in all of my many projects. I am extremely fortunate to have Matt Goldstein as my editor. He and Kelsey Loanes, Editorial Assistant, guided me through the delicate process of revising the book. I am also fortunate to have Demetrius Hall and Bram Van Kempen as marketing managers. They do a great job getting my books out to the academic community. I had a great production team led by Camille Trentacoste. Thanks to you all!

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1.1

HAPTE

Introduction to Computers and Programming

TOPICS

- 1.1 Why Program?
- 1.2 Computer Systems: Hardware and Software
- 1.3 Programs and Programming Languages
- 1.4 What Is a Program Made of?
- 1.5 Input, Processing, and Output
- 1.6 The Programming Process
- 1.7 Procedural and Object-Oriented Programming

Why Program?

CONCEPT: Computers can do many different jobs because they are programmable.

Think about some of the different ways that people use computers. In school, students use computers for tasks such as writing papers, searching for articles, sending e-mail, and participating in online classes. At work, people use computers to analyze data, make presentations, conduct business transactions, communicate with customers and coworkers, control machines in manufacturing facilities, and do many other things. At home, people use computers for tasks such as paying bills, shopping online, social networking, and playing computer games. And don't forget that smart phones, iPods[®], car navigation systems, and many other devices are computers as well. The uses of computers are almost limitless in our everyday lives.

Computers can do such a wide variety of things because they can be programmed. This means that computers are not designed to do just one job, but any job that their programs tell them to do. A *program* is a set of instructions that a computer follows to perform a task. For example, Figure 1-1 shows screens using Microsoft Word and PowerPoint, two commonly used programs.

Programs are commonly referred to as *software*. Software is essential to a computer because without software, a computer can do nothing. All of the software that we use to make our computers useful is created by individuals known as programmers or software developers. A *programmer*, or *software developer*, is a person with the training and skills necessary to design, create, and test computer programs. Computer programming is an exciting and rewarding career. Today, you will find programmers working in business, medicine, government, law enforcement, agriculture, academics, entertainment, and almost every other field.



Figure 1-1 A word processing program and a presentation program

Computer programming is both an art and a science. It is an art because every aspect of a program should be carefully designed. Listed below are a few of the things that must be designed for any real-world computer program:

- The logical flow of the instructions
- The mathematical procedures
- The appearance of the screens
- The way information is presented to the user
- The program's "user-friendliness"
- Manuals and other forms of written documentation

There is also a scientific, or engineering, side to programming. Because programs rarely work right the first time they are written, a lot of testing, correction, and redesigning is required. This demands patience and persistence from the programmer. Writing software demands discipline as well. Programmers must learn special languages like C++ because computers do not understand English or other human languages. Languages such as C++ have strict rules that must be carefully followed.

Both the artistic and scientific nature of programming make writing computer software like designing a car: Both cars and programs should be functional, efficient, powerful, easy to use, and pleasing to look at.

1.2 Computer Systems: Hardware and Software CONCEPT: All computer systems consist of similar hardware devices and software

NCEPT: All computer systems consist of similar hardware devices and software components. This section provides an overview of standard computer hardware and software organization.

Hardware

Hardware refers to the physical components that a computer is made of. A computer, as we generally think of it, is not an individual device, but a system of devices. Like the instruments in a symphony orchestra, each device plays its own part. A typical computer system consists of the following major components:

- The central processing unit (CPU)
- Main memory
- Secondary storage devices
- Input devices
- Output devices

The organization of a computer system is depicted in Figure 1-2.



The CPU

When a computer is performing the tasks that a program tells it to do, we say that the computer is *running* or *executing* the program. The *central processing unit*, or *CPU*, is the part of a computer that actually runs programs. The CPU is the most important component in a computer because without it, the computer could not run software.

In the earliest computers, CPUs were huge devices made of electrical and mechanical components such as vacuum tubes and switches. Figure 1-3 shows such a device. The two women in

Figure 1-3



the photo are working with the historic ENIAC computer. The *ENIAC*, considered by many to be the world's first programmable electronic computer, was built in 1945 to calculate artillery ballistic tables for the U.S. Army. This machine, which was primarily one big CPU, was 8 feet tall, 100 feet long, and weighed 30 tons.

Today, CPUs are small chips known as *microprocessors*. Figure 1-4 shows a photo of a lab technician holding a modern-day microprocessor. In addition to being much smaller than the old electro-mechanical CPUs in early computers, microprocessors are also much more powerful.



Figure 1-4

The CPU's job is to fetch instructions, follow the instructions, and produce some result. Internally, the central processing unit consists of two parts: the *control unit* and the *arithmetic and logic unit (ALU)*. The control unit coordinates all of the computer's operations. It is responsible for determining where to get the next instruction and regulating the other major components of the computer with control signals. The arithmetic and logic unit, as its name suggests, is designed to perform mathematical operations. The organization of the CPU is shown in Figure 1-5.

Figure 1-5



A program is a sequence of instructions stored in the computer's memory. When a computer is running a program, the CPU is engaged in a process known formally as the *fetch/decode/ execute cycle*. The steps in the fetch/decode/execute cycle are as follows:

Fetch	The CPU's control unit fetches, from main memory, the next instruc- tion in the sequence of program instructions
Decode	The instruction is encoded in the form of a number. The control unit decodes the instruction and generates an electronic signal.
Execute	The signal is routed to the appropriate component of the computer (such as the ALU, a disk drive, or some other device). The signal causes the component to perform an operation.

These steps are repeated as long as there are instructions to perform.

Main Memory

You can think of main memory as the computer's work area. This is where the computer stores a program while the program is running, as well as the data that the program is working with. For example, suppose you are using a word processing program to write an essay for one of your classes. While you do this, both the word processing program and the essay are stored in main memory.

Main memory is commonly known as *random-access memory* or *RAM*. It is called this because the CPU is able to quickly access data stored at any random location in RAM. RAM is usually a *volatile* type of memory that is used only for temporary storage while a program is running. When the computer is turned off, the contents of RAM are erased. Inside your computer, RAM is stored in small chips.

A computer's memory is divided into tiny storage locations known as bytes. One *byte* is enough memory to store only a letter of the alphabet or a small number. In order to do
anything meaningful, a computer must have lots of bytes. Most computers today have millions, or even billions, of bytes of memory.

Each byte is divided into eight smaller storage locations known as bits. The term *bit* stands for *binary digit*. Computer scientists usually think of bits as tiny switches that can be either on or off. Bits aren't actual "switches," however, at least not in the conventional sense. In most computer systems, bits are tiny electrical components that can hold either a positive or a negative charge. Computer scientists think of a positive charge as a switch in the *on* position and a negative charge as a switch in the *off* position.

Each byte is assigned a unique number known as an *address*. The addresses are ordered from lowest to highest. A byte is identified by its address in much the same way a post office box is identified by an address. Figure 1-6 shows a group of memory cells with their addresses. In the illustration, sample data is stored in memory. The number 149 is stored in the cell with the address 16, and the number 72 is stored at address 23.

Figure 1-6

0	1	2	3	4	5	6	7	8	9
10	11	12	13	14	15	16 149	17	18	19
20	21	22	23 72	24	25	26	27	28	29

Secondary Storage

Secondary storage is a type of memory that can hold data for long periods of time—even when there is no power to the computer. Frequently used programs are stored in secondary memory and loaded into main memory as needed. Important information, such as word processing documents, payroll data, and inventory figures, is saved to secondary storage as well.

The most common type of secondary storage device is the disk drive. A *disk drive* stores data by magnetically encoding it onto a circular disk. Most computers have a disk drive mounted inside their case. External disk drives, which connect to one of the computer's communication ports, are also available. External disk drives can be used to create backup copies of important data or to move data to another computer.

In addition to external disk drives, many types of devices have been created for copying data and for moving it to other computers. For many years floppy disk drives were popular. A *floppy disk drive* records data onto a small floppy disk, which can be removed from the drive. The use of floppy disk drives has declined dramatically in recent years, in favor of superior devices such as USB drives. *USB drives* are small devices that plug into the computer's USB (universal serial bus) port and appear to the system as a disk drive. USB drives, which use *flash memory* to store data, are inexpensive, reliable, and small enough to be carried in your pocket.

Optical devices such as the *CD* (compact disc) and the *DVD* (digital versatile disc) are also popular for data storage. Data is not recorded magnetically on an optical disc, but is encoded as a series of pits on the disc surface. CD and DVD drives use a laser to detect the pits and thus read the encoded data. Optical discs hold large amounts of data, and because recordable CD and DVD drives are now commonplace, they are good mediums for creating backup copies of data.

Input Devices

Input is any information the computer collects from the outside world. The device that collects the information and sends it to the computer is called an *input device*. Common input devices are the keyboard, mouse, scanner, digital camera, and microphone. Disk drives, CD/DVD drives, and USB drives can also be considered input devices because programs and information are retrieved from them and loaded into the computer's memory.

Output Devices

Output is any information the computer sends to the outside world. It might be a sales report, a list of names, or a graphic image. The information is sent to an *output device*, which formats and presents it. Common output devices are monitors, printers, and speakers. Disk drives, USB drives, and CD/DVD recorders can also be considered output devices because the CPU sends them information to be saved.

Software

If a computer is to function, software is not optional. Everything that a computer does, from the time you turn the power switch on until you shut the system down, is under the control of software. There are two general categories of software: system software and application software. Most computer programs clearly fit into one of these two categories. Let's take a closer look at each.

System Software

The programs that control and manage the basic operations of a computer are generally referred to as *system software*. System software typically includes the following types of programs:

• Operating Systems

An operating system is the most fundamental set of programs on a computer. The operating system controls the internal operations of the computer's hardware, manages all the devices connected to the computer, allows data to be saved to and retrieved from storage devices, and allows other programs to run on the computer.

• Utility Programs

A *utility program* performs a specialized task that enhances the computer's operation or safeguards data. Examples of utility programs are virus scanners, file-compression programs, and data-backup programs.

• Software Development Tools

The software tools that programmers use to create, modify, and test software are referred to as *software development tools*. Compilers and integrated development environments, which we discuss later in this chapter, are examples of programs that fall into this category.

Application Software

Programs that make a computer useful for everyday tasks are known as *application software*. These are the programs that people normally spend most of their time running on their computers. Figure 1-1, at the beginning of this chapter, shows screens from two commonly used applications—Microsoft Word, a word processing program, and Microsoft

PowerPoint, a presentation program. Some other examples of application software are spreadsheet programs, e-mail programs, Web browsers, and game programs.



Checkpoint

- 1.1 Why is the computer used by so many different people, in so many different professions?
- 1.2 List the five major hardware components of a computer system.
- 1.3 Internally, the CPU consists of what two units?
- 1.4 Describe the steps in the fetch/decode/execute cycle.
- 1.5 What is a memory address? What is its purpose?
- 1.6 Explain why computers have both main memory and secondary storage.
- 1.7 What are the two general categories of software?
- 1.8 What fundamental set of programs control the internal operations of the computer's hardware?
- 1.9 What do you call a program that performs a specialized task, such as a virus scanner, a file-compression program, or a data-backup program?
- 1.10 Word processing programs, spreadsheet programs, e-mail programs, Web browsers, and game programs belong to what category of software?

1.3

Programs and Programming Languages

CONCEPT: A program is a set of instructions a computer follows in order to perform a task. A programming language is a special language used to write computer programs.

What Is a Program?

Computers are designed to follow instructions. A computer program is a set of instructions that tells the computer how to solve a problem or perform a task. For example, suppose we want the computer to calculate someone's gross pay. Here is a list of things the computer should do:

- 1. Display a message on the screen asking "How many hours did you work?"
- 2. Wait for the user to enter the number of hours worked. Once the user enters a number, store it in memory.
- 3. Display a message on the screen asking "How much do you get paid per hour?"
- 4. Wait for the user to enter an hourly pay rate. Once the user enters a number, store it in memory.
- 5. Multiply the number of hours by the amount paid per hour, and store the result in memory.
- 6. Display a message on the screen that tells the amount of money earned. The message must include the result of the calculation performed in Step 5.

Collectively, these instructions are called an *algorithm*. An algorithm is a set of well-defined steps for performing a task or solving a problem. Notice these steps are sequentially ordered. Step 1 should be performed before Step 2, and so forth. It is important that these instructions be performed in their proper sequence.

Although you and I might easily understand the instructions in the pay-calculating algorithm, it is not ready to be executed on a computer. A computer's CPU can only process instructions that are written in *machine language*. If you were to look at a machine language program, you would see a stream of *binary numbers* (numbers consisting of only 1s and 0s). The binary numbers form machine language instructions, which the CPU interprets as commands. Here is an example of what a machine language instruction might look like:

101101000000101

As you can imagine, the process of encoding an algorithm in machine language is very tedious and difficult. In addition, each different type of CPU has its own machine language. If you wrote a machine language program for computer *A* and then wanted to run it on computer *B*, which has a different type of CPU, you would have to rewrite the program in computer B's machine language.

Programming languages, which use words instead of numbers, were invented to ease the task of programming. A program can be written in a programming language, such as C++, which is much easier to understand than machine language. Programmers save their programs in text files, and then use special software to convert their programs to machine language.

Program 1-1 shows how the pay-calculating algorithm might be written in C++.

The "Program Output with Example Input" shows what the program will display on the screen when it is running. In the example, the user enters 10 for the number of hours worked and 15 for the hourly pay rate. The program displays the earnings, which are \$150.

NOTE: The line numbers that are shown in Program 1-1 are *not* part of the program. This book shows line numbers in all program listings to help point out specific parts of the program.

Program 1-1

```
// This program calculates the user's pay.
 1
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
 7
         double hours, rate, pay;
 8
 9
         // Get the number of hours worked.
        cout << "How many hours did you work? ";
10
11
        cin >> hours;
12
13
        // Get the hourly pay rate.
        cout << "How much do you get paid per hour? ";
14
15
        cin >> rate;
16
        // Calculate the pay.
17
18
        pay = hours * rate;
```

(program continues)

```
Program 1-1(continued)1920// Display the pay.21cout << "You have earned $" << pay << endl;</td>22return 0;23}
```

How many hours did you work? **10 [Enter]** How much do you get paid per hour? **15 [Enter]** You have earned \$150

Programming Languages

In a broad sense, there are two categories of programming languages: low-level and highlevel. A low-level language is close to the level of the computer, which means it resembles the numeric machine language of the computer more than the natural language of humans. The easiest languages for people to learn are *high-level languages*. They are called "highlevel" because they are closer to the level of human-readability than computer-readability. Figure 1-7 illustrates the concept of language levels.

Figure 1-7



Many high-level languages have been created. Table 1-1 lists a few of the well-known ones.

In addition to the high-level features necessary for writing applications such as payroll systems and inventory programs, C++ also has many low-level features. C++ is based on the C language, which was invented for purposes such as writing operating systems and compilers. Since C++ evolved from C, it carries all of C's low-level capabilities with it.

Language	Description
BASIC	Beginners All-purpose Symbolic Instruction Code. A general programming language originally designed to be simple enough for beginners to learn.
FORTRAN	Formula Translator. A language designed for programming complex mathematical algorithms.
COBOL	Common Business-Oriented Language. A language designed for business applications.
Pascal	A structured, general-purpose language designed primarily for teaching programming.
С	A structured, general-purpose language developed at Bell Laboratories. C offers both high-level and low-level features.
C++	Based on the C language, C++ offers object-oriented features not found in C. Also invented at Bell Laboratories.
C#	Pronounced "C sharp." A language invented by Microsoft for developing applications based on the Microsoft .NET platform.
Java	An object-oriented language invented at Sun Microsystems. Java may be used to develop programs that run over the Internet, in a Web browser.
JavaScript	JavaScript can be used to write small programs that run in Web pages. Despite its name, JavaScript is not related to Java.
Python	Python is a general-purpose language created in the early 1990s. It has become popular in both business and academic applications.
Ruby	Ruby is a general-purpose language that was created in the 1990s. It is increas- ingly becoming a popular language for programs that run on Web servers.
Visual Basic	A Microsoft programming language and software development environment that allows programmers to quickly create Windows-based applications.

Table 1-1

C++ is popular not only because of its mixture of low- and high-level features, but also because of its *portability*. This means that a C++ program can be written on one type of computer and then run on many other types of systems. This usually requires the program to be recompiled on each type of system, but the program itself may need little or no change.

NOTE: Programs written for specific graphical environments often require significant changes when moved to a different type of system. Examples of such graphical environments are Windows, the X-Window System, and the Mac OS operating system.

Source Code, Object Code, and Executable Code

When a C++ program is written, it must be typed into the computer and saved to a file. A *text editor*, which is similar to a word processing program, is used for this task. The statements written by the programmer are called *source code*, and the file they are saved in is called the *source file*.

After the source code is saved to a file, the process of translating it to machine language can begin. During the first phase of this process, a program called the *preprocessor* reads the source code. The preprocessor searches for special lines that begin with the # symbol. These lines contain commands that cause the preprocessor to modify the source code in

some way. During the next phase the *compiler* steps through the preprocessed source code, translating each source code instruction into the appropriate machine language instruction. This process will uncover any *syntax errors* that may be in the program. Syntax errors are illegal uses of key words, operators, punctuation, and other language elements. If the program is free of syntax errors, the compiler stores the translated machine language instructions, which are called *object code*, in an *object file*.

Although an object file contains machine language instructions, it is not a complete program. Here is why: C++ is conveniently equipped with a library of prewritten code for performing common operations or sometimes-difficult tasks. For example, the library contains hardware-specific code for displaying messages on the screen and reading input from the keyboard. It also provides routines for mathematical functions, such as calculating the square root of a number. This collection of code, called the *run-time library*, is extensive. Programs almost always use some part of it. When the compiler generates an object file, however, it does not include machine code for any run-time library routines the programmer might have used. During the last phase of the translation process, another program called the *linker* combines the object file with the necessary library routines. Once the linker has finished with this step, an *executable file* is created. The executable file contains machine language instructions, or *executable code*, and is ready to run on the computer.

Figure 1-8 illustrates the process of translating a C++ source file into an executable file.

The entire process of invoking the preprocessor, compiler, and linker can be initiated with a single action. For example, on a Linux system, the following command causes the C++ program named hello.cpp to be preprocessed, compiled, and linked. The executable code is stored in a file named hello.

g++ -o hello hello.cpp

Figure 1-8



Appendix G explains how compiling works in .Net. You can download Appendix G from the book's companion Web site at www.pearsonglobaleditions.com/gaddis.

Many development systems, particularly those on personal computers, have *integrated development environments (IDEs)*. These environments consist of a text editor, compiler, debugger, and other utilities integrated into a package with a single set of menus. Preprocessing, compiling, linking, and even executing a program is done with a single click of a button, or by selecting a single item from a menu. Figure 1-9 shows a screen from the Microsoft Visual Studio IDE.

Figure 1-9

Gross Pay - Microsoft Visual Studio	Quick Launch (Ctrl+Q)	P = 0	×
FILE EDIT VIEW PROJECT BUILD DEBUG TEAM SQL TOOLS TES	ST ANALYZE WIND	OW HELP		
© - ○ 🛱 - 🚔 🔛 🖆 🏷 🏷 ፇ - 🤆 - 🕨 Local Windows Debugger	- 11 = 4. 6, 6 0	Debug 👻	<i>5</i> 1 ₊	
GrossPay.cpp + ×	-	Solution Explor	er ::::::::::::::::::::::::::::::::::::	ıх
(Global Scope) - @ main()	-	000	`o. ∠ ∂ ©	
// This progam calculates the user's pay.	+			
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using namespace std;		👍 Gross Pay		
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		🔺 🛒 Source	Files	
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// Display the pay.		IsInjected	False	
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return 0;		(Name)		
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Checkpoint

- 1.11 What is an algorithm?
- 1.12 Why were computer programming languages invented?
- 1.13 What is the difference between a high-level language and a low-level language?
- 1.14 What does *portability* mean?
- 1.15 Explain the operations carried out by the preprocessor, compiler, and linker.
- 1.16 Explain what is stored in a source file, an object file, and an executable file.
- 1.17 What is an integrated development environment?

1.4 What Is a Program Made of?

CONCEPT: There are certain elements that are common to all programming languages.

Language Elements

All programming languages have a few things in common. Table 1-2 lists the common elements you will find in almost every language.

Table 1-2

Language Element	Description
Key Words	Words that have a special meaning. Key words may only be used for their intended purpose. Key words are also known as reserved words.
Programmer-Defined Identifiers	Words or names defined by the programmer. They are symbolic names that refer to variables or programming routines.
Operators	Operators perform operations on one or more operands. An operand is usually a piece of data, like a number.
Punctuation	Punctuation characters that mark the beginning or ending of a statement, or separate items in a list.
Syntax	Rules that must be followed when constructing a program. Syntax dictates how key words and operators may be used, and where punctuation symbols must appear.

Let's look at some specific parts of Program 1-1 (the pay-calculating program) to see examples of each element listed in the table above. For your convenience, Program 1-1 is listed again.

Program 1-1

```
1
   // This program calculates the user's pay.
 2
   #include <iostream>
 3
   using namespace std;
 4
 5 int main()
 6
   {
 7
        double hours, rate, pay;
 8
9
        // Get the number of hours worked.
10
        cout << "How many hours did you work? ";
11
        cin >> hours;
12
13
       // Get the hourly pay rate.
       cout << "How much do you get paid per hour? ";
14
       cin >> rate;
15
16
17
       // Calculate the pay.
```

```
18 pay = hours * rate;
19
20 // Display the pay.
21 cout << "You have earned $" << pay << endl;
22 return 0;
23 }
```

Key Words (Reserved Words)

Three of C++'s key words appear on lines 3 and 5: using, namespace, and int. The word double, which appears on line 7, is also a C++ key word. These words, which are always written in lowercase, each have a special meaning in C++ and can only be used for their intended purposes. As you will see, the programmer is allowed to make up his or her own names for certain things in a program. Key words, however, are reserved and cannot be used for anything other than their designated purposes. Part of learning a programming language is learning what the key words are, what they mean, and how to use them.



NOTE: The #include <iostream> statement in line 2 is a preprocessor directive.



NOTE: In C++, key words are written in all lowercase.

Programmer-Defined Identifiers

The words hours, rate, and pay that appear in the program on lines 7, 11, 15, 18, and 21 are programmer-defined identifiers. They are not part of the C++ language but rather are names made up by the programmer. In this particular program, these are the names of variables. As you will learn later in this chapter, variables are the names of memory locations that may hold data.

Operators

On line 18 the following code appears:

pay = hours * rate;

The = and * symbols are both operators. They perform operations on pieces of data known as operands. The * operator multiplies its two operands, which in this example are the variables hours and rate. The = symbol is called the assignment operator. It takes the value of the expression on the right and stores it in the variable whose name appears on the left. In this example, the = operator stores in the pay variable the result of the hours variable multiplied by the rate variable. In other words, the statement says, "Make the pay variable equal to hours times rate, or "pay is assigned the value of hours times rate."

Punctuation

Notice that lines 3, 7, 10, 11, 14, 15, 18, 21, and 22 all end with a semicolon. A semicolon in C++ is similar to a period in English: It marks the end of a complete sentence (or statement, as it is called in programming jargon). Semicolons do not appear at the end of every line in a C++ program, however. There are rules that govern where semicolons are required

and where they are not. Part of learning C++ is learning where to place semicolons and other punctuation symbols.

Lines and Statements

Often, the contents of a program are thought of in terms of lines and statements. A "line" is just that—a single line as it appears in the body of a program. Program 1-1 is shown with each of its lines numbered. Most of the lines contain something meaningful; however, some of the lines are empty. The blank lines are only there to make the program more readable.

A statement is a complete instruction that causes the computer to perform some action. Here is the statement that appears in line 10 of Program 1-1:

cout << "How many hours did you work? ";</pre>

This statement causes the computer to display the message "How many hours did you work?" on the screen. Statements can be a combination of key words, operators, and programmerdefined symbols. Statements often occupy only one line in a program, but sometimes they are spread out over more than one line.

Variables

A variable is a named storage location in the computer's memory for holding a piece of information. The information stored in variables may change while the program is running (hence the name "variable"). Notice that in Program 1-1 the words hours, rate, and pay appear in several places. All three of these are the names of variables. The hours variable is used to store the number of hours the user has worked. The rate variable stores the user's hourly pay rate. The pay variable holds the result of hours multiplied by rate, which is the user's gross pay.



NOTE: Notice the variables in Program 1-1 have names that reflect their purpose. In fact, it would be easy to guess what the variables were used for just by reading their names. This is discussed further in Chapter 2.

Variables are symbolic names that represent locations in the computer's random-access memory (RAM). When information is stored in a variable, it is actually stored in RAM. Assume a program has a variable named length. Figure 1-10 illustrates the way the variable name represents a memory location.

Figure 1-10

					<u> </u>	9
10 11 12	13	14 14	15 16	17	18	19
20 21 22	23 72	24 2	25 26	27	28	29

length

In Figure 1-10, the variable length is holding the value 72. The number 72 is actually stored in RAM at address 23, but the name length symbolically represents this storage location. If it helps, you can think of a variable as a box that holds information. In Figure 1-10, the number 72 is stored in the box named length. Only one item may be stored in the box at any given time. If the program stores another value in the box, it will take the place of the number 72.

Variable Definitions

In programming, there are two general types of data: numbers and characters. Numbers are used to perform mathematical operations, and characters are used to print data on the screen or on paper.

Numeric data can be categorized even further. For instance, the following are all whole numbers, or integers:

The following are real, or floating-point numbers:

3.14159 6.7 1.0002

When creating a variable in a C++ program, you must know what type of data the program will be storing in it. Look at line 7 of Program 1-1:

double hours, rate, pay;

The word double in this statement indicates that the variables hours, rate, and pay will be used to hold double precision floating-point numbers. This statement is called a *variable definition*. It is used to *define* one or more variables that will be used in the program and to indicate the type of data they will hold. The variable definition causes the variables to be created in memory, so all variables must be defined before they can be used. If you review the listing of Program 1-1, you will see that the variable definitions come before any other statements using those variables.

NOTE: Programmers often use the term "variable declaration" to mean the same thing as "variable definition." Strictly speaking, there is a difference between the two terms. A definition statement always causes a variable to be created in memory. Some types of declaration statements, however, do not cause a variable to be created in memory. You will learn more about declarations later in this book.

1.5 Input, Processing, and Output

CONCEPT: The three primary activities of a program are input, processing, and output.

Computer programs typically perform a three-step process of gathering input, performing some process on the information gathered, and then producing output. Input is information

a program collects from the outside world. It can be sent to the program from the user, who is entering data at the keyboard or using the mouse. It can also be read from disk files or hardware devices connected to the computer. Program 1-1 allows the user to enter two pieces of information: the number of hours worked and the hourly pay rate. Lines 11 and 15 use the cin (pronounced "see in") object to perform these input operations:

cin >> hours; cin >> rate;

Once information is gathered from the outside world, a program usually processes it in some manner. In Program 1-1, the hours worked and hourly pay rate are multiplied in line 18 and the result is assigned to the pay variable:

pay = hours * rate;

Output is information that a program sends to the outside world. It can be words or graphics displayed on a screen, a report sent to the printer, data stored in a file, or information sent to any device connected to the computer. Lines 10, 14, and 21 in Program 1-1 all perform output:

cout << "How many hours did you work? "; cout << "How much do you get paid per hour? "; cout << "You have earned \$" << pay << endl;</pre>

These lines use the cout (pronounced "see out") object to display messages on the computer's screen. You will learn more details about the cin and cout objects in Chapter 2.



Checkpoint

- 1.18 Describe the difference between a key word and a programmer-defined identifier.
- 1.19 Describe the difference between operators and punctuation symbols.
- 1.20 Describe the difference between a program line and a statement.
- 1.21 Why are variables called "variable"?
- 1.22 What happens to a variable's current contents when a new value is stored there?
- 1.23 What must take place in a program before a variable is used?
- 1.24 What are the three primary activities of a program?

1.6 The Programming Process

CONCEPT: The programming process consists of several steps, which include design, creation, testing, and debugging activities.

Designing and Creating a Program

Now that you have been introduced to what a program is, it's time to consider the process of creating a program. Quite often, when inexperienced students are given programming assignments, they have trouble getting started because they don't know what to do first. If you find yourself in this dilemma, the steps listed in Figure 1-11 may help. These are the steps recommended for the process of writing a program.

- 1. Clearly define what the program is to do.
- 2. Visualize the program running on the computer.
- 3. Use design tools such as a hierarchy chart, flowcharts, or pseudocode to create a model of the program.
- 4. Check the model for logical errors.
- 5. Type the code, save it, and compile it.
- 6. Correct any errors found during compilation. Repeat Steps 5 and 6 as many times as necessary.
- 7. Run the program with test data for input.
- 8. Correct any errors found while running the program. Repeat Steps 5 through 8 as many times as necessary.
- 9. Validate the results of the program.

The steps listed in Figure 1-11 emphasize the importance of planning. Just as there are good ways and bad ways to paint a house, there are good ways and bad ways to create a program. A good program always begins with planning.

With the pay-calculating program as our example, let's look at each of the steps in more detail.

1. Clearly define what the program is to do.

This step requires that you identify the purpose of the program, the information that is to be input, the processing that is to take place, and the desired output. Let's examine each of these requirements for the example program:

- *Purpose* To calculate the user's gross pay.
- *Input* Number of hours worked, hourly pay rate.
- *Process* Multiply number of hours worked by hourly pay rate. The result is the user's gross pay.
- *Output* Display a message indicating the user's gross pay.

2. Visualize the program running on the computer.

Before you create a program on the computer, you should first create it in your mind. Step 2 is the visualization of the program. Try to imagine what the computer screen looks like while the program is running. If it helps, draw pictures of the screen, with sample input and output, at various points in the program. For instance, here is the screen produced by the pay-calculating program:

How many hours did you work? 10 How much do you get paid per hour? 15 You have earned \$150

In this step, you must put yourself in the shoes of the user. What messages should the program display? What questions should it ask? By addressing these concerns, you will have already determined most of the program's output.

3. Use design tools such as a hierarchy chart, flowcharts, or pseudocode to create a model of the program.

While planning a program, the programmer uses one or more design tools to create a model of the program. Three common design tools are hierarchy charts, flowcharts, and pseudocode. A *hierarchy chart* is a diagram that graphically depicts the structure of a program. It has boxes that represent each step in the program. The boxes are connected in a way that illustrates their relationship to one another. Figure 1-12 shows a hierarchy chart for the pay-calculating program.





A hierarchy chart begins with the overall task and then refines it into smaller subtasks. Each of the subtasks is then refined into even smaller sets of subtasks, until each is small enough to be easily performed. For instance, in Figure 1-12, the overall task "Calculate Gross Pay" is listed in the top-level box. That task is broken into three subtasks. The first subtask, "Get Payroll Data from User," is broken further into two subtasks. This process of "divide and conquer" is known as *top-down design*.

A *flowchart* is a diagram that shows the logical flow of a program. It is a useful tool for planning each operation a program performs and the order in which the operations are to occur. For more information see Appendix D, Introduction to Flowcharting.

Pseudocode is a cross between human language and a programming language. Although the computer can't understand pseudocode, programmers often find it helpful to write an algorithm in a language that's "almost" a programming language, but still very similar to natural language. For example, here is pseudocode that describes the pay-calculating program:



Get payroll data. Calculate gross pay. Display gross pay.

Although the pseudocode above gives a broad view of the program, it doesn't reveal all the program's details. A more detailed version of the pseudocode follows.



Display "How many hours did you work?". Input hours. Display "How much do you get paid per hour?". Input rate. Store the value of hours times rate in the pay variable. Display the value in the pay variable.

Notice the pseudocode contains statements that look more like commands than the English statements that describe the algorithm in Section 1.4 (What Is a Program Made of?). The pseudocode even names variables and describes mathematical operations.

4. Check the model for logical errors.

Logical errors are mistakes that cause the program to produce erroneous results. Once a hierarchy chart, flowchart, or pseudocode model of the program is assembled, it should be checked for these errors. The programmer should trace through the charts or pseudocode, checking the logic of each step. If an error is found, the model can be corrected before the next step is attempted.

5. Type the code, save it, and compile it.

Once a model of the program (hierarchy chart, flowchart, or pseudocode) has been created, checked, and corrected, the programmer is ready to write source code on the computer. The programmer saves the source code to a file and begins the process of translating it to machine language. During this step the compiler will find any syntax errors that may exist in the program.

6. Correct any errors found during compilation. Repeat Steps 5 and 6 as many times as necessary.

If the compiler reports any errors, they must be corrected. Steps 5 and 6 must be repeated until the program is free of compile-time errors.

7. Run the program with test data for input.

Once an executable file is generated, the program is ready to be tested for run-time errors. A run-time error is an error that occurs while the program is running. These are usually logical errors, such as mathematical mistakes.

Testing for run-time errors requires that the program be executed with sample data or sample input. The sample data should be such that the correct output can be predicted. If the program does not produce the correct output, a logical error is present in the program.

8. Correct any errors found while running the program. Repeat Steps 5 through 8 as many times as necessary.

When run-time errors are found in a program, they must be corrected. You must identify the step where the error occurred and determine the cause. Desk-checking is a process that can help locate run-time errors. The term *desk-checking* means the programmer starts reading the program, or a portion of the program, and steps through each statement. A sheet of paper is often used in this process to jot down the current contents of all variables and sketch what the screen looks like after each output operation. When a variable's contents change, or information is displayed on the screen, this is noted. By stepping through each statement, many errors can be located and corrected. If an error is a result of incorrect logic (such as an improperly stated math formula), you must correct the statement or statements involved in the logic. If an error is due to an incomplete understanding of the program requirements, then you must restate the program purpose and modify the hierarchy and/or flowcharts, pseudocode, and source code. The program must then be saved, recompiled and retested. This means Steps 5 though 8 must be repeated until the program reliably produces satisfactory results.

9. Validate the results of the program.

When you believe you have corrected all the run-time errors, enter test data and determine whether the program solves the original problem.

What Is Software Engineering?

The field of software engineering encompasses the whole process of crafting computer software. It includes designing, writing, testing, debugging, documenting, modifying, and maintaining complex software development projects. Like traditional engineers, software engineers use a number of tools in their craft. Here are a few examples:

- Program specifications
- Charts and diagrams of screen output
- Hierarchy charts and flowcharts
- Pseudocode
- Examples of expected input and desired output
- Special software designed for testing programs

Most commercial software applications are very large. In many instances one or more teams of programmers, not a single individual, develop them. It is important that the program requirements be thoroughly analyzed and divided into subtasks that are handled by individual teams, or individuals within a team.

In Step 3 of the programming process, you were introduced to the hierarchy chart as a tool for top-down design. The subtasks that are identified in a top-down design can easily become modules, or separate components of a program. If the program is very large or complex, a team of software engineers can be assigned to work on the individual modules. As the project develops, the modules are coordinated to finally become a single software application.

1.7

Procedural and Object-Oriented Programming

CONCEPT: Procedural programming and object-oriented programming are two ways of thinking about software development and program design.

C++ is a language that can be used for two methods of writing computer programs: *procedural programming* and *object-oriented programming*. This book is designed to teach you some of both.

In procedural programming, the programmer constructs procedures (or functions, as they are called in C++). The procedures are collections of programming statements that perform a specific task. The procedures each contain their own variables and commonly share variables with other procedures. This is illustrated by Figure 1-13.



Program
PROCEDURE A Variables Programming END OF PROCEDURE A
PROCEDURE B Variables Programming END OF PROCEDURE B

Procedural programming is centered on the procedure, or function. Object-oriented programming (OOP), on the other hand, is centered on the object. An object is a programming element that contains data and the procedures that operate on the data. It is a self-contained unit. This is illustrated in Figure 1-14.





The objects contain, within themselves, both information and the ability to manipulate the information. Operations are carried out on the information in an object by sending the object a *message*. When an object receives a message instructing it to perform some operation, it carries out the instruction. As you study this text, you will encounter many other aspects of object-oriented programming.



Checkpoint

- 1.25 What four items should you identify when defining what a program is to do?
- 1.26 What does it mean to "visualize a program running"? What is the value of such an activity?
- 1.27 What is a hierarchy chart?
- 1.28 Describe the process of desk-checking.

- 1.29 Describe what a compiler does with a program's source code.
- 1.30 What is a run-time error?
- 1.31 Is a syntax error (such as misspelling a key word) found by the compiler or when the program is running?
- 1.32 What is the purpose of testing a program with sample data or input?
- 1.33 Briefly describe the difference between procedural and object-oriented programming.

Review Questions and Exercises

Short Answer

- 1. Both main memory and secondary storage are types of memory. Describe the difference between the two.
- 2. What is the difference between system software and application software?
- 3. What type of software controls the internal operations of the computer's hardware?
- 4. Why must programs written in a high-level language be translated into machine language before they can be run?
- 5. What is a source code and an object code?
- 6. Explain the difference between an object file and an executable file.
- 7. What is the difference between a syntax error and a logical error?

Fill-in-the-Blank

- 8. Computers can do many different jobs because they can be _____.
- 9. The job of the ______ is to fetch instructions, carry out the operations commanded by the instructions, and produce some outcome or resultant information.
- 10. The ______ is the part of a computer in which programs actually execute.
- 11. The main memory is commonly known as _____.
- 12. The two general categories of software are _____ and _____.
- 13. A program is a set of _____
- 14. A(n) _____ is an ordered set of steps written in human language to perform a task or to solve any problem.
- 15. _____ is the only language computers really process.
- 16. _____ languages are close to the level of humans in terms of readability.
- 17. C++ is a high-level language that has ______ features.
- 18. A program's ability to run on several different types of computer systems is called
- 19. Words that have special meaning in a programming language are called ______.
- 20. Words or names defined by the programmer are called _____.
- 21. A(n) _____ translates each source code instruction to the equivalent machine language instruction(s).

- 22. _____ characters or symbols mark the beginning or ending of programming statements, or separate items in a list.
- 23. The statement #include<iostream> is a(n) _____.
- 24. A(n) _____ is a named storage location.
- 25. When data is stored in a variable, it is actually stored in the ______ of the computer.
- 26. The three primary activities of a program are _____, ____, and _____.
- 27. _____ is information a program gathers from the outside world.
- 28. A(n) ______ is a diagrammatic representation of the logical flow of a program.
- 29. A(n) ______ is a diagram that graphically illustrates the structure of a program.

Algorithm Workbench

Draw hierarchy charts or flowcharts that depict the programs described below. (See Appendix D for instructions on creating flowcharts.)

30. Available Credit

The following steps should be followed in a program that calculates a customer's available credit:

- 1. Display the message "Enter the customer's maximum credit."
- 2. Wait for the user to enter the customer's maximum credit.
- 3. Display the message "Enter the amount of credit used by the customer."
- 4. Wait for the user to enter the customer's credit used.
- 5. Subtract the used credit from the maximum credit to get the customer's available credit.
- 6. Display a message that shows the customer's available credit.
- 31. Sales Tax

Design a hierarchy chart or flowchart for a program that calculates the total of a retail sale. The program should ask the user for:

- The retail price of the item being purchased
- The sales tax rate

Once these items have been entered, the program should calculate and display:

- The sales tax for the purchase
- The total of the sale
- 32. Account Balance

Design a hierarchy chart or flowchart for a program that calculates the current balance in a savings account. The program must ask the user for:

- The starting balance
- The total dollar amount of deposits made
- The total dollar amount of withdrawals made
- The monthly interest rate

Once the program calculates the current balance, it should be displayed on the screen.



Predict the Result

Questions 33–35 are programs expressed as English statements. What would each display on the screen if they were actual programs?



- 33. The variable i starts with the value 5. The variable j starts with the value 6. Increment i by 1. Decrement j by 1. Add i and j, and store the result in a variable sum. Display the value of sum on the screen.
- 34. The variable x starts with the value 20. The variable y starts with the value 10. Store the value of x in a variable t.Store the value of y in x. Store the value of t in y. Display the value of x on the screen. Display the value of y on the screen
- 35. The variable a starts with the value 1. The variable b starts with the value 10. The variable c starts with the value 100. The variable x starts with the value 0. Store the value of c times 3 in x. Add the value of b times 6 to the value already in x. Add the value of a times 5 to the value already in x. Display the value in x on the screen.

Find the Error

36. The following *pseudocode algorithm* has an error. The program is supposed to ask the user for the length and width of a rectangular room, and then display the room's area. The program must multiply the width by the length in order to determine the area. Find the error.

area = width × length. Display "What is the room's width?". Input width. Display "What is the room's length?". Input length. Display area.

PTE

HAF

Introduction to C++

TOPICS

- 2.1 The Parts of a C++ Program
- 2.2 The cout Object
- 2.3 The #include Directive
- 2.4 Variables and Literals
- 2.5 Identifiers
- 2.6 Integer Data Types
- 2.7 The char Data Type
- 2.8 The C++ string Class
- 2.9 Floating-Point Data Types
- 2.10 The bool Data Type

- 2.11 Determining the Size of a Data Type
- 2.12 Variable Assignments
 - and Initialization
- 2.13 Scope
- 2.14 Arithmetic Operators
- 2.15 Comments
- 2.16 Named Constants
- 2.17 Programming Style

2.1 The Parts of a C++ Program

CONCEPT: C++ programs have parts and components that serve specific purposes.

Every C++ program has an anatomy. Unlike human anatomy, the parts of C++ programs are not always in the same place. Nevertheless, the parts are there, and your first step in learning C++ is to learn what they are. We will begin by looking at Program 2-1.

Let's examine the program line by line. Here's the first line:

// A simple C++ program

The // marks the beginning of a *comment*. The compiler ignores everything from the double slash to the end of the line. That means you can type anything you want on that line and the compiler will never complain! Although comments are not required, they are very important to programmers. Most programs are much more complicated than the example in Program 2-1, and comments help explain what's going on.

Program 2-1

```
1
   // A simple C++ program
2
   #include <iostream>
3
   using namespace std;
4
5
   int main()
6
   {
7
        cout << "Programming is great fun!";</pre>
8
        return 0:
9
   }
```

The output of the program is shown below. This is what appears on the screen when the program runs.

Program Output

Programming is great fun!

Line 2 looks like this:

#include <iostream>

Because this line starts with a #, it is called a *preprocessor directive*. The preprocessor reads your program before it is compiled and only executes those lines beginning with a # symbol. Think of the preprocessor as a program that "sets up" your source code for the compiler.

The #include directive causes the preprocessor to include the contents of another file in the program. The word inside the brackets, iostream, is the name of the file that is to be included. The iostream file contains code that allows a C++ program to display output on the screen and read input from the keyboard. Because this program uses cout to display screen output, the iostream file must be included. The contents of the iostream file are included in the program at the point the #include statement appears. The iostream file is called a *header file*, so it should be included at the head, or top, of the program.

Line 3 reads:

using namespace std;

Programs usually contain several items with unique names. In this chapter you will learn to create variables. In Chapter 6 you will learn to create functions. In Chapter 13 you will learn to create objects. Variables, functions, and objects are examples of program entities that must have names. C++ uses *namespaces* to organize the names of program entities. The statement using namespace std; declares that the program will be accessing entities whose names are part of the namespace called std. (Yes, even namespaces have names.) The reason the program needs access to the std namespace is because every name created by the iostream file is part of that namespace. In order for a program to use the entities in iostream, it must have access to the std namespace.

Line 5 reads:

int main()

This marks the beginning of a function. A *function* can be thought of as a group of one or more programming statements that collectively has a name. The name of this function is *main*, and the set of parentheses that follows the name indicate that it is a function. The

word int stands for "integer." It indicates that the function sends an integer value back to the operating system when it is finished executing.

Although most C++ programs have more than one function, every C++ program must have a function called main. It is the starting point of the program. If you are ever reading someone else's C++ program and want to find where it starts, just look for the function named main.

NOTE: C++ is a case-sensitive language. That means it regards uppercase letters as being entirely different characters than their lowercase counterparts. In C++, the name of the function main must be written in all lowercase letters. C++ doesn't see "Main" the same as "main," or "INT" the same as "int." This is true for all the C++ key words.

Line 6 contains a single, solitary character:

{

This is called a left-brace, or an opening brace, and it is associated with the beginning of the function main. All the statements that make up a function are enclosed in a set of braces. If you look at the third line down from the opening brace you'll see the closing brace. Everything between the two braces is the contents of the function main.



WARNING! Make sure you have a closing brace for every opening brace in your program!

After the opening brace you see the following statement in line 7:

```
cout << "Programming is great fun!";</pre>
```

To put it simply, this line displays a message on the screen. You will read more about cout and the << operator later in this chapter. The message "Programming is great fun!" is printed without the quotation marks. In programming terms, the group of characters inside the quotation marks is called a *string literal* or *string constant*.

NOTE: This is the only line in the program that causes anything to be printed on the screen. The other lines, like #include <iostream> and int main(), are necessary for the framework of your program, but they do not cause any screen output. Remember, a program is a set of instructions for the computer. If something is to be displayed on the screen, you must use a programming statement for that purpose.

At the end of the line is a semicolon. Just as a period marks the end of a sentence, a semicolon marks the end of a complete statement in C++. Comments are ignored by the compiler, so the semicolon isn't required at the end of a comment. Preprocessor directives, like #include statements, simply end at the end of the line and never require semicolons. The beginning of a function, like int main(), is not a complete statement, so you don't place a semicolon there either.

It might seem that the rules for where to put a semicolon are not clear at all. Rather than worry about it now, just concentrate on learning the parts of a program. You'll soon get a feel for where you should and should not use semicolons.

Line 8 reads:

return 0;

This sends the integer value 0 back to the operating system upon the program's completion. The value 0 usually indicates that a program executed successfully.

Line 9 contains the closing brace:

}

This brace marks the end of the main function. Since main is the only function in this program, it also marks the end of the program.

In the sample program you encountered several sets of special characters. Table 2-1 provides a short summary of how they were used.

Character	Name	Description
//	Double slash	Marks the beginning of a comment.
#	Pound sign	Marks the beginning of a preprocessor directive.
< >	Opening and closing brackets	Encloses a filename when used with the #include directive.
()	Opening and closing parentheses	Used in naming a function, as in int main()
{ }	Opening and closing braces	Encloses a group of statements, such as the contents of a function.
	Opening and closing quotation marks	Encloses a string of characters, such as a message that is to be printed on the screen.
;	Semicolon	Marks the end of a complete programming statement.

Table 2-1 Special Characters



Checkpoint

2.1 The following C++ program will not compile because the lines have been mixed up.

```
int main()
}
// A crazy mixed up program
return 0;
#include <iostream>
cout << "In 1492 Columbus sailed the ocean blue.";
{
using namespace std;</pre>
```

When the lines are properly arranged the program should display the following on the screen:

In 1492 Columbus sailed the ocean blue.

Rearrange the lines in the correct order. Test the program by entering it on the computer, compiling it, and running it.

2.2 The cout Object

CONCEPT: Use the cout object to display information on the computer's screen.

In this section you will learn to write programs that produce output on the screen. The simplest type of screen output that a program can display is *console output*, which is merely plain text. The word *console* is an old computer term. It comes from the days when a computer operator interacted with the system by typing on a terminal. The terminal, which consisted of a simple screen and keyboard, was known as the *console*.

On modern computers, running graphical operating systems such as Windows or Mac OS X, console output is usually displayed in a window such as the one shown in Figure 2-1. In C++ you use the cout object to produce console output. (You can think of the word cout as meaning console output.)

Figure 2-1 A Console Window



cout is classified as a *stream object*, which means it works with streams of data. To print a message on the screen, you send a stream of characters to cout. Let's look at line 7 from Program 2-1:

cout << "Programming is great fun!";</pre>

Notice that the << operator is used to send the string "Programming is great fun!" to cout. When the << symbol is used this way, it is called the *stream insertion operator*. The item immediately to the right of the operator is sent to cout and then displayed on the screen.

The stream insertion operator is always written as two less-than signs with no space between them. Because you are using it to send a stream of data to the cout object, you can think of the stream insertion operator as an arrow that must point toward cout. This is illustrated in Figure 2-2.

Program 2-2 is another way to write the same program.



Figure 2-2

Program 2-2

```
// A simple C++ program
1
2
   #include <iostream>
3
   using namespace std;
4
5
   int main()
6
   {
7
        cout << "Programming is " << "great fun!";</pre>
8
       return 0;
9
   }
```

Program Output

Programming is great fun!

As you can see, the stream-insertion operator can be used to send more than one item to cout. The output of this program is identical to that of Program 2-1. Program 2-3 shows yet another way to accomplish the same thing.

Program 2-3

```
1
    // A simple C++ program
 2
    #include <iostream>
 3 using namespace std;
 4
 5
    int main()
 6
    {
 7
         cout << "Programming is ";</pre>
        cout << "great fun!";</pre>
 8
9
        return 0;
10 }
```

Program Output

Programming is great fun!

An important concept to understand about Program 2-3 is that, although the output is broken up into two programming statements, this program will still display the message on a single line. Unless you specify otherwise, the information you send to cout is displayed in a continuous stream. Sometimes this can produce less-than-desirable results. Program 2-4 is an example.

The layout of the actual output looks nothing like the arrangement of the strings in the source code. First, notice there is no space displayed between the words "sellers" and "during," or

between "June:" and "Computer." cout displays messages exactly as they are sent. If spaces are to be displayed, they must appear in the strings.

Program 2-4

```
// An unruly printing program
 1
    #include <iostream>
 2
 3 using namespace std;
 4
 5 int main()
 6 {
 7
         cout << "The following items were top sellers";</pre>
 8
         cout << "during the month of June:";</pre>
 9
         cout << "Computer games";</pre>
10
         cout << "Coffee";</pre>
         cout << "Aspirin";</pre>
11
12
         return 0;
13 }
```

Program Output

The following items were top sellersduring the month of June:Computer gamesCoffeeAspirin

Second, even though the output is broken into five lines in the source code, it comes out as one long line of output. Because the output is too long to fit on one line on the screen, it wraps around to a second line when displayed. The reason the output comes out as one long line is because cout does not start a new line unless told to do so. There are two ways to instruct cout to start a new line. The first is to send cout a *stream manipulator* called end1 (which is pronounced "end-line" or "end-L"). Program 2-5 is an example.

Program 2-5

```
1
   // A well-adjusted printing program
 2
   #include <iostream>
 3
   using namespace std;
 4
 5 int main()
 6 {
 7
         cout << "The following items were top sellers" << endl;</pre>
 8
         cout << "during the month of June:" << endl;</pre>
 9
         cout << "Computer games" << endl;</pre>
         cout << "Coffee" << endl;</pre>
11
         cout << "Aspirin" << endl;</pre>
12
         return 0;
13
   }
```

Program Output

The following items were top sellers during the month of June: Computer games Coffee Aspirin



NOTE: The last character in endl is the lowercase letter L, not the number one.

Every time cout encounters an endl stream manipulator it advances the output to the beginning of the next line for subsequent printing. The manipulator can be inserted anywhere in the stream of characters sent to cout, outside the double quotes. The following statements show an example.

cout << "My pets are" << endl << "dog"; cout << endl << "cat" << endl << "bird" << endl;</pre>

Another way to cause cout to go to a new line is to insert an *escape sequence* in the string itself. An escape sequence starts with the backslash character (\backslash) and is followed by one or more control characters. It allows you to control the way output is displayed by embedding commands within the string itself. Program 2-6 is an example.

Program 2-6

```
1
    // Yet another well-adjusted printing program
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
 7
        cout << "The following items were top sellers\n";</pre>
 8
         cout << "during the month of June:\n";</pre>
         cout << "Computer games\nCoffee";</pre>
 9
10
         cout << "\nAspirin\n";</pre>
11
         return 0;
12 }
```

Program Output

The following items were top sellers during the month of June: Computer games Coffee Aspirin

The *newline escape sequence* is \n. When cout encounters \n in a string, it doesn't print it on the screen, but interprets it as a special command to advance the output cursor to the next line. You have probably noticed inserting the escape sequence requires less typing than inserting endl. That's why many programmers prefer it.

A common mistake made by beginning C++ students is to use a forward slash (/) instead of a backslash (\setminus) when trying to write an escape sequence. This will not work. For example, look at the following code.

// Error!
cout << "Four Score/nAnd seven/nYears ago./n";</pre>

In this code, the programmer accidentally wrote /n when he or she meant to write \n. The cout object will simply display the /n characters on the screen. This code will display the following output:

Four Score/nAnd seven/nYears ago./n

Another common mistake is to forget to put the n inside quotation marks. For example, the following code will not compile.

```
// Error! This code will not compile.
cout << "Good" << \n;
cout << "Morning" << \n;</pre>
```

This code will result in an error because the \n sequences are not inside quotation marks. We can correct the code by placing the \n sequences inside the string literals, as shown here:

// This will work.
cout << "Good\n";
cout << "Morning\n";</pre>

There are many escape sequences in C++. They give you the ability to exercise greater control over the way information is output by your program. Table 2-2 lists a few of them.

Escape		
Sequence	Name	Description
∖n	Newline	Causes the cursor to go to the next line for subsequent printing.
\t	Horizontal tab	Causes the cursor to skip over to the next tab stop.
\a	Alarm	Causes the computer to beep.
\b	Backspace	Causes the cursor to back up, or move left one position.
\r	Return	Causes the cursor to go to the beginning of the current line, not the next line.
$\setminus \setminus$	Backslash	Causes a backslash to be printed.
\'	Single quote	Causes a single quotation mark to be printed.
\"	Double quote	Causes a double quotation mark to be printed.

Table 2-2 Common Escape Sequences

WARNING! When using escape sequences, do not put a space between the backslash and the control character.

When you type an escape sequence in a string, you type two characters (a backslash followed by another character). However, an escape sequence is stored in memory as a single character. For example, consider the following string literal:

"One\nTwo\nThree\n"

The diagram in Figure 2-3 breaks this string into its individual characters. Notice how each of the \n escape sequences are considered one character.

Figure 2-3

2.3 The #include Directive

CONCEPT: The **#include** directive causes the contents of another file to be inserted into the program.

Now is a good time to expand our discussion of the #include directive. The following line has appeared near the top of every example program.

#include <iostream>

The header file iostream must be included in any program that uses the cout object. This is because cout is not part of the "core" of the C++ language. Specifically, it is part of the *input-output stream library*. The header file, iostream, contains information describing iostream objects. Without it, the compiler will not know how to properly compile a program that uses cout.

Preprocessor directives are not C++ statements. They are commands to the preprocessor, which runs prior to the compiler (hence the name "preprocessor"). The preprocessor's job is to set programs up in a way that makes life easier for the programmer.

For example, any program that uses the cout object must contain the extensive setup information found in iostream. The programmer could type all this information into the program, but it would be too time consuming. An alternative would be to use an editor to "cut and paste" the information into the program, but that would quickly become tiring as well. The solution is to let the preprocessor insert the contents of iostream automatically.

WARNING! Do not put semicolons at the end of processor directives. Because preprocessor directives are not C++ statements, they do not require semicolons. In many cases an error will result from a preprocessor directive terminated with a semicolon.

An #include directive must always contain the name of a file. The preprocessor inserts the entire contents of the file into the program at the point it encounters the #include directive. The compiler doesn't actually see the #include directive. Instead it sees the code that was inserted by the preprocessor, just as if the programmer had typed it there.

The code contained in header files is C++ code. Typically it describes complex objects like cout. Later you will learn to create your own header files.

Checkpoint

2.2 The following C++ program will not compile because the lines have been mixed up.

```
cout << "Success\n";
cout << " Success\n\n";
int main()
cout << "Success";
}
```

```
using namespace std;
// It's a mad, mad program
#include <iostream>
cout << "Success\n";
{
return 0;
```

When the lines are properly arranged the program should display the following on the screen:

Program Output

```
Success
Success Success
```

Success

Rearrange the lines in the correct order. Test the program by entering it on the computer, compiling it, and running it.

2.3 Study the following program and show what it will print on the screen.

```
// The Works of Wolfgang
#include <iostream>
using namespace std;
int main()
{
    cout << "The works of Wolfgang\ninclude the following";
    cout << "InThe Turkish March" << endl;
    cout << "and Symphony No. 40 ";
    cout << "in G minor." << endl;
    return 0;
}</pre>
```

2.4 On paper, write a program that will display your name on the first line, your street address on the second line, your city, state, and ZIP code on the third line, and your telephone number on the fourth line. Place a comment with today's date at the top of the program. Test your program by entering, compiling, and running it.

2.4 Variables and Literals

CONCEPT: Variables represent storage locations in the computer's memory. Literals are constant values that are assigned to variables.

As you discovered in Chapter 1, variables allow you to store and work with data in the computer's memory. They provide an "interface" to RAM. Part of the job of programming is to determine how many variables a program will need and what types of information they will hold. Program 2-7 is an example of a C++ program with a variable. Take a look at line 7:

int number;

This is called a *variable definition*. It tells the compiler the variable's name and the type of data it will hold. This line indicates the variable's name is number. The word int stands for integer, so number will only be used to hold integer numbers. Later in this chapter you will learn all the types of data that C++ allows.



Program 2-7

```
1
    // This program has a variable.
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
         int number;
 7
 8
9
        number = 5;
         cout << "The value in number is " << number << endl;</pre>
10
11
        return 0;
12
  }
```

Program Output

The value in number is 5



NOTE: You must have a definition for every variable you intend to use in a program. In C++, variable definitions can appear at any point in the program. Later in this chapter, and throughout the book, you will learn the best places to define variables.

Notice that variable definitions end with a semicolon. Now look at line 9:

```
number = 5;
```

This is called an *assignment*. The equal sign is an operator that copies the value on its right (5) into the variable named on its left (number). After this line executes, number will be set to 5.



NOTE: This line does not print anything on the computer's screen. It runs silently behind the scenes, storing a value in RAM.

Look at line 10.

```
cout << "The value in number is " << number << endl;</pre>
```

The second item sent to cout is the variable name number. When you send a variable name to cout it prints the variable's contents. Notice there are no quotation marks around number. Look at what happens in Program 2-8.

Program 2-8

```
1
   // This program has a variable.
2
   #include <iostream>
3
   using namespace std;
4
5
   int main()
6
   {
7
        int number;
8
9
        number = 5;
```

```
10 cout << "The value in number is " << "number" << endl;
11 return 0;
12 }
```

Program Output

The value in number is number

When double quotation marks are placed around the word number it becomes a string literal and is no longer a variable name. When string literals are sent to cout they are printed exactly as they appear inside the quotation marks. You've probably noticed by now that the endl stream manipulator has no quotation marks around it, for the same reason.

Sometimes a Number Isn't a Number

As shown in Program 2-8, just placing quotation marks around a variable name changes the program's results. In fact, placing double quotation marks around anything that is not intended to be a string literal will create an error of some type. For example, in Program 2-8 the number 5 was assigned to the variable number. It would have been incorrect to perform the assignment this way:

number = "5";

In this line, 5 is no longer an integer, but a string literal. Because number was defined as an integer variable, you can only store integers in it. The integer 5 and the string literal "5" are not the same thing.

The fact that numbers can be represented as strings frequently confuses students who are new to programming. Just remember that strings are intended for humans to read. They are to be printed on computer screens or paper. Numbers, however, are intended primarily for mathematical operations. You cannot perform math on strings. Before numbers can be displayed on the screen, they must first be converted to strings. (Fortunately, cout handles the conversion automatically when you send a number to it.)

Literals

A literal is a piece of data that is written directly into a program's code. One of the most common uses of literals is to assign a value to a variable. For example, in the following statement assume that number is an int variable. The statement assigns the literal value 100 to the variable number:

```
number = 100;
```

Another common use of literals is to display something on the screen. For example, the following statement displays the string literal "Welcome to my program."

cout << "Welcome to my program." << endl;</pre>

Program 2-9 shows an example that uses a variable and several literals.

Program 2-9

```
    // This program has literals and a variable.
    #include <iostream>
    using namespace std;
```

(program continues)

```
Program 2-9
                   (continued)
 4
 5
    int main()
 6
    {
 7
         int apples;
 8
 9
        apples = 20;
10
         cout << "Today we sold " << apples << " bushels of apples.\n";</pre>
        return 0;
11
12 }
```

Program Output

Today we sold 20 bushels of apples.

Of course, the variable is apples. It is defined as an integer. Table 2-3 lists the literals found in the program.

Table 2-3

Literal	Type of Literal
20	Integer literal
"Today we sold "	String literal
"bushels of apples.\n"	String literal
0	Integer literal



NOTE: Literals are also called constants.

Checkpoint

2.5 Examine the following program.

```
// This program uses variables and literals.
#include <iostream>
using namespace std;
int main()
{
    int little;
    int big;
    little = 2;
    big = 2000;
    cout << "The little number is " << little << endl;
    cout << "The big number is " << big << endl;
    return 0;
}</pre>
```

List all the variables and literals that appear in the program.

2.6 What will the following program display on the screen?

```
#include <iostream>
using namespace std;
```

```
int main()
{
    int number;
    number = 712;
    cout << "The value is " << "number" << endl;
    return 0;
}</pre>
```

2.5 Identifiers

CONCEPT: Choose variable names that indicate what the variables are used for.

An *identifier* is a programmer-defined name that represents some element of a program. Variable names are examples of identifiers. You may choose your own variable names in C++, as long as you do not use any of the C++ *key words*. The key words make up the "core" of the language and have specific purposes. Table 2-4 shows a complete list of the C++ key words. Note that they are all lowercase.

alignas	const	for	private	throw
alignof	constexpr	friend	protected	true
and	const_cast	goto	public	try
and_eq	continue	if	register	typedef
asm	decltype	inline	reinterpret_cast	typeid
auto	default	int	return	typename
bitand	delete	long	short	union
bitor	do	mutable	signed	unsigned
bool	double	namespace	sizeof	using
break	dynamic_cast	new	static	virtual
case	else	noexcept	static_assert	void
catch	enum	not	static_cast	volatile
char	explicit	not_eq	struct	wchar_t
char16_t	export	nullptr	switch	while
char32_t	extern	operator	template	xor
class	false	or	this	xor_eq
compl	float	or_eq	thread_local	

Table 2-4The C++ Key Words

You should always choose names for your variables that give an indication of what the variables are used for. You may be tempted to define variables with names like this:

int x;

The rather nondescript name, x, gives no clue as to the variable's purpose. Here is a better example.

int itemsOrdered;
The name itemsOrdered gives anyone reading the program an idea of the variable's use. This way of coding helps produce self-documenting programs, which means you get an understanding of what the program is doing just by reading its code. Because real-world programs usually have thousands of lines, it is important that they be as self-documenting as possible.

You probably have noticed the mixture of uppercase and lowercase letters in the name itemsOrdered. Although all of C++'s key words must be written in lowercase, you may use uppercase letters in variable names.

The reason the 0 in itemsOrdered is capitalized is to improve readability. Normally "items ordered" is two words. Unfortunately you cannot have spaces in a variable name, so the two words must be combined into one. When "items" and "ordered" are stuck together you get a variable definition like this:

int itemsordered;

Capitalization of the first letter of the second word and succeeding words makes itemsOrdered easier to read. It should be mentioned that this style of coding is not required. You are free to use all lowercase letters, all uppercase letters, or any combination of both. In fact, some programmers use the underscore character to separate words in a variable name, as in the following.

int items_ordered;

Legal Identifiers

Regardless of which style you adopt, be consistent and make your variable names as sensible as possible. Here are some specific rules that must be followed with all identifiers.

- The first character must be one of the letters a through z, A through Z, or an underscore character (_).
- After the first character you may use the letters a through z or A through Z, the digits 0 through 9, or underscores.
- Uppercase and lowercase characters are distinct. This means ItemsOrdered is not the same as itemsordered.

Table 2-5 lists variable names and tells whether each is legal or illegal in C++.

Table 2-5 Some Variable	e Names
Variable Name	Legal or Illegal?
dayOfWeek	Legal.
3dGraph	Illegal. Variable names cannot begin with a digit.
_employee_num	Legal.
June1997	Legal.
Mixture#3	Illegal. Variable names may only use letters, digits, or underscores.

2.6 Integer Data Types

CONCEPT: There are many different types of data. Variables are classified according to their data type, which determines the kind of information that may be stored in them. Integer variables can only hold whole numbers.

Computer programs collect pieces of data from the real world and manipulate them in various ways. There are many different types of data. In the realm of numeric information, for example, there are whole numbers and fractional numbers. There are negative numbers and positive numbers. And there are numbers so large, and others so small, that they don't even have a name. Then there is textual information. Names and addresses, for instance, are stored as groups of characters. When you write a program you must determine what types of information it will be likely to encounter.

If you are writing a program to calculate the number of miles to a distant star, you'll need variables that can hold very large numbers. If you are designing software to record microscopic dimensions, you'll need to store very small and precise numbers. Additionally, if you are writing a program that must perform thousands of intensive calculations, you'll want variables that can be processed quickly. The data type of a variable determines all of these factors.

Although C++ offers many data types, in the very broadest sense there are only two: numeric and character. Numeric data types are broken into two additional categories: integer and floating point. Integers are whole numbers like 12, 157, -34, and 2. Floating point numbers have a decimal point, like 23.7, 189.0231, and 0.987. Additionally, the integer and floating point data types are broken into even more classifications. Before we discuss the character data type, let's carefully examine the variations of numeric data.

Your primary considerations for selecting a numeric data type are

- The largest and smallest numbers that may be stored in the variable
- How much memory the variable uses
- Whether the variable stores signed or unsigned numbers
- The number of decimal places of precision the variable has

The size of a variable is the number of bytes of memory it uses. Typically, the larger a variable is, the greater the range it can hold.

Table 2-6 shows the C++ integer data types with their typical sizes and ranges.



NOTE: The data type sizes and ranges shown in Table 2-6 are typical on many systems. Depending on your operating system, the sizes and ranges may be different.

5 71		
Data Type	Typical Size	Typical Range
short int	2 bytes	-32,768 to $+32,767$
unsigned short int	2 bytes	0 to +65,535
int	4 bytes	-2,147,483,648 to +2,147,483,647
unsigned int	4 bytes	0 to 4,294,967,295
long int	4 bytes	-2,147,483,648 to +2,147,483,647
unsigned long int	4 bytes	0 to 4,294,967,295
long long int	8 bytes	-9,223,372,036,854,775,808 to 9,223,372,036,854,775,807
unsigned long long int	8 bytes	0 to 18,446,744,073,709,551,615

Table 2-6Integer Data Types

Here are some examples of variable definitions:

```
int days;
unsigned int speed;
short int month;
unsigned short int amount;
long int deficit;
unsigned long int insects;
```

Each of the data types in Table 2-6, except int, can be abbreviated as follows:

- short int can be abbreviated as short
- unsigned short int can be abbreviated as unsigned short
- unsigned int can be abbreviated as unsigned
- long int can be abbreviated as long
- unsigned long int can be abbreviated as unsigned long
- long long int can be abbreviated as long long
- unsigned long long int can be abbreviated as unsigned long long

Because they simplify definition statements, programmers commonly use the abbreviated data type names. Here are some examples:

```
unsigned speed;
short month;
unsigned short amount;
long deficit;
unsigned long insects;
long long grandTotal;
unsigned long long lightYearDistance;
```

Unsigned data types can only store nonnegative values. They can be used when you know your program will not encounter negative values. For example, variables that hold ages or weights would rarely hold numbers less than 0.

Notice in Table 2-6 that the int and long data types have the same sizes and ranges, and that the unsigned int data type has the same size and range as the unsigned long data type. This is not always true because the size of integers is dependent on the type of system you are using. Here are the only guarantees:

- Integers are at least as big as short integers.
- Long integers are at least as big as integers.
- Unsigned short integers are the same size as short integers.
- Unsigned integers are the same size as integers.
- Unsigned long integers are the same size as long integers.
- The long long int and the unsigned long long int data types are guaranteed to be at least 8 bytes (64 bits) in size.

Later in this chapter you will learn to use the sizeof operator to determine how large all the data types are on your computer.



NOTE: The long long int and the unsigned long long int data types were introduced in C++ 11.

As mentioned before, variables are defined by stating the data type key word followed by the name of the variable. In Program 2-10 an integer, an unsigned integer, and a long integer have been defined.

Program 2-10

```
// This program has variables of several of the integer types.
 1
   #include <iostream>
 2
   using namespace std;
 3
 4
 5
   int main()
 6
   {
 7
         int checking;
         unsigned int miles;
 8
 9
         long days;
10
11
        checking = -20;
12
        miles = 4276;
       days = 189000;
13
       cout << "We have made a long journey of " << miles;
14
15
       cout << " miles.\n";</pre>
16
       cout << "Our checking account balance is " << checking;</pre>
        cout << "\nAbout " << days << " days ago Columbus ";</pre>
17
18
        cout << "stood on this spot.\n";
19
        return 0;
20 }
```

Program Output

We have made a long journey of 4276 miles. Our checking account balance is -20 About 189000 days ago Columbus stood on this spot.

In most programs you will need more than one variable of any given data type. If a program uses two integers, length and width, they could be defined separately, like this:

int length; int width;

It is easier, however, to combine both variable definitions on one line:

int length, width;

You can define several variables of the same type like this, simply separating their names with commas. Program 2-11 illustrates this.

Program 2-11

```
1 // This program shows three variables defined on the same line.
2 #include <iostream>
3 using namespace std;
4
5 int main()
```

(program continues)

```
Program 2-11
                   (continued)
 6
    {
 7
         int floors, rooms, suites;
 8
9
         floors = 15;
10
         rooms = 300;
         suites = 30;
11
12
         cout << "The Grande Hotel has " << floors << " floors \n";</pre>
13
         cout << "with " << rooms << " rooms and " << suites;
14
         cout << " suites.\n";</pre>
15
         return 0;
16 }
```

Program Output

The Grande Hotel has 15 floors with 300 rooms and 30 suites.

Integer and Long Integer Literals

In C++, if a numeric literal is an integer (not written with a decimal point) and it fits within the range of an int (see Table 2-6 for the minimum and maximum values), then the numeric literal is treated as an int. A numeric literal that is treated as an int is called an *integer literal*. For example, look at lines 9, 10, and 11 in Program 2-11:

```
floors = 15;
rooms = 300;
suites = 30;
```

Each of these statements assigns an integer literal to a variable.

One of the pleasing characteristics of the C++ language is that it allows you to control almost every aspect of your program. If you need to change the way something is stored in memory, the tools are provided to do that. For example, what if you are in a situation where you have an integer literal, but you need it to be stored in memory as a long integer? (Rest assured, this is a situation that does arise.) C++ allows you to force an integer literal to be stored as a long integer by placing the letter L at the end of the number. Here is an example:

long amount; amount = 32L;

The first statement defines a long variable named amount. The second statement assigns the literal value 32 to the amount variable. In the second statement, the literal is written as 32L, which makes it a *long integer literal*. This means the literal is treated as a long.



If you want an integer literal to be treated as a long long int, you can append LL at the end of the number. Here is an example:

```
long long amount;
amount = 32LL;
```

The first statement defines a long long variable named amount. The second statement assigns the literal value 32 to the amount variable. In the second statement, the literal is written as 32LL, which makes it a *long long integer literal*. This means the literal is treated as a long long int.

TIP: When writing long integer literals or long long integer literals, you can use either an uppercase or lowercase L. Because the lowercase l looks like the number 1, you should always use the uppercase L.

If You Plan to Continue in Computer Science: Hexadecimal and Octal Literals

Programmers commonly express values in numbering systems other than decimal (or base 10). Hexadecimal (base 16) and octal (base 8) are popular because they make certain programming tasks more convenient than decimal numbers do.

By default, C++ assumes that all integer literals are expressed in decimal. You express hexadecimal numbers by placing 0x in front of them. (This is zero-x, not oh-x.) Here is how the hexadecimal number F4 would be expressed in C++:

0xF4

Octal numbers must be preceded by a 0 (zero, not oh). For example, the octal 31 would be written

031



NOTE: You will not be writing programs for some time that require this type of manipulation. It is important, however, that you understand this material. Good programmers should develop the skills for reading other people's source code. You may find yourself reading programs that use items like long integer, hexadecimal, or octal literals.



Checkpoint

2.7 Which of the following are illegal variable names, and why?

```
X
99bottles
july97
theSalesFigureForFiscalYear98
r&d
grade_report
```

- 2.8 Is the variable name Sales the same as sales? Why or why not?
- 2.9 Refer to the data types listed in Table 2-6 for these questions.
 - A) If a variable needs to hold numbers in the range 32 to 6,000, what data type would be best?
 - B) If a variable needs to hold numbers in the range -40,000 to +40,000, what data type would be best?
 - C) Which of the following literals uses more memory? 20 or 20L
- 2.10 On any computer, which data type uses more memory, an integer or an unsigned integer?

2.7 The char Data Type

The char data type is used to store individual characters. A variable of the char data type can hold only one character at a time. Here is an example of how you might declare a char variable:

char letter;

This statement declares a char variable named letter, which can store one character. In C++, *character literals* are enclosed in single quotation marks. Here is an example showing how we would assign a character to the letter variable:

letter = 'g';

This statement assigns the character 'g' to the letter variable. Because char variables can hold only one character, they are not compatible with strings. For example, you cannot assign a string to a char variable, even if the string contains only one character. The following statement, for example, will not compile because it attempts to assign a string literal to a char variable.

letter = "g"; // ERROR! Cannot assign a string to a char

It is important that you do not confuse character literals, which are enclosed in single quotation marks, with string literals, which are enclosed in double quotation marks.

Program 2-12 shows an example program that works with characters.

Program 2-12

```
1
    // This program works with characters.
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
 7
         char letter;
 8
9
         letter = 'A';
10
         cout << letter << endl;</pre>
11
         letter = 'B';
12
         cout << letter << endl;</pre>
13
         return 0;
14
   }
```

Program Output

A B

Although the char data type is used for storing characters, it is actually an integer data type that typically uses 1 byte of memory. (The size is system dependent. On some systems, the char data type is larger than 1 byte.)

The reason an integer data type is used to store characters is because characters are internally represented by numbers. Each printable character, as well as many nonprintable characters, is assigned a unique number. The most commonly used method for encoding characters is ASCII, which stands for the American Standard Code for Information Interchange. (There are other codes, such as EBCDIC, which is used by many IBM mainframes.)

When a character is stored in memory, it is actually the numeric code that is stored. When the computer is instructed to print the value on the screen, it displays the character that corresponds with the numeric code.

You may want to refer to Appendix B, which shows the ASCII character set. Notice that the number 65 is the code for A, 66 is the code for B, and so on. Program 2-13 demonstrates that when you work with characters, you are actually working with numbers.

Program 2-13

```
1
    // This program demonstrates the close relationship between
 2
    // characters and integers.
 3
    #include <iostream>
 4
    using namespace std;
 5
 6
    int main()
 7
    {
 8
         char letter;
 9
10
         letter = 65;
         cout << letter << endl;</pre>
11
         letter = 66;
12
13
         cout << letter << endl;</pre>
         return 0;
14
15
    }
Program Output
Α
```

Figure 2-4 illustrates that when characters, such as A, B, and C, are stored in memory, it is really the numbers 65, 66, and 67 that are stored.

Figure 2-4

в



The Difference Between String Literals and Character Literals

It is important that you do not confuse character literals with string literals. Strings, which are a series of characters stored in consecutive memory locations, can be virtually any length. This means that there must be some way for the program to know how long a string is. In C++ an extra byte is appended to the end of string literals when they are stored in memory. In this last byte, the number 0 is stored. It is called the *null terminator* or *null character*, and it marks the end of the string.

Don't confuse the null terminator with the character '0'. If you look at Appendix B, you will see that ASCII code 48 corresponds to the character '0', whereas the null terminator is the same as the ASCII code 0. If you want to print the character 0 on the screen, you use ASCII code 48. If you want to mark the end of a string, however, you use ASCII code 0.

Let's look at an example of how a string literal is stored in memory. Figure 2-5 depicts the way the string literal "Sebastian" would be stored.

Figure 2-5

S e b a s t i a n \0

First, notice the quotation marks are not stored with the string. They are simply a way of marking the beginning and end of the string in your source code. Second, notice the very last byte of the string. It contains the null terminator, which is represented by the 0 character. The addition of this last byte means that although the string "Sebastian" is 9 characters long, it occupies 10 bytes of memory.

The null terminator is another example of something that sits quietly in the background. It doesn't print on the screen when you display a string, but nevertheless, it is there silently doing its job.



NOTE: C++ automatically places the null terminator at the end of string literals.

Now let's compare the way a string and a char are stored. Suppose you have the literals 'A' and "A" in a program. Figure 2-6 depicts their internal storage.

Figure 2-6

'A' is stored as	Α
"A" is stored as	A \0

As you can see, 'A' is a 1-byte element and "A" is a 2-byte element. Since characters are really stored as ASCII codes, Figure 2-7 shows what is actually being stored in memory.

Figure 2-7			
	'A' is stored as	65	
	"A" is stored as	65 0	

Because char variables are only large enough to hold one character, you cannot assign string literals to them. For example, the following code defines a char variable named letter. The character literal 'A' can be assigned to the variable, but the string literal "A" cannot.

```
char letter;
letter = 'A'; // This will work.
letter = "A"; // This will not work!
```

One final topic about characters should be discussed. You have learned that some strings look like a single character but really aren't. It is also possible to have a character that looks like a string. A good example is the newline character, \n. Although it is represented by two characters, a slash and an n, it is internally represented as one character. In fact, all escape sequences, internally, are just 1 byte.

Program 2-14 shows the use of \n as a character literal, enclosed in single quotation marks. If you refer to the ASCII chart in Appendix B, you will see that ASCII code 10 is the linefeed character. This is the code C++ uses for the newline character.

Program 2-14

```
// This program uses character literals.
 1
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
 7
        char letter;
 8
 9
         letter = 'A';
10
        cout << letter << '\n';</pre>
11
         letter = 'B';
12
         cout << letter << '\n';
13
         return 0;
14
    }
```

Program Output

A B

Let's review some important points regarding characters and strings:

- Printable characters are internally represented by numeric codes. Most computers use ASCII codes for this purpose.
- Characters normally occupy a single byte of memory.

- Strings are consecutive sequences of characters that occupy consecutive bytes of memory.
- String literals are always stored in memory with a null terminator at the end. This marks the end of the string.
- Character literals are enclosed in single quotation marks.
- String literals are enclosed in double quotation marks.
- Escape sequences such as '\n' are stored internally as a single character.

2.8 The C++ string Class

CONCEPT: Standard C++ provides a special data type for storing and working with strings.

Because a char variable can store only one character in its memory location, another data type is needed for a variable able to hold an entire string. Although C++ does not have a built-in data type able to do this, standard C++ provides something called the string class that allows the programmer to create a string type variable.

Using the string Class

The first step in using the string class is to #include the string header file. This is accomplished with the following preprocessor directive:

#include <string>

The next step is to define a string type variable, called a string object. Defining a string object is similar to defining a variable of a primitive type. For example, the following statement defines a string object named movieTitle.

```
string movieTitle;
```

You can assign a string literal to movieTitle with the assignment operator:

```
movieTitle = "Wheels of Fury";
```

You can use cout to display the value of the movieTitle object, as shown in the next statement:

cout << "My favorite movie is " << movieTitle << endl;</pre>

Program 2-15 is a complete program that demonstrates the preceding statements.

Program 2-15

```
1 // This program demonstrates the string class.
```

```
2 #include <iostream>
```

```
3 #include <string> // Required for the string class.
```

```
4 using namespace std;
```

```
5
 6
    int main()
 7
    {
 8
         string movieTitle;
 9
         movieTitle = "Wheels of Fury";
10
         cout << "My favorite movie is " << movieTitle << endl;</pre>
11
12
         return 0;
13
    }
```

Program Output

My favorite movie is Wheels of Fury

As you can see, working with string objects is similar to working with variables of other types. Throughout this text we will continue to discuss string class features and capabilities.



Checkpoint

- 2.11 What are the ASCII codes for the following characters? (Refer to Appendix B)
 - C F
 - W
- 2.12 Which of the following is a character literal?

'B' "B"

2.13 Assuming the char data type uses 1 byte of memory, how many bytes do the following literals use?

'Q' "Q" "Sales" '\n'

- 2.14 Write a program that has the following character variables: first, middle, and last. Store your initials in these variables and then display them on the screen.
- 2.15 What is wrong with the following program statement?

char letter = "Z";

- 2.16 What header file must you include in order to use string objects?
- 2.17 Write a program that stores your name, address, and phone number in three separate string objects. Display the contents of the string objects on the screen.

2.9 Floating-Point Data Types

CONCEPT: Floating-point data types are used to define variables that can hold real numbers.

Whole numbers are not adequate for many jobs. If you are writing a program that works with dollar amounts or precise measurements, you need a data type that allows fractional values. In programming terms, these are called *floating-point* numbers.

Internally, floating-point numbers are stored in a manner similar to *scientific notation*. Take the number 47,281.97. In scientific notation this number is 4.728197×10^4 . (10^4 is equal to 10,000, and $4.728197 \times 10,000$ is 47,281.97.) The first part of the number, 4.728197, is called the *mantissa*. The mantissa is multiplied by a power of ten.

Computers typically use *E notation* to represent floating-point values. In E notation, the number 47,281.97 would be 4.728197E4. The part of the number before the E is the mantissa, and the part after the E is the power of 10. When a floating point number is stored in memory, it is stored as the mantissa and the power of 10.

Table 2-7 shows other numbers represented in scientific and E notation.

Decimal Notation	Scientific Notation	E Notation
247.91	2.4791×10^{2}	2.4791E2
0.00072	7.2×10^{-4}	7.2E—4
2,900,000	2.9×10^{6}	2.9E6

 Table 2-7
 Floating Point Representations

In C++ there are three data types that can represent floating-point numbers. They are

float double long double

The float data type is considered *single precision*. The double data type is usually twice as big as float, so it is considered *double precision*. As you've probably guessed, the long double is intended to be larger than the double. Of course, the exact sizes of these data types are dependent on the computer you are using. The only guarantees are

- A double is at least as big as a float.
- A long double is at least as big as a double.

Table 2-8 shows the sizes and ranges of floating-point data types usually found on PCs.

 Table 2-8
 Floating Point Data Types on PCs

Data Type	Key Word	Description
Single precision	float	4 bytes. Numbers between $\pm 3.4E-38$ and $\pm 3.4E38$
Double precision	double	8 bytes. Numbers between ±1.7E-308 and ±1.7E308
Long double precision	long double	8 bytes*. Numbers between ±1.7E-308 and ±1.7E308

*Some compilers use 10 bytes for long doubles. This allows a range of ±3.4E-4932 to ±1.1E4832

You will notice there are no unsigned floating point data types. On all machines, variables of the float, double, and long double data types can store positive or negative numbers.

Floating Point Literals

Floating point literals may be expressed in a variety of ways. As shown in Program 2-16, E notation is one method. When you are writing numbers that are extremely large or extremely small, this will probably be the easiest way. E notation numbers may be expressed with an uppercase E or a lowercase e. Notice that in the source code the literals were written as 1.495979E11 and 1.989E30, but the program printed them as 1.49598e+ 011 and 1.989e+30. The two sets of numbers are equivalent. (The plus sign in front of the exponent is also optional.) In Chapter 3 you will learn to control the way cout displays E notation numbers.

Program 2-16

```
// This program uses floating point data types.
 1
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
 7
         float distance;
         double mass;
 8
 9
10
         distance = 1.495979E11;
11
         mass = 1.989E30;
         cout << "The Sun is " << distance << " meters away.\n";</pre>
12
13
         cout << "The Sun\'s mass is " << mass << " kilograms.\n";</pre>
14
         return 0;
15 }
```

Program Output

```
The Sun is 1.49598e+011 meters away.
The Sun's mass is 1.989e+030 kilograms.
```

You can also express floating-point literals in decimal notation. The literal 1.495979E11 could have been written as

149597900000.00

Obviously the E notation is more convenient for lengthy numbers, but for numbers like 47.39, decimal notation is preferable to 4.739E1.

All of the following floating-point literals are equivalent:

```
1.4959E11
1.4959e11
1.4959E+11
1.4959e+11
149590000000.00
```

Floating-point literals are normally stored in memory as doubles. But remember, C++ provides tools for handling just about any situation. Just in case you need to force a literal to be stored as a float, you can append the letter F or f to the end of it. For example, the following literals would be stored as floats:

1.2F 45.907f



NOTE: Because floating-point literals are normally stored in memory as doubles, many compilers issue a warning message when you assign a floating-point literal to a float variable. For example, assuming num is a float, the following statement might cause the compiler to generate a warning message:

```
num = 14.725;
```

You can suppress the warning message by appending the f suffix to the floating-point literal, as shown below:

num = 14.725f;

If you want to force a value to be stored as a long double, append an L or l to it, as in the following examples:

1034.56L 89.21

The compiler won't confuse these with long integers because they have decimal points. (Remember, the lowercase L looks so much like the number 1 that you should always use the uppercase L when suffixing literals.)

Assigning Floating-Point Values to Integer Variables

When a floating-point value is assigned to an integer variable, the fractional part of the value (the part after the decimal point) is discarded. For example, look at the following code.

```
int number;
number = 7.5; // Assigns 7 to number
```

This code attempts to assign the floating-point value 7.5 to the integer variable number. As a result, the value 7 will be assigned to number, with the fractional part discarded. When part of a value is discarded, it is said to be *truncated*.

Assigning a floating-point variable to an integer variable has the same effect. For example, look at the following code.

When the float variable f is assigned to the int variable i, the value being assigned (7.5) is truncated. After this code executes i will hold the value 7 and f will hold the value 7.5.

NOTE: When a floating-point value is truncated, it is not rounded. Assigning the value 7.9 to an int variable will result in the value 7 being stored in the variable.

WARNING! Floating-point variables can hold a much larger range of values than integer variables can. If a floating-point value is being stored in an integer variable, and the whole part of the value (the part before the decimal point) is too large for the integer variable, an invalid value will be stored in the integer variable.

2.10 The bool Data Type

CONCEPT: Boolean variables are set to either true or false.

Expressions that have a true or false value are called *Boolean* expressions, named in honor of English mathematician George Boole (1815–1864).

The bool data type allows you to create small integer variables that are suitable for holding true or false values. Program 2-17 demonstrates the definition and assignment of a bool variable.

Program 2-17

```
// This program demonstrates boolean variables.
 1
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
 7
         bool boolValue;
 8
 9
         boolValue = true;
10
         cout << boolValue << endl;</pre>
11
         boolValue = false;
12
         cout << boolValue << endl;</pre>
13
         return 0;
14
    }
```

Program Output

1

0

As you can see from the program output, the value true is represented in memory by the number 1, and false is represented by 0. You will not be using bool variables until Chapter 4, however, so just remember they are useful for evaluating conditions that are either true or false.

2.11 Determining the Size of a Data Type

CONCEPT: The sizeof operator may be used to determine the size of a data type on any system.

Chapter 1 discussed the portability of the C++ language. As you have seen in this chapter, one of the problems of portability is the lack of common sizes of data types on all machines. If you are not sure what the sizes of data types are on your computer, C++ provides a way to find out.

A special operator called sizeof will report the number of bytes of memory used by any data type or variable. Program 2-18 illustrates its use. The first line that uses the operator is line 10:

cout << "The size of an integer is " << sizeof(int);</pre>

The name of the data type or variable is placed inside the parentheses that follow the operator. The operator "returns" the number of bytes used by that item. This operator can be invoked anywhere you can use an unsigned integer, including in mathematical operations.

Program 2-18

```
1
    // This program determines the size of integers, long
 2
    // integers, and long doubles.
 3
    #include <iostream>
 4
    using namespace std;
 5
 6 int main()
 7
    {
 8
         long double apple;
 9
         cout << "The size of an integer is " << sizeof(int);</pre>
10
11
         cout << " bytes.\n";</pre>
12
         cout << "The size of a long integer is " << sizeof(long);</pre>
13
         cout << " bytes.\n";</pre>
         cout << "An apple can be eaten in " << sizeof(apple);</pre>
14
15
         cout << " bytes!\n";</pre>
16
         return 0;
17 }
```

Program Output

```
The size of an integer is 4 bytes.
The size of a long integer is 4 bytes.
An apple can be eaten in 8 bytes!
```



Checkpoint

- 2.18 Yes or No: Is there an unsigned floating point data type? If so, what is it?
- 2.19 How would the following number in scientific notation be represented in E notation?

 6.31×10^{17}

2.20 Write a program that defines an integer variable named age and a float variable named weight. Store your age and weight, as literals, in the variables. The program should display these values on the screen in a manner similar to the following:

Program Output

My age is 26 and my weight is 180 pounds.

(Feel free to lie to the computer about your age and your weight it'll never know!)

2.12 Variable Assignments and Initialization

CONCEPT: An assignment operation assigns, or copies, a value into a variable. When a value is assigned to a variable as part of the variable's definition, it is called an initialization.

As you have already seen in several examples, a value is stored in a variable with an *assignment statement*. For example, the following statement copies the value 12 into the variable unitsSold.

unitsSold = 12;

The = symbol is called the *assignment operator*. Operators perform operations on data. The data that operators work with are called *operands*. The assignment operator has two operands. In the previous statement, the operands are unitsSold and 12.

In an assignment statement, C++ requires the name of the variable receiving the assignment to appear on the left side of the operator. The following statement is incorrect.

12 = unitsSold; // Incorrect!

In C++ terminology, the operand on the left side of the = symbol must be an *lvalue*. It is called an lvalue because it is a value that may appear on the left side of an assignment operator. An lvalue is something that identifies a place in memory whose contents may be changed. Most of the time this will be a variable name. The operand on the right side of the = symbol must be an *rvalue*. An rvalue is any expression that has a value. The assignment statement takes the value of the rvalue and puts it in the memory location of the object identified by the lvalue.

You may also assign values to variables as part of the definition. This is called *initialization*. Program 2-19 shows how it is done.

Program 2-19

```
1
    // This program shows variable initialization.
    #include <iostream>
 2
 3
    using namespace std;
 4
 5
   int main()
 6
    {
 7
        int month = 2, days = 28;
 8
9
        cout << "Month " << month << " has " << days << " days.\n";
10
        return 0;
11
   }
```

Program Output

Month 2 has 28 days.

As you can see, this simplifies the program and reduces the number of statements that must be typed by the programmer. Here are examples of other definition statements that perform initialization.

```
double interestRate = 12.9;
char stockCode = 'D';
long customerNum = 459L;
```

Of course, there are always variations on a theme. C++ allows you to define several variables and only initialize some of them. Here is an example of such a definition:

```
int flightNum = 89, travelTime, departure = 10, distance;
```

The variable flightNum is initialized to 89 and departure is initialized to 10. The variables travelTime and distance remain uninitialized.



Declaring Variables With the auto Key Word

C++ 11 introduces an alternative way to define variables, using the auto key word and an initialization value. Here is an example:

auto amount = 100;

Notice that this statement uses the word auto instead of a data type. The auto key word tells the compiler to determine the variable's data type from the initialization value. In this example the initialization value, 100, is an int, so amount will be an int variable. Here are other examples:

```
auto interestRate = 12.0;
auto stockCode = 'D';
auto customerNum = 459L;
```

In this code, the interestRate variable will be a double because the initialization value, 12.0, is a double. The stockCode variable will be a char because the initialization value, 'D', is a char. The customerNum variable will be a long because the initialization value, 459L, is a long.

These examples show how to use the auto key word, but they don't really show its usefulness. The auto key word is intended to simplify the syntax of declarations that are more complex than the ones shown here. Later in the book, you will see examples of how the auto key word can improve the readability of complex definition statements.

2.13 **Scope**

CONCEPT: A variable's scope is the part of the program that has access to the variable.

Every variable has a *scope*. The scope of a variable is the part of the program where the variable may be used. The rules that define a variable's scope are complex, and you will only be introduced to the concept here. In other sections of the book we will revisit this topic and expand on it.

The first rule of scope you should learn is that a variable cannot be used in any part of the program before the definition. Program 2-20 illustrates this.

Program 2-20

```
// This program can't find its variable.
 1
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
 7
         cout << value; // ERROR! value not defined yet!</pre>
 8
 9
         int value = 100;
10
         return 0;
11
    }
```

The program will not work because line 7 attempts to send the contents of the variable value to cout before the variable is defined. The compiler reads your program from top to bottom. If it encounters a statement that uses a variable before the variable is defined, an error will result. To correct the program, the variable definition must be put before any statement that uses it.

2.14 Arithmetic Operators

CONCEPT: There are many operators for manipulating numeric values and performing arithmetic operations.

C++ offers a multitude of operators for manipulating data. Generally, there are three types of operators: *unary*, *binary*, and *ternary*. These terms reflect the number of operands an operator requires.



Unary operators only require a single operand. For example, consider the following expression:

-5

Of course, we understand this represents the value negative five. The literal 5 is preceded by the minus sign. The minus sign, when used this way, is called the *negation operator*. Since it only requires one operand, it is a unary operator.

Binary operators work with two operands. The assignment operator is in this category. Ternary operators, as you may have guessed, require three operands. C++ only has one ternary operator, which will be discussed in Chapter 4.

Arithmetic operations are very common in programming. Table 2-9 shows the common arithmetic operators in C++.

Operator	Meaning	Туре	Example
+	Addition	Binary	<pre>total = cost + tax;</pre>
-	Subtraction	Binary	<pre>cost = total - tax;</pre>
*	Multiplication	Binary	<pre>tax = cost * rate;</pre>
/	Division	Binary	<pre>salePrice = original / 2;</pre>
80	Modulus	Binary	remainder = value % 3;

Table 2-9 Fundamental Arithmetic Operators

Each of these operators works as you probably expect. The addition operator returns the sum of its two operands. In the following assignment statement, the variable amount will be assigned the value 12:

```
amount = 4 + 8;
```

The subtraction operator returns the value of its right operand subtracted from its left operand. This statement will assign the value 98 to temperature:

temperature = 112 - 14;

The multiplication operator returns the product of its two operands. In the following statement, markUp is assigned the value 3:

markUp = 12 * 0.25;

The division operator returns the quotient of its left operand divided by its right operand. In the next statement, points is assigned the value 5:

points = 100 / 20;

It is important to note that when both of the division operator's operands are integers, the result of the division will also be an integer. If the result has a fractional part, it will be thrown away. We will discuss this behavior, which is known as *integer division*, in greater detail later in this section.

The modulus operator, which only works with integer operands, returns the remainder of an integer division. The following statement assigns 2 to leftOver:

leftOver = 17 % 3;

In Chapter 3 you will learn how to use these operators in more complex mathematical formulas. For now we will concentrate on their basic usage. For example, suppose we need to write a program that calculates and displays an employee's total wages for the week. The regular hours for the work week are 40, and any hours worked over 40 are considered overtime. The employee earns \$18.25 per hour for regular hours and \$27.78 per hour for overtime hours. The employee has worked 50 hours this week. The following pseudocode algorithm shows the program's logic.

Regular wages = base pay rate × regular hours Overtime wages = overtime pay rate × overtime hours Total wages = regular wages + overtime wages Display the total wages

Program 2-21 shows the C++ code for the program.

Program 2-21

```
// This program calculates hourly wages, including overtime.
 1
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
   int main()
 6
    {
 7
        double regularWages,
                                         // To hold regular wages
 8
               basePayRate = 18.25,
                                       // Base pay rate
               regularHours = 40.0,
 9
                                       // Hours worked less overtime
                                         // To hold overtime wages
10
               overtimeWages,
                overtimePayRate = 27.78, // Overtime pay rate
11
                overtimeHours = 10, // Overtime hours worked
12
                                         // To hold total wages
13
                totalWages;
14
        // Calculate the regular wages.
15
16
        regularWages = basePayRate * regularHours;
17
18
        // Calculate the overtime wages.
19
        overtimeWages = overtimePayRate * overtimeHours;
20
21
        // Calculate the total wages.
22
        totalWages = regularWages + overtimeWages;
23
24
        // Display the total wages.
25
        cout << "Wages for this week are $" << totalWages << endl;</pre>
26
        return 0;
27 }
```

Program Output

Wages for this week are \$1007.8

Let's take a closer look at the program. As mentioned in the comments, there are variables for regular wages, base pay rate, regular hours worked, overtime wages, overtime pay rate, overtime hours worked, and total wages.

Here is line 16, which multiplies basePayRate times regularHours and stores the result in regularWages:

regularWages = basePayRate * regularHours;

Here is line 19, which multiplies overtimePayRate times overtimeHours and stores the result in overtimeWages:

overtimeWages = overtimePayRate * overtimeHours;

Line 22 adds the regular wages and the overtime wages and stores the result in totalWages:

```
totalWages = regularWages + overtimeWages;
```

Line 25 displays the message on the screen reporting the week's wages.

Integer Division

When both operands of a division statement are integers, the statement will result in *integer division*. This means the result of the division will be an integer as well. If there is a remainder, it will be discarded. For example, look at the following code:

double number; number = 5 / 2;

This code divides 5 by 2 and assigns the result to the number variable. What will be stored in number? You would probably assume that 2.5 would be stored in number because that is the result your calculator shows when you divide 5 by 2. However, that is not what happens when the previous C++ code is executed. Because the numbers 5 and 2 are both integers, the fractional part of the result will be thrown away, or truncated. As a result, the value 2 will be assigned to the number variable.

In the previous code, it doesn't matter that the number variable is declared as a double because the fractional part of the result is discarded before the assignment takes place. In order for a division operation to return a floating-point value, one of the operands must be of a floating-point data type. For example, the previous code could be written as follows:

```
double number;
number = 5.0 / 2;
```

In this code, 5.0 is treated as a floating-point number, so the division operation will return a floating-point number. The result of the division is 2.5.

In the Spotlight:

Calculating Percentages and Discounts

Determining percentages is a common calculation in computer programming. Although the % symbol is used in general mathematics to indicate a percentage, most programming languages (including C++) do not use the % symbol for this purpose. In a program, you have to convert a percentage to a floating-point number, just as you would if you were using a calculator. For example, 50 percent would be written as 0.5 and 2 percent would be written as 0.02.

Let's look at an example. Suppose you earn \$6,000 per month and you are allowed to contribute a portion of your gross monthly pay to a retirement plan. You want to determine the amount of your pay that will go into the plan if you contribute 5 percent, 7 percent, or 10 percent of your gross wages. To make this determination you write the program shown in Program 2-22.

Program 2-22

```
// This program calculates the amount of pay that
 2 // will be contributed to a retirement plan if 5%,
 3
   // 7%, or 10% of monthly pay is withheld.
 4 #include <iostream>
 5 using namespace std;
 6
   int main()
 8
   {
9
        // Variables to hold the monthly pay and the
        // amount of contribution.
        double monthlyPay = 6000.0, contribution;
        // Calculate and display a 5% contribution.
        contribution = monthlyPay * 0.05;
14
        cout << "5 percent is $" << contribution</pre>
15
             << " per month.\n";
16
18
        // Calculate and display a 7% contribution.
19
        contribution = monthlyPay * 0.07;
        cout << "7 percent is $" << contribution
21
             << " per month.\n";
22
        // Calculate and display a 10% contribution.
24
        contribution = monthlyPay * 0.1;
        cout << "10 percent is $" << contribution
             << " per month.\n";
27
28
        return 0;
29 }
```

Program Output

5 percent is \$300 per month. 7 percent is \$420 per month. 10 percent is \$600 per month.

Line 11 defines two variables: monthlyPay and contribution. The monthlyPay variable, which is initialized with the value 6000.0, holds the amount of your monthly pay. The contribution variable will hold the amount of a contribution to the retirement plan.

The statements in lines 14 through 16 calculate and display 5 percent of the monthly pay. The calculation is done in line 14, where the monthlyPay variable is multiplied by 0.05. The result is assigned to the contribution variable, which is then displayed in line 15.

Similar steps are taken in Lines 18 through 21, which calculate and display 7 percent of the monthly pay, and lines 24 through 26, which calculate and display 10 percent of the monthly pay.

Calculating a Percentage Discount

Another common calculation is determining a percentage discount. For example, suppose a retail business sells an item that is regularly priced at \$59.95 and is planning to have a sale where the item's price will be reduced by 20 percent. You have been asked to write a program to calculate the sale price of the item.

To determine the sale price you perform two calculations:

- First, you get the amount of the discount, which is 20 percent of the item's regular price.
- Second, you subtract the discount amount from the item's regular price. This gives you the sale price.

Program 2-23 shows how this is done in C++.

Program 2-23

```
1
    // This program calculates the sale price of an item
 2
    // that is regularly priced at $59.95, with a 20 percent
 3
    // discount subtracted.
 4
    #include <iostream>
 5
    using namespace std;
 6
    int main()
 8
    {
 9
        // Variables to hold the regular price, the
        // amount of a discount, and the sale price.
11
        double regularPrice = 59.95, discount, salePrice;
12
        // Calculate the amount of a 20% discount.
14
        discount = regularPrice * 0.2;
15
16
        // Calculate the sale price by subtracting the
        // discount from the regular price.
        salePrice = regularPrice - discount;
18
19
        // Display the results.
20
        cout << "Regular price: $" << regularPrice << endl;</pre>
        cout << "Discount amount: $" << discount << endl;</pre>
23
        cout << "Sale price: $" << salePrice << endl;</pre>
24
        return 0;
25 }
```

Program Output

```
Regular price: $59.95
Discount amount: $11.99
Sale price: $47.96
```

Line 11 defines three variables. The regularPrice variable holds the item's regular price, and is initialized with the value 59.95. The discount variable will hold the amount of the discount once it is calculated. The salePrice variable will hold the item's sale price.

Line 14 calculates the amount of the 20 percent discount by multiplying regularPrice by 0.2. The result is stored in the discount variable. Line 18 calculates the sale price by subtracting discount from regularPrice. The result is stored in the salePrice variable. The cout statements in lines 21 through 23 display the item's regular price, the amount of the discount, and the sale price.

In the Spotlight:

Using the Modulus Operator and Integer Division

The modulus operator (\$) is surprisingly useful. For example, suppose you need to extract the rightmost digit of a number. If you divide the number by 10, the remainder will be the rightmost digit. For instance, $123 \div 10 = 12$ with a remainder of 3. In a computer program you would use the modulus operator to perform this operation. Recall that the modulus operator divides an integer by another integer, and gives the remainder. This is demonstrated in Program 2-24. The program extracts the rightmost digit of the number 12345.

Program 2-24

```
1
    // This program extracts the rightmost digit of a number.
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
    int main()
 6
    {
        int number = 12345;
 8
        int rightMost = number % 10;
 9
        cout << "The rightmost digit in "
             << number << " is "
11
             << rightMost << endl;
14
        return 0;
   }
```

Program Output

```
The rightmost digit in 12345 is 5
```

Interestingly, the expression number % 100 will give you the rightmost two digits in number, the expression number % 1000 will give you the rightmost three digits in number, etc.

The modulus operator (%) is useful in many other situations. For example, Program 2-25 converts 125 seconds to an equivalent number of minutes, and seconds.

Program 2-25

```
// This program converts seconds to minutes and seconds.
    #include <iostream>
    using namespace std;
 4
 5
   int main()
 6
    {
        // The total seconds is 125.
        int totalSeconds = 125;
 8
 0
        // Variables for the minutes and seconds
11
        int minutes, seconds;
13
        // Get the number of minutes.
14
        minutes = totalSeconds / 60;
15
16
        // Get the remaining seconds.
17
        seconds = totalSeconds % 60;
18
19
        // Display the results.
        cout << totalSeconds << " seconds is equivalent to:\n";</pre>
        cout << "Minutes: " << minutes << endl;</pre>
21
22
        cout << "Seconds: " << seconds << endl;</pre>
23
        return 0;
24 }
```

Program Output

125 seconds is equivalent to: Minutes: 2 Seconds: 5

Let's take a closer look at the code:

- Line 8 defines an int variable named totalSeconds, initialized with the value 125.
- Line 11 declares the int variables minutes and seconds.
- Line 14 calculates the number of minutes in the specified number of seconds. There are 60 seconds in a minute, so this statement divides totalSeconds by 60. Notice that we are performing integer division in this statement. Both totalSeconds and the numeric literal 60 are integers, so the division operator will return an integer result. This is intentional because we want the number of minutes with no fractional part.
- Line 17 calculates the number of remaining seconds. There are 60 seconds in a minute, so this statement uses the % operator to divide the totalSeconds by 60, and get the remainder of the division. The result is the number of remaining seconds.
- Lines 20 through 22 display the number of minutes and seconds.

🗸 Checkpoint

2.21 Is the following assignment statement valid or invalid? If it is invalid, why?

```
72 = \text{amount};
```

2.22 How would you consolidate the following definitions into one statement?

```
int x = 7;
int y = 16;
int z = 28;
```

2.23 What is wrong with the following program? How would you correct it?

```
#include <iostream>
using namespace std;
int main()
{
    number = 62.7;
    double number;
    cout << number << endl;
    return 0;
}</pre>
```

2.24 Is the following an example of integer division or floating-point division? What value will be stored in portion?

```
portion = 70 / 3;
```



CONCEPT: Comments are notes of explanation that document lines or sections of a program. Comments are part of the program, but the compiler ignores them. They are intended for people who may be reading the source code.

It may surprise you that one of the most important parts of a program has absolutely no impact on the way it runs. In fact, the compiler ignores this part of a program. Of course, I'm speaking of the comments.

As a beginning programmer, you might be resistant to the idea of liberally writing comments in your programs. After all, it can seem more productive to write code that actually does something! It is crucial, however, that you develop the habit of thoroughly annotating your code with descriptive comments. It might take extra time now, but it will almost certainly save time in the future.

Imagine writing a program of medium complexity with about 8,000 to 10,000 lines of C++ code. Once you have written the code and satisfactorily debugged it, you happily put it away and move on to the next project. Ten months later you are asked to make a modification to the program (or worse, track down and fix an elusive bug). You open the file that contains your source code and stare at thousands of statements that now make no sense at all. If only you had left some notes to yourself explaining the program's code. Of course it's too late now. All that's left to do is decide what will take less time: figuring out the old program or completely rewriting it!

This scenario might sound extreme, but it's one you don't want to happen to you. Realworld programs are big and complex. Thoroughly documented code will make your life easier, not to mention the other programmers who may have to read your code in the future.

Single-Line Comments

You have already seen one way to place comments in a C++ program. You simply place two forward slashes (//) where you want the comment to begin. The compiler ignores everything from that point to the end of the line. Program 2-26 shows that comments may be placed liberally throughout a program.

Program 2-26

```
// PROGRAM: PAYROLL.CPP
 1
 2
    // Written by Herbert Dorfmann
 3
    // This program calculates company payroll
    // Last modification: 8/20/2014
 4
 5
    #include <iostream>
 6
    using namespace std;
7
8
   int main()
9
    {
10
      double payRate;
                        // Holds the hourly pay rate
11
      double hours; // Holds the hours worked
12
      int employNumber; // Holds the employee number
```

(The remainder of this program is left out.)

In addition to telling who wrote the program and describing the purpose of variables, comments can also be used to explain complex procedures in your code.

Multi-Line Comments

The second type of comment in C++ is the multi-line comment. *Multi-line comments* start with /* (a forward slash followed by an asterisk) and end with */ (an asterisk followed by a forward slash). Everything between these markers is ignored. Program 2-27 illustrates how multi-line comments may be used. Notice that a multi-line comment starts in line 1 with the /* symbol, and it ends in line 6 with the */ symbol.

Program 2-27

```
1 /*
2 PROGRAM: PAYROLL.CPP
3 Written by Herbert Dorfmann
4 This program calculates company payroll
5 Last modification: 8/20/2014
6 */
7
8 #include <iostream>
```

```
9 using namespace std;
10
11 int main()
12 {
13 double payRate; // Holds the hourly pay rate
14 double hours; // Holds the hours worked
15 int employNumber; // Holds the employee number
(The remainder of this program is left out.)
```

Unlike a comment started with //, a multi-line comment can span several lines. This makes it more convenient to write large blocks of comments because you do not have to mark every line. Consequently, the multi-line comment is inconvenient for writing single-line

comments because you must type both a beginning and ending comment symbol.

NOTE: Many programmers use a combination of single-line comments and multi-line comments in their programs. Convenience usually dictates which style to use.

Remember the following advice when using multi-line comments:

- Be careful not to reverse the beginning symbol with the ending symbol.
- Be sure not to forget the ending symbol.

Both of these mistakes can be difficult to track down and will prevent the program from compiling correctly.

2.16 Named Constants

CONCEPT: Literals may be given names that symbolically represent them in a program.

Assume the following statement appears in a banking program that calculates data pertaining to loans:

```
amount = balance * 0.069;
```

In such a program, two potential problems arise. First, it is not clear to anyone other than the original programmer what 0.069 is. It appears to be an interest rate, but in some situations there are fees associated with loan payments. How can the purpose of this statement be determined without painstakingly checking the rest of the program?

The second problem occurs if this number is used in other calculations throughout the program and must be changed periodically. Assuming the number is an interest rate, what if the rate changes from 6.9 percent to 7.2 percent? The programmer will have to search through the source code for every occurrence of the number.

Both of these problems can be addressed by using named constants. A *named constant* is like a variable, but its content is read-only and cannot be changed while the program is running. Here is a definition of a named constant:

```
const double INTEREST_RATE = 0.069;
```

It looks just like a regular variable definition except that the word const appears before the data type name, and the name of the variable is written in all uppercase characters. The key word const is a qualifier that tells the compiler to make the variable read-only. Its value will remain constant throughout the program's execution. It is not required that the variable name be written in all uppercase characters, but many programmers prefer to write them this way so they are easily distinguishable from regular variable names.

An initialization value must be given when defining a constant with the const qualifier, or an error will result when the program is compiled. A compiler error will also result if there are any statements in the program that attempt to change the value of a named constant.

An advantage of using named constants is that they make programs more self-documenting. The following statement

amount = balance * 0.069;

can be changed to read

amount = balance * INTEREST_RATE;

A new programmer can read the second statement and know what is happening. It is evident that balance is being multiplied by the interest rate. Another advantage to this approach is that widespread changes can easily be made to the program. Let's say the interest rate appears in a dozen different statements throughout the program. When the rate changes, the initialization value in the definition of the named constant is the only value that needs to be modified. If the rate increases to 7.2%, the definition is changed to the following:

```
const double INTEREST RATE = 0.072;
```

The program is then ready to be recompiled. Every statement that uses INTEREST_RATE will then use the new value.

Named constants can also help prevent typographical errors in a program's code. For example, suppose you use the number 3.14159 as the value of pi in a program that performs various geometric calculations. Each time you type the number 3.14159 in the program's code, there is a chance that you will make a mistake with one or more of the digits. As a result, the program will not produce the correct results. To help prevent a mistake such as this, you can define a named constant for pi, initialized with the correct value, and then use that constant in all of the formulas that require its value. Program 2-28 shows an example. It calculates the circumference of a circle that has a diameter of 10.

Program 2-28

```
1 // This program calculates the circumference of a circle.
2 #include <iostream>
3 using namespace std;
4
5 int main()
6 {
7    // Constants
8    const double PI = 3.14159;
9    const double DIAMETER = 10.0;
10
11   // Variable to hold the circumference
```

```
12
        double circumference;
13
14
        // Calculate the circumference.
        circumference = PI * DIAMETER;
15
16
        // Display the circumference.
17
        cout << "The circumference is: " << circumference << endl;</pre>
18
19
        return 0;
20
    }
```

Program Output

The circumference is: 31.4159

Let's take a closer look at the program. Line 8 defines a constant double named PI, initialized with the value 3.14159. This constant will be used for the value of *pi* in the program's calculation. Line 9 defines a constant double named DIAMETER, initialized with the value 10. This will be used for the circle's diameter. Line 12 defines a double variable named circumference, which will be used to hold the circle's circumference. Line 15 calculates the circle's circumference by multiplying PI by DIAMETER. The result of the calculation is assigned to the circumference variable. Line 18 displays the circle's circumference.



Checkpoint

2.25 Write statements using the const qualifier to create named constants for the following literal values:

Literal Value	Description
2.71828	Euler's number (known in mathematics as e)
5.256E5	Number of minutes in a year
32.2	The gravitational acceleration constant (in feet per second ²)
9.8	The gravitational acceleration constant (in meters per second ²)
1609	Number of meters in a mile



2.17 Programming Style

CONCEPT: Programming style refers to the way a programmer uses identifiers, spaces, tabs, blank lines, and punctuation characters to visually arrange a program's source code. These are some, but not all, of the elements of programming style.

In Chapter 1 you learned that syntax rules govern the way a language may be used. The syntax rules of C++ dictate how and where to place key words, semicolons, commas, braces, and other components of the language. The compiler's job is to check for syntax errors and, if there are none, generate object code.

When the compiler reads a program it processes it as one long stream of characters. The compiler doesn't care that each statement is on a separate line, or that spaces separate operators from operands. Humans, on the other hand, find it difficult to read programs that aren't written in a visually pleasing manner. Consider Program 2-29 for example.

Program 2-29

- 1 #include <iostream>
- 2 using namespace std;int main(){double shares=220.0;
- 3 double avgPrice=14.67;cout<<"There were "<<shares</pre>
- 4 <<" shares sold at \$"<<avgPrice<<" per share.\n";</pre>
- 5 return 0;}

Program Output

There were 220 shares sold at \$14.67 per share.

Although the program is syntactically correct (it doesn't violate any rules of C++), it is very difficult to read. The same program is shown in Program 2-30, written in a more reasonable style.

Program 2-30

```
// This example is much more readable than Program 2-29.
 1
 2
    #include <iostream>
 3
    using namespace std;
 4
 5
   int main()
 6
    {
 7
         double shares = 220.0;
 8
        double avgPrice = 14.67;
 9
        cout << "There were " << shares << " shares sold at $";</pre>
10
11
        cout << avgPrice << " per share.\n";</pre>
12
        return 0;
13 }
```

Program Output

There were 220 shares sold at \$14.67 per share.

Programming style refers to the way source code is visually arranged. Ideally, it is a consistent method of putting spaces and indentions in a program so visual cues are created. These cues quickly tell a programmer important information about a program.

For example, notice in Program 2-30 that inside the function main's braces each line is indented. It is a common C++ style to indent all the lines inside a set of braces. You will also notice the blank line between the variable definitions and the cout statements. This is intended to visually separate the definitions from the executable statements.



NOTE: Although you are free to develop your own style, you should adhere to common programming practices. By doing so, you will write programs that visually make sense to other programmers.

Another aspect of programming style is how to handle statements that are too long to fit on one line. Because C++ is a free-flowing language, it is usually possible to spread a statement over several lines. For example, here is a cout statement that uses five lines:

```
cout << "The Fahrenheit temperature is "
    << fahrenheit
    << " and the Celsius temperature is "
    << celsius
    << endl;</pre>
```

This statement will work just as if it were typed on one line. Here is an example of variable definitions treated similarly:

```
int fahrenheit,
    celsius,
    kelvin;
```

There are many other issues related to programming style. They will be presented throughout the book.

Review Questions and Exercises

Short Answer

- 1. How many operands does each of the following types of operators require?
 - _____ Unary

_____ Binary

_____ Ternary

- 2. How may the double variables temp, weight, and age be defined in one statement?
- 3. How can the values of three variables length, breadth, and height be displayed using one statement, such that each variable is displayed in a new line?
- 4. Assume that x is an integer variable, y is a floating point variable, and z is a character variable. Write statements in C++ to perform the following operations:
 - A) Add 10 to x.
 - B) Square the value of y.
 - C) Divide x by 7 and store the result in y.
 - D) Store '&' in z.
 - E) Display the values of y and z on the screen.
 - F) Display the rightmost digit of x on the screen.
 - G) Display the number of bytes used by an integer variable.
- 5. Is the following comment written using single-line or multi-line comment symbols?
 - /* This program was written by M. A. Codewriter*/
- 6. Is the following comment written using single-line or multi-line comment symbols?
 - // This program was written by M. A. Codewriter