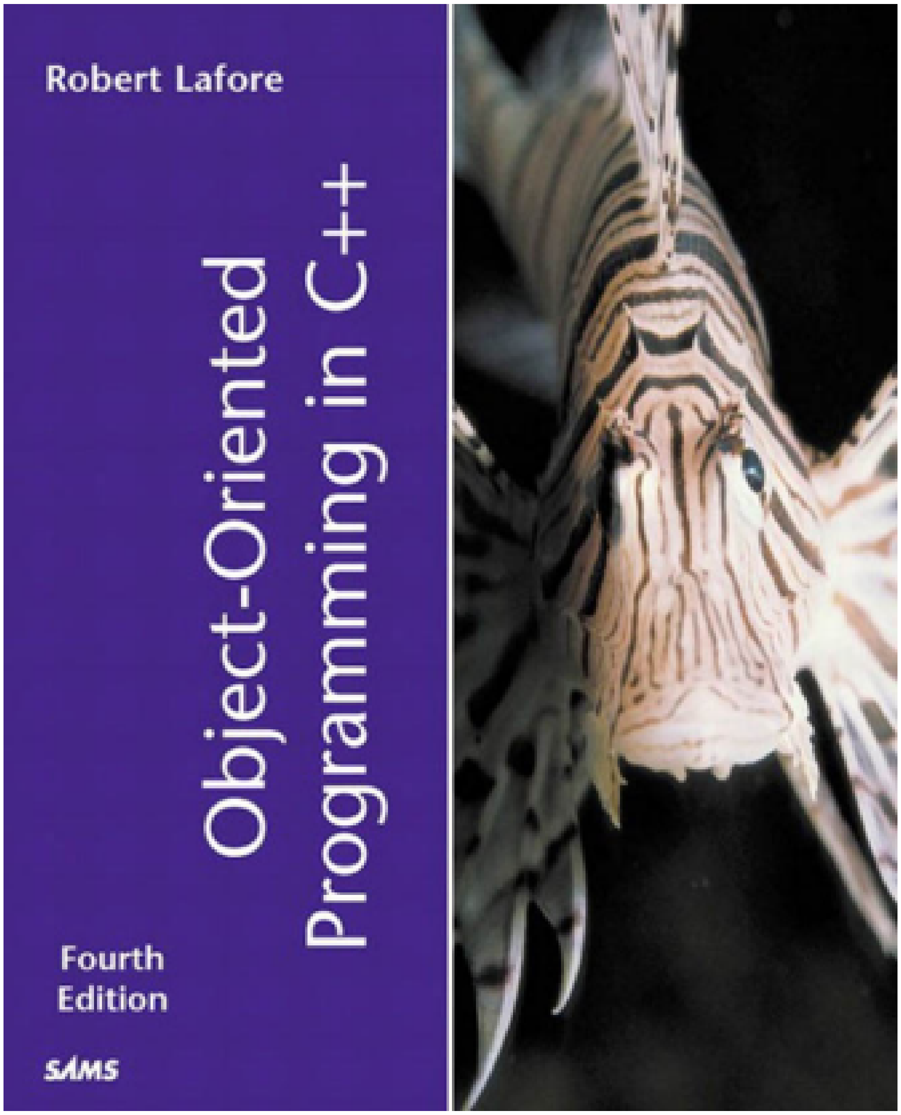

Object-Oriented Programming in C++, Fourth Edition

Robert Lafore

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Overview

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Preface

The major changes to this Fourth Edition include an earlier introduction to UML, a new section on inter-file communication in Chapter 13, and a revised approach to software develop ment in Chapter 16.

Introducing the UML at the beginning allows the use of UML diagrams where they fit naturally with topics in the text, so there are many new UML diagrams throughout the book. The section on inter-file communication gathers together many concepts that were previously scattered throughout the book. The industry's approach to object-oriented analysis and design has evolved since the last edition, and accordingly we've modified the chapter on this topic to reflect recent developments.

C++ itself has changed very little since the last edition. However, besides the revisions just mentioned, we've made many smaller changes to clarify existing topics and correct typos and inaccuracies in the text.

About the Author

Robert Lafore has been writing books about computer programming since 1982. His best selling titles include *Assembly Language Programming for the IBM PC*, *C Programming Using Turbo C++*, *C++ Interactive Course*, and *Data Structures and Algorithms in Java*. Mr. Lafore holds degrees in mathematics and electrical engineering, and has been active in programming since the days of the PDP-5, when 4K of main memory was considered luxurious. His interests include hiking, windsurfing, and recreational mathematics.

Dedication

This book is dedicated to GGL and her indomitable spirit.

Acknowledgments to the Fourth Edition

My thanks to many readers who e-mailed comments and corrections. I am also indebted to the following professors of computer science who offered their suggestions and corrections: Bill Blomberg of Regis University in Denver; Richard Daehler-Wilking of the College of Charleston in South Carolina; Frank Hoffmann of the Royal Institute of Technology in Sweden, and David Blockus of San Jose State University in California. My special thanks to David Topham of Ohlone College in Fremont, California, for his many detailed ideas and his sharp eye for problems.

At Sams Publishing, Michael Stephens provided an expert and friendly liaison with the details of publishing. Reviewer Robin Rowe and Technical Editor Mark Cashman attempted with great care to save me from myself; any lack of success is entirely my fault. Project Manager Christina Smith made sure that everything came together in an amazingly short time, Angela Boley helped keep everything moving smoothly, and Matt Wynalda provided expert proofread ing. I'm grateful to you all.

Acknowledgments to the Third Edition

I'd like to thank the entire team at MacMillan Computer Publishing. In particular, Tracy Dunkelberger ably spearheaded the entire project and exhibited great patience with what turned out to be a lengthy schedule. Jeff Durham handled the myriad details involved in inter facing between me and the editors with skill and good humor. Andrei Kossorouko lent his expertise in C++ to ensure that I didn't make this edition worse instead of better.

Acknowledgments to the Second Edition

My thanks to the following professors—users of this book as a text at their respective colleges and universities—for their help in planning the second edition: Dave Bridges, Frank Cioch, Jack Davidson, Terrence Fries, Jimmie Hattemer, Jack Van Luik, Kieran Mathieson, Bill McCarty, Anita Millspaugh, Ian Moraes, Jorge Prendes, Steve Silva, and Edward Wright.

I would like to thank the many readers of the first edition who wrote in with corrections and suggestions, many of which were invaluable.

At Waite Group Press, Joanne Miller has ably ridden herd on my errant scheduling and filled in as academic liaison, and Scott Calamar, as always, has made sure that everyone knew what they were doing. Deirdre Greene provided an uncannily sharp eye as copy editor.

Thanks, too, to Mike Radtke and Harry Henderson for their expert technical reviews.

Special thanks to Edward Wright, of Western Oregon State College, for reviewing and experi menting with the new exercises.

Acknowledgments to the First Edition

My primary thanks go to Mitch Waite, who poured over every inch of the manuscript with painstaking attention to detail and made a semi-infinite number of helpful suggestions.

Bill McCarty of Azusa Pacific University reviewed the content of the manuscript and its suit ability for classroom use, suggested many excellent improvements, and attempted to correct my dyslexic spelling.

George Leach ran all the programs, and, to our horror, found several that didn't perform cor rectly in certain circumstances. I trust these problems have all been fixed; if not, the fault is entirely mine.

Scott Calamar of the Waite Group dealt with the myriad organizational aspects of writing and producing this book. His competence and unfailing good humor were an important ingredient in its completion.

I would also like to thank Nan Borreson of Borland for supplying the latest releases of the software (among other useful tidbits), Harry Henderson for reviewing the exercises, Louise Orlando of the Waite Group for ably shepherding the book through production, Merrill Peterson of Matrix Productions for coordinating the most trouble-free production run I've ever been involved with, Juan Vargas for the innovative design, and Frances Hasegawa for her uncanny ability to decipher my sketches and produce beautiful and effective art.

Tell Us What You Think!

As the reader of this book, *you* are our most important critic and commentator. We value your opinion and want to know what we're doing right, what we could do better, what areas you'd like to see us publish in, and any other words of wisdom you're willing to pass our way.

As an executive editor for Sams Publishing, I welcome your comments. You cane-mail or write me directly to let me know what you did or didn't like about this book—as well as what we can do to make our books stronger.

Please note that I cannot help you with technical problems related to the topic of this book, and that due to the high volume of mail I receive, I might not be able to reply to every mes sage.

When you write, please be sure to include this book's title and author's name as well as your name and phone or fax number. I will carefully review your comments and share them with the author and editors who worked on the book.

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Introduction

This book teaches you how to write programs in a the C++ programming language. However, it does more than that. In the past few years, several major innovations in software develop ment have appeared on the scene. This book teaches C++ in the context of these new develop ments. Let's see what they are.

Programming Innovations

In the old days, 20 or so years ago, programmers starting a project would sit down almost immediately and start writing code. However, as programming projects became large and more complicated, it was found that this approach did not work very well. The problem was com plexity.

Large programs are probably the most complicated entities ever created by humans. Because of this complexity, programs are prone to error, and software errors can be expensive and even life threatening (in air traffic control, for example). Three major innovations in programming have been devised to cope with the problem of complexity. They are

- Object-oriented programming (OOP)
- The Unified Modeling Language (UML)
- Improved software development processes

This book teaches the C++ language with these developments in mind. You will not only learn a computer language, but new ways of conceptualizing software development.

Object-Oriented Programming

Why has object-oriented programming become the preferred approach for most software pro jects? OOP offers a new and powerful way to cope with complexity. Instead of viewing a pro gram as a series of steps to be carried out, it views it as a group of objects that have certain properties and can take certain actions. This may sound obscure until you learn more about it, but it results in programs that are clearer, more reliable, and more easily maintained.

A major goal of this book is to teach object-oriented programming. We introduce it as early as possible, and cover all its major features. The majority of our example programs are object oriented.

The Unified Modeling Language

The Unified Modeling Language (UML) is a graphical language consisting of many kinds of diagrams. It helps program analysts figure out what a program should do, and helps program mers design and understand how a program works. The UML is a powerful tool that can make programming easier and more effective.

We give an overview of the UML in Chapter 1, and then discuss specific features of the UML throughout the book. We introduce each UML feature where it will help to clarify the OOP topic being discussed. In this way you learn the UML painlessly at the same time the UML helps you to learn C++.

Languages and Development Platforms

Of the object-oriented programming languages, C++ is by far the most widely used. Java, a recent addition to the field of OO languages, lacks certain features—such as pointers, tem plates, and multiple inheritance—that make it less powerful and versatile than C++. (If you ever do want to learn Java, its syntax is very similar to that of C++, so learning C++ gives you a head start in Java.)

Several other OO languages have been introduced recently, such as C#, but they have not yet attained the wide acceptance of C++.

Until recently the standards for C++ were in a constant state of evolution. This meant that each compiler vendor handled certain details differently. However, in November 1997, the ANSI/ISO C++ standards committee approved the final draft of what is now known as Standard C++. (ANSI stands for American National Standards Institute, and ISO stands for International Standards Institute.) Standard C++ adds many new features to the language, such as the Standard Template Library (STL). In this book we follow Standard C++ (in all but a few places, which we'll note as we go along).

The most popular development environments for C++ are manufactured by Microsoft and Borland (Inprise) and run on the various flavors of Microsoft Windows. In this book we've attempted to ensure that all sample programs run on the current versions of both Borland and Microsoft compilers. (See Appendix C, "Microsoft Visual C++," and Appendix D, "Borland C++Builder," for more on these compilers.)

What This Book Does

This book teaches object-oriented programming with the C++ programming language, using either Microsoft or Borland compilers. It also introduces the UML and software development processes. It is suitable for professional programmers, students, and kitchen-table enthusiasts.

New Concepts

OOP involves concepts that are new to programmers of traditional languages such as Pascal, Basic, and C. These ideas, such as classes, inheritance, and polymorphism, lie at the heart of object-oriented programming. But it's easy to lose sight of these concepts when discussing the specifics of an object-oriented language. Many books overwhelm the reader with the details of language features, while ignoring the reason these features exist. This book attempts to keep an eye on the big picture and relate the details to the larger concepts.

The Gradual Approach

We take a gradual approach in this book, starting with very simple programming examples and working up to full-fledged object-oriented applications. We introduce new concepts slowly so that you will have time to digest one idea before going on to the next. We use illustrations whenever possible to help clarify new ideas. There are questions and programming exercises at the end of most chapters to enhance the book's usefulness in the classroom. Answers to the questions and to the first few (starred) exercises can be found in Appendix G. The exercises vary in difficulty to pose a variety of challenges for the student.

What You Need to Know to Use This Book

You can use this book even if you have no previous programming experience. However, such experience, in Visual Basic for example, certainly won't hurt.

You do not need to know the C language to use this book. Many books on C++ assume that you already know C, but this one does not. It teaches C++ from the ground up. If you do know C, it won't hurt, but you may be surprised at how little overlap there is between C and C++.

You should be familiar with the basic operations of Microsoft Windows, such as starting appli cations and copying files.

Software and Hardware

You will need a C++ compiler. The programs in this book have been tested with Microsoft Visual C++ and Borland C++Builder. Both compilers come in low-priced "Learning Editions" suitable for students.

Appendix C provides detailed information on operating the Microsoft compiler, while Appendix D does the same for the Inprise (Borland) product. Other compilers, if they adhere to Standard C++, will probably handle most of the programs in this book as written.

Your computer should have enough processor speed, memory, and hard disk space to run the compiler you've chosen. You can check the manufacturer's specifications to determine these requirements.

Console-Mode Programs

There are numerous example programs throughout the book. They are console-mode programs, which run in a character-mode window within the compiler environment, or directly within an MS-DOS box. This avoids the complexity of full-scale graphics-oriented Windows programs.

Example Program Source Code

You can obtain the source code for the example programs from the Sams Publishing Web site

at http://www.samspublishing.com

Type the ISBN (found at the front of the book) or the book's title and click Search to find the data on this book. Then click Source Code to download the program examples.

Console Graphics Lite

A few example programs draw pictures using a graphics library we call Console Graphics Lite. The graphics rely on console characters, so they are not very sophisticated, but they allow some interesting programs. The files for this library are provided on the publisher's Web site, along with the source files for the example programs.

To compile and run these graphics examples, you'll need to include a header file in your pro gram, either MSOFTCON.H or BORLACON.H, depending on your compiler. You'll also need to add either MSOFTCON.CPP or BORLACON.CPP to the project for the graphics example. Appendix E, "Console Graphics Lite," provides listings of these files and tells how to use them. Appendixes C and D explain how to work with files and projects in a specific compiler's environment.

Programming Exercises

Each chapter contains roughly 12 exercises, each requiring the creation of a complete C++ program. Solutions for the first three or four exercises in each chapter are provided in Appendix G. For the remainder of the exercises, readers are on their own. (However, if you are teaching a C++ course, see the "Note to Teachers" at the end of this Introduction.)

Easier Than You Think

You may have heard that C++ is difficult to learn, but it's really quite similar to other lan guages, with two or three "grand ideas" thrown in. These new ideas are fascinating in them selves, and we think you'll have fun learning about them. They are also becoming part of the programming culture; they're something everyone should know a little bit about, like evolution and psychoanalysis. We hope this book will help you enjoy learning about these new ideas, at the same time that it teaches you the details of programming in C++.

A Note to Teachers

Teachers, and others who already know something about C++ or C, may be interested in some details of the approach we use in this book and how it's organized.

Standard C++

All the programs in this book are compatible with Standard C++, with a few minor exceptions that are needed to accommodate compiler quirks. We devote a chapter to the STL (Standard Template Library), which is included in Standard C++.

The Unified Modeling Language (UML)

In the previous edition, we introduced the UML in the final chapter. In this edition we have integrated the UML into the body of the book, introducing UML topics in appropriate places. For example, UML class diagrams are introduced where we first show different classes com municating, and generalization is covered in the chapter on inheritance.

Chapter 1, "The Big Picture," includes a list showing where the various UML topics are intro duced.

Software Development Processes

Formal software development processes are becoming an increasingly important aspect of pro gramming. Also, students are frequently mystified by the process of designing an object oriented program. For these reasons we include a chapter on software development processes, with an emphasis on object-oriented programming. In the last edition we focused on CRC cards, but the emphasis in software development has shifted more in the direction of use case analysis, so we use that to analyze our programming projects.

C++ Is Not the Same as C

A few institutions still want their students to learn C before learning C++. In our view this is a mistake. C and C++ are entirely separate languages. It's true that their syntax is similar, and C is actually a subset of C++. But the similarity is largely a historical accident. In fact, the basic approach in a C++ program is radically different from that in a C program.

C++ has overtaken C as the preferred language for serious software development. Thus we don't believe it is necessary or advantageous to teach C before teaching C++. Students who don't know C are saved the time and trouble of learning C and then learning C++, an ineffi cient approach. Students who already know C may be able to skim parts of some chapters, but they will find that a remarkable percentage of the material is new.

Optimize Organization for OOP

We could have begun the book by teaching the procedural concepts common to C and C++, and moved on to the new OOP concepts once the procedural approach had been digested. That seemed counterproductive, however, because one of our goals is to begin true object-oriented programming as quickly as possible. Accordingly, we provide a minimum of procedural groundwork before getting to classes in Chapter 6. Even the initial chapters are heavily steeped in C++, as opposed to C, usage.

We introduce some concepts earlier than is traditional in books on C. For example, structures are a key feature for understanding C++ because classes are syntactically an extension of struc tures. For this reason, we introduce structures in Chapter 5 so that they will be familiar when we discuss classes.

Some concepts, such as pointers, are introduced later than in traditional C books. It's not nec essary to understand pointers to follow the essentials of OOP, and pointers are usually a stum bling block for C and C++ students. Therefore, we defer a discussion of pointers until the main concepts of OOP have been thoroughly digested.

Substitute Superior C++ Features

Some features of C have been superseded by new approaches in C++. For instance, the printf() and scanf() functions, input/output workhorses in C, are seldom used in C++ because cout and cin do a better job. Consequently, we leave out descriptions of these func tions. Similarly, #define constants and macros in C have been largely superseded by the const qualifier and inline functions in C++, and need be mentioned only briefly.

Minimize Irrelevant Capabilities

Because the focus in this book is on object-oriented programming, we can leave out some fea tures of C that are seldom used and are not particularly relevant to OOP. For instance, it isn't necessary to understand the C bit-wise operators (used to operate on individual bits) to learn object-oriented programming. These and a few other features can be dropped from our discus sion, or mentioned only briefly, with no loss in understanding of the major features of C++.

The result is a book that focuses on the fundamentals of OOP, moving the reader gently but briskly toward an understanding of new concepts and their application to real programming problems.

Programming Exercises

No answers to the unstarred exercises are provided in this book. However, qualified instructors can obtain suggested solutions from the Sams Publishing Web site. Type the ISBN or title and click Search to move to this book's page, then click Downloads.

The exercises vary considerably in their degree of difficulty. In each chapter the early exercises are fairly easy, while later ones are more challenging. Instructors will probably want to assign only those exercises suited to the level of a particular class.

CHAPTER 1 The Big Picture

IN THIS CHAPTER

This book teaches you how to program in C++, a computer language that supports *object oriented programming* (*OOP*). Why do we need OOP? What does it do that traditional lan guages such as C, Pascal, and BASIC don't? What are the principles behind OOP? Two key concepts in OOP are *objects* and *classes*. What do these terms mean? What is the relationship between C++ and the older C language?

This chapter explores these questions and provides an overview of the features to be discussed in the balance of the book. What we say here will necessarily be rather general (although mer cifully brief). If you find the discussion somewhat abstract, don't worry. The concepts we men tion here will come into focus as we demonstrate them in detail in subsequent chapters.

Why Do We Need Object-Oriented Programming?

Object-oriented programming was developed because limitations were discovered in earlier approaches to programming. To appreciate what OOP does, we need to under stand what these limitations are and how they arose from traditional programming languages.

Procedural Languages

C, Pascal, FORTRAN, and similar languages are *procedural languages*. That is, each statement in the language tells the computer to do something: Get some input, add these numbers, divide by six, display that output. A program in a procedural language is a list of instructions.

For very small programs, no other organizing principle (often called a *paradigm*) is needed. The programmer creates the list of instructions, and the computer carries them out.

Division into Functions

When programs become larger, a single list of instructions becomes unwieldy. Few programmers can comprehend a program of more than a few hundred statements unless it is broken down into smaller units. For this reason the *function* was adopted as a way to make programs more comprehensible to their human creators. (The term function is used in C++ and C. In other languages the same concept may be referred to as a subroutine, a subprogram, or a procedure.) A procedural program is divided into functions, and (ideally, at least) each function has a clearly defined purpose and a clearly defined interface to the other functions in the program.

The idea of breaking a program into functions can be further extended by grouping a number

of functions together into a larger entity called a *module* (which is often a file), but the princi ple is similar: a grouping of components that execute lists of instructions.

Dividing a program into functions and modules is one of the cornerstones of *structured pro gramming*, the somewhat loosely defined discipline that influenced programming organization for several decades before the advent of object-oriented programming.

Problems with Structured Programming

As programs grow ever larger and more complex, even the structured programming approach begins to show signs of strain. You may have heard about, or been involved in, horror stories of program development. The project is too complex, the schedule slips, more programmers are added, complexity increases, costs skyrocket, the sched ule slips further, and disaster ensues. (See *The Mythical Man-Month* by Frederick P. Brooks, Jr. [Addison Wesley, 1982] for a vivid description of this process.)

Analyzing the reasons for these failures reveals that there are weaknesses in the procedural paradigm itself. No matter how well the structured programming approach is implemented, large programs become excessively complex.

What are the reasons for these problems with procedural languages? There are two related problems. First, functions have unrestricted access to global data. Second, unrelated functions and data, the basis of the procedural paradigm, provide a poor model of the real world.

Let's examine these problems in the context of an inventory program. One important global data item in such a program is the collection of items in the inventory. Various functions access this data to input a new item, display an item, modify an item, and so on.

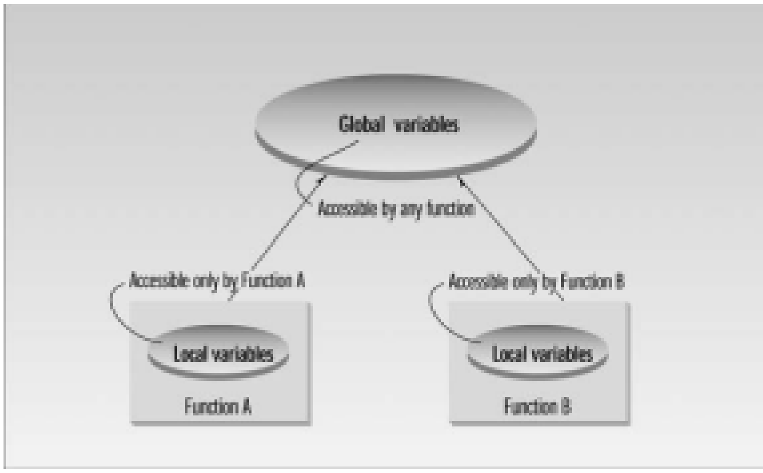
Unrestricted Access

In a procedural program, one written in C for example, there are two kinds of data.

Local data is hidden inside a function, and is used exclusively by the function. In the inventory program a display function might use local data to remember which item it was displaying. Local data is closely related to its function and is safe from modifica tion by other functions.

However, when two or more functions must access the same data—and this is true of the most important data in a program—then the data must be made *global*, as our collection of inven tory items is. Global data can be accessed by *any* function in the program. (We ignore the issue of grouping functions into modules, which doesn't materially affect our argument.) The arrangement of local and global variables in a procedural program is shown in Figure 1.1.

FIGURE 1.1


Global variables
Accessible by any function
Accessible only by Function A
Accessible only by Function B
Local variables
Function A
Local variables
Function B

Global and local variables.

In a large program, there are many functions and many global data items. The problem with the procedural paradigm is that this leads to an even larger number of potential connections between functions and data, as shown in Figure 1.2.

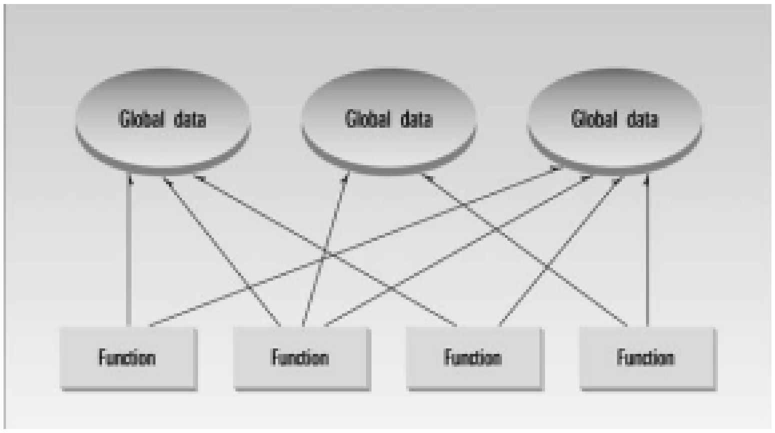


FIGURE 1.2
The procedural paradigm.

This large number of connections causes problems in several ways. First, it makes a program's structure difficult to conceptualize. Second, it makes the program difficult to modify. A change made in a global data item may necessitate rewriting all the functions that access that item.

For example, in our inventory program, someone may decide that the product codes for the inventory items should be changed from 5 digits to 12 digits. This may necessitate a change from a short to a long data type.

Now all the functions that operate on the data must be modified to deal with a long instead of a short. It's similar to what happens when your local supermarket moves the bread from aisle 4 to aisle 7. Everyone who patronizes the supermarket must then figure out where the bread has gone, and adjust their shopping habits accordingly.

When data items are modified in a large program it may not be easy to tell which functions access the data, and even when you figure this out, modifications to the functions may cause them to work incorrectly with other global data items. Everything is related to everything else, so a modification anywhere has far-reaching, and often unintended, consequences.

Real-World Modeling

The second—and more important—problem with the procedural paradigm is that its arrangement of separate data and functions does a poor job of modeling things in the real world. In the physical world we deal with objects such as people and cars. Such objects aren't like data and they aren't like functions. Complex real-world objects have both *attributes* and *behavior*.

Attributes

Examples of attributes (sometimes called *characteristics*) are, for people, eye color and job title; and, for cars, horsepower and number of doors. As it turns out, attributes in the real world are equivalent to data in a program: they have a certain specific val ues, such as blue (for eye color) or four (for the number of doors).

Behavior

Behavior is something a real-world object does in response to some stimulus. If you ask your boss for a raise, she will generally say yes or no. If you apply the brakes in a car, it will generally stop. Saying something and stopping are examples of behavior. Behavior is like a function: you call a function to do something (display the inventory, for example) and it does it.

So neither data nor functions, by themselves, model real-world objects effectively.

The Object-Oriented Approach

The fundamental idea behind object-oriented languages is to combine into a single unit both *data* and the *functions that operate on that data*. Such a unit is called an *object*.

An object's functions, called *member functions* in C++, typically provide the only way to access its data. If you want to read a data item in an object, you call a member function in the object. It will access the data and return the value to you. You can't access the data directly. The data is *hidden*, so it is safe from accidental alteration. Data and its functions are said to be *encapsulated* into a single entity. *Data encapsulation* and *data hiding* are key terms in the description of object-oriented languages.

If you want to modify the data in an object, you know exactly what functions interact with it: the member functions in the object. No other functions can access the data. This simplifies writing, debugging, and maintaining the program.

A C++ program typically consists of a number of objects, which communicate with each other by calling one another's member functions. The organization of a C++ program is shown in Figure 1.3.

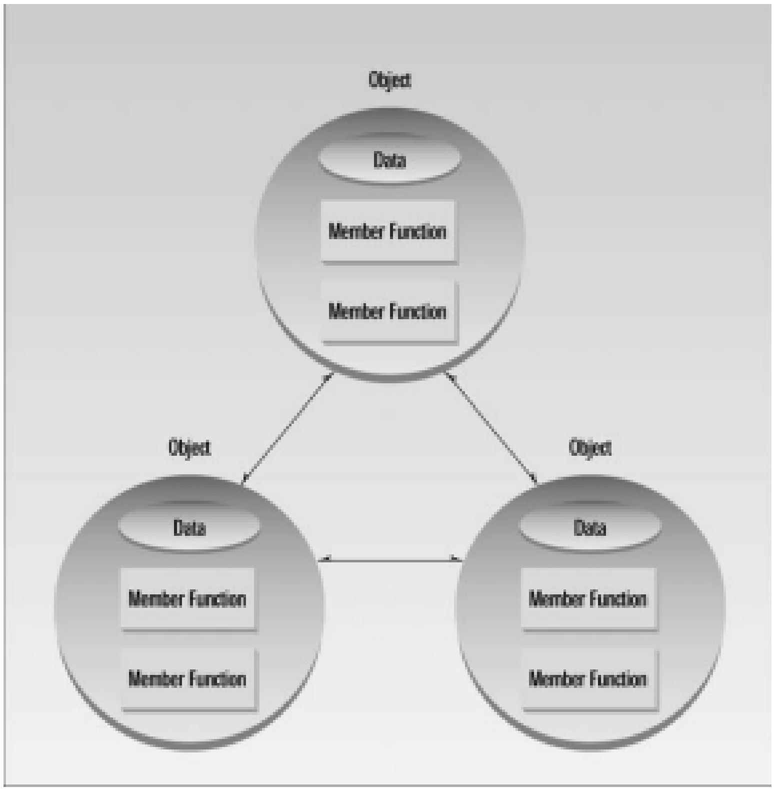


FIGURE 1.3
The object-oriented paradigm.

We should mention that what are called member functions in C++ are called *methods* in some

other object-oriented (OO) languages (such as Smalltalk, one of the first OO languages). Also, data items are referred to as *attributes* or *instance variables*. Calling an object's member func tion is referred to as *sending a message* to the object. These terms are not official C++ termi

nology, but they are used with increasing frequency, especially in object-oriented design.

An Analogy

You might want to think of objects as departments—such as sales, accounting, per sonnel, and so on—in a company. Departments provide an important approach to cor porate organization. In most companies (except very small ones), people don't work on personnel problems one day, the payroll the next, and then go out in the field as salespeople the week after. Each department has its own personnel, with clearly assigned duties. It also has its own data: the accounting department has payroll fig ures, the sales department has sales figures, the personnel department keeps records of each employee, and so on.

The people in each department control and operate on that department's data. Dividing the company into departments makes it easier to comprehend and control the company's activities, and helps maintain the integrity of the information used by the company. The accounting department, for instance, is responsible for the payroll data. If you're a sales manager, and you need to know the total of all the salaries paid in the southern region in July, you don't just walk into the accounting department and start rummaging through file cabinets. You send a memo to the appropriate person in the department, then wait for that person to access the data and send you a reply with the information you want. This ensures that the data is accessed accurately and that it is not corrupted by inept outsiders. This view of corporate organization is shown in Figure 1.4. In the same way, objects provide an approach to program organization while help ing to maintain the integrity of the program's data.

OOP: An Approach to Organization

Keep in mind that object-oriented programming is not primarily concerned with the details of program operation. Instead, it deals with the overall organization of the pro gram. Most individual program statements in C++ are similar to statements in proce dural languages, and many are identical to statements in C. Indeed, an entire member function in a C++ program may be very similar to a procedural function in C. It is only when you look at the larger context that you can determine whether a statement or a function is part of a procedural C program or an object-oriented C++ program.

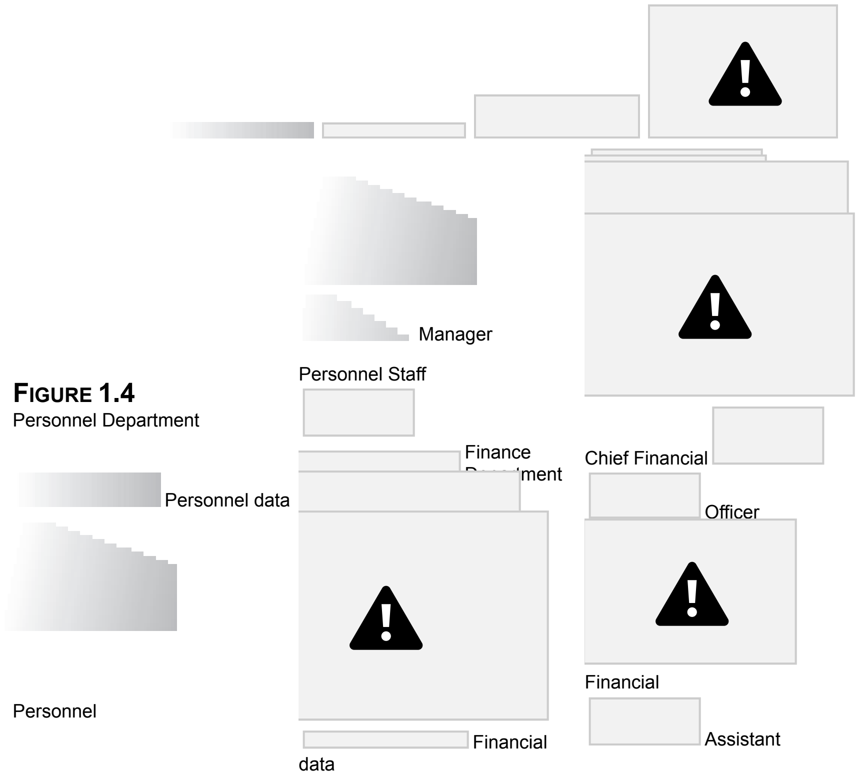


FIGURE 1.4
Personnel Department

The corporate paradigm.

Characteristics of Object-Oriented Languages

Let's briefly examine a few of the major elements of object-oriented languages in general, and C++ in particular.

Objects

When you approach a programming problem in an object-oriented language, you no longer ask how the problem will be divided into functions, but how it will be divided into objects. Thinking in terms of objects, rather than functions, has a surprisingly helpful effect on how easily programs can be designed. This results from the close match between objects in the programming sense and objects in the real world. This process is described in detail in Chapter 16, "Object-Oriented Software Development."

What kinds of things become objects in object-oriented programs? The answer to this is limited only by your imagination, but here are some typical categories to start you thinking:

- **Physical objects**

  Automobiles in a traffic-flow simulation

  Electrical components in a circuit-design program

  Countries in an economics model

  Aircraft in an air traffic control system

- **Elements of the computer-user environment**

  Windows

  Menus

  Graphics objects (lines, rectangles, circles)

  The mouse, keyboard, disk drives, printer

- **Data-storage constructs**

  Customized arrays

  Stacks

  Linked lists

  Binary trees

- **Human entities**

  Employees

  Students

  Customers

  Salespeople

- **Collections of data**

  An inventory

  A personnel file

  A dictionary

  A table of the latitudes and longitudes of world cities

- **User-defined data types**

  Time

  Angles

  Complex numbers

  Points on the plane

- **Components in computer games**

  Cars in an auto race

  Positions in a board game (chess, checkers)

Animals in an ecological simulation

Opponents and friends in adventure games

The match between programming objects and real-world objects is the happy result of combin ing data and functions: The resulting objects offer a revolution in program design. No such close match between programming constructs and the items being modeled exists in a procedural language.

Classes

In OOP we say that objects are members of *classes*. What does this mean? Let's look at an analogy. Almost all computer languages have built-in data types. For instance, a data type int, meaning integer, is predefined in C++ (as we'll see in Chapter 3, "Loops and Decisions"). You can declare as many variables of type int as you need in your program:

```
int day;
int count;
int divisor;
int answer;
```

In a similar way, you can define many objects of the same class, as shown in Figure 1.5. A class serves as a plan, or blueprint. It specifies what data and what functions will be included in objects of that class. Defining the class doesn't create any objects, just as the mere existence of data type int doesn't create any variables.

A class is thus a description of a number of similar objects. This fits our non-technical under standing of the word *class*. Prince, Sting, and Madonna are members of the rock musician class. There is no one person called "rock musician," but specific people with specific names are members of this class if they possess certain characteristics. An object is often called an "instance" of a class.

Inheritance

The idea of classes leads to the idea of *inheritance*. In our daily lives, we use the con cept of classes divided into subclasses. We know that the animal class is divided into mammals, amphibians, insects, birds, and so on. The vehicle class is divided into cars, trucks, buses, motorcycles, and so on.

FIGURE 1.5

A class and its objects.

The principle in this sort of division is that each subclass shares common characteristics with the class from which it's derived. Cars, trucks, buses, and motorcycles all have wheels and a motor; these are the defining characteristics of vehicles. In addition to the characteristics shared with other members of the class, each subclass also has its own particular characteris tics: Buses, for instance, have seats for many people, while trucks have space for hauling heavy loads.

This idea is shown in Figure 1.6. Notice in the figure that features A and B, which are part of the base class, are common to all the derived classes, but that each derived class also has fea tures of its own.

Inheritance.

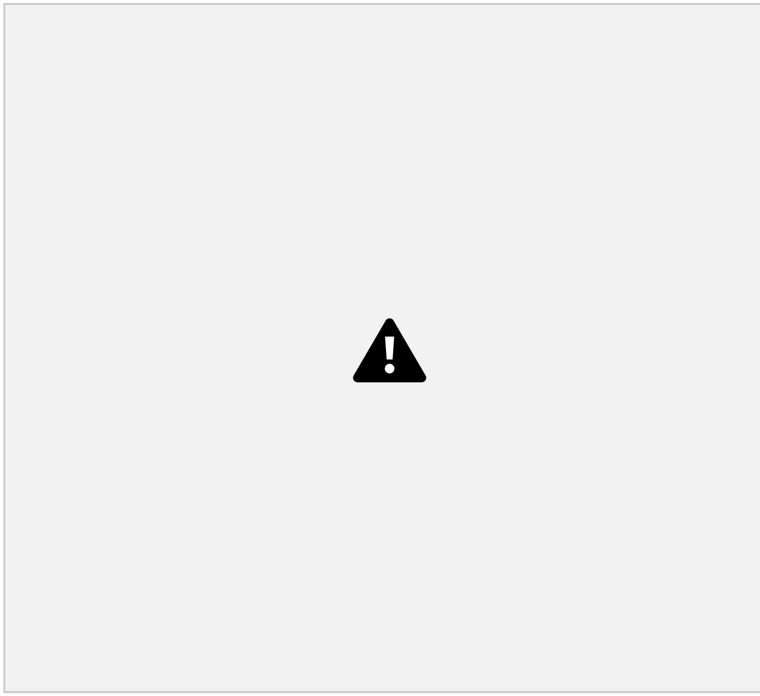


FIGURE 1.6

In a similar way, an OOP class can become a parent of several subclasses. In C++ the original class is called the *base class*; other classes can be defined that share its characteristics, but add their own as well. These are called *derived classes*.

Don't confuse the relation of objects to classes, on the one hand, with the relation of a base class to derived classes, on the other. Objects, which exist in the computer's memory, each embody the exact characteristics of their class, which serves as a template. Derived classes inherit some characteristics from their base class, but add new ones of their own.

Inheritance is somewhat analogous to using functions to simplify a traditional procedural pro gram. If we find that three different sections of a procedural program do almost exactly the same thing, we recognize an opportunity to extract the common elements of these three sec tions and put them into a single function. The three sections of the program can call the func tion to execute the common actions, and they can perform their own individual processing as well. Similarly, a base class contains elements common to a group of derived classes. As func tions do in a procedural program, inheritance shortens an object-oriented program and clarifies the relationship among program elements.

Reusability

Once a class has been written, created, and debugged, it can be distributed to other programmers for use in their own programs. This is called *reusability*. It is similar to

the way a library of functions in a procedural language can be incorporated into dif

ferent programs.

However, in OOP, the concept of inheritance provides an important extension to the idea of

reusability. A programmer can take an existing class and, without modifying it, add additional features and capabilities to it. This is done by deriving a new class from the existing one. The new class will inherit the capabilities of the old one, but is free to add new features of its own.

For example, you might have written (or purchased from someone else) a class that creates a menu system, such as that used in Windows or other Graphic User Interfaces (GUIs). This class works fine, and you don't want to change it, but you want to add the capability to make some menu entries flash on and off. To do this, you simply create a new class that inherits all the capabilities of the existing one but adds flashing menu entries.

The ease with which existing software can be reused is an important benefit of OOP. Many companies find that being able to reuse classes on a second project provides an increased return on their original programming investment. We'll have more to say about this in later chapters.

Creating New Data Types

One of the benefits of objects is that they give the programmer a convenient way to construct new data types. Suppose you work with two-dimensional positions (such as x and y coordinates, or latitude and longitude) in your program. You would like to express operations on these positional values with normal arithmetic operations, such as

```
position1 = position2 + origin
```

where the variables position1, position2, and origin each represent a pair of inde pendent numerical quantities. By creating a class that incorporates these two values, and declaring position1, position2, and origin to be objects of this class, we can, in effect, create a new data type. Many features of C++ are intended to facilitate the creation of new data types in this manner.

Polymorphism and Overloading

Note that the = (equal) and + (plus) operators, used in the position arithmetic shown above, don't act the same way they do in operations on built-in types such as int. The objects position1 and so on are not predefined in C++, but are programmer-defined

objects of class Position. How do the = and + operators know how to operate on objects? The answer is that we can define new behaviors for these operators. These operations will be member functions of the Position class.

Using operators or functions in different ways, depending on what they are operating on, is called *polymorphism* (one thing with several distinct forms). When an existing operator, such as + or =, is given the capability to operate on a new data type, it is said to be *overloaded*. Overloading is a kind of polymorphism; it is also an important feature of OOP.

C++ and C

C++ is derived from the C language. Strictly speaking, it is a superset of C: Almost every correct statement in C is also a correct statement in C++, although the reverse is not true. The most important elements added to C to create C++ concern classes, objects, and object-oriented programming. (C++ was originally called “C with classes.”) However, C++ has many other new features as well, including an improved approach to input/output (I/O) and a new way to write comments. Figure 1.7 shows the relationship of C and C++.

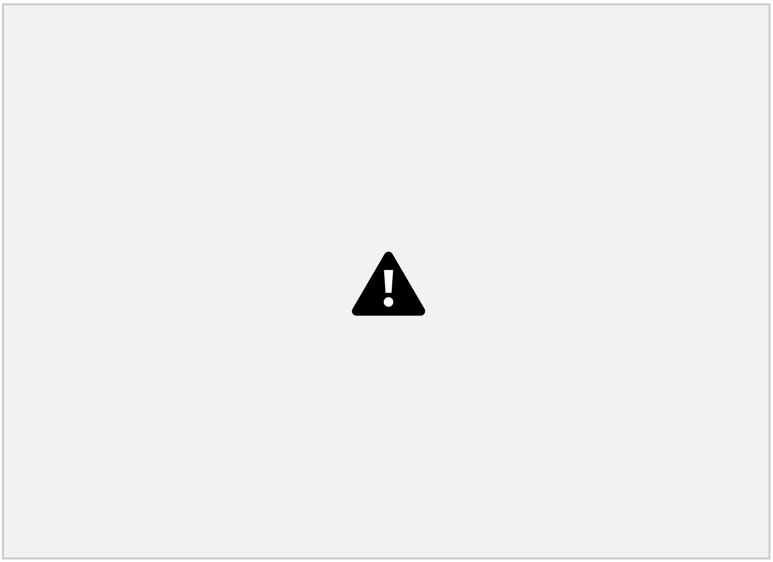


FIGURE 1.7
The relationship between C and C++.

In fact, the practical differences between C and C++ are larger than you might think. Although you can write a program in C++ that looks like a program in C, hardly anyone does. C++ pro-
grammers not only make use of the new features of C++, they also emphasize the traditional C features in different proportions than do C programmers.

If you already know C, you will have a head start in learning C++ (although you may also have some bad habits to unlearn), but much of the material will be new.

Laying the Groundwork

Our goal is to help you begin writing OOP programs as soon as possible. However, as we noted, much of C++ is inherited from C, so while the overall structure of a C++ program may be OOP, down in the trenches you need to know some old-fashioned procedural fundamentals. Chapters 2–5 therefore deal with the "traditional" aspects of C++, many of which are also found in C. You will learn about variables and I/O, about control structures such as loops and decisions, and about functions themselves. You will also learn about structures, since the same syntax that's used for structures is used for classes.

If you already know C, you might be tempted to skip these chapters. However, you will find that there are many differences, some obvious and some rather subtle, between C and C++. Our advice is to read these chapters, skimming what you know, and concentrating on the ways C++ differs from C.

The specific discussion of OOP starts in Chapter 6, "Objects and Classes." From then on the examples will be object oriented.

The Unified Modeling Language (UML)

The UML is a graphical "language" for modeling computer programs. "Modeling" means to create a simplified representation of something, as a blueprint models a house. The UML pro vides a way to visualize the higher-level organization of programs without getting mired down in the details of actual code.

The UML began as three separate modeling languages, one created by Grady Booch at Rational Software, one by James Rumbaugh at General Electric, and one by Ivar Jacobson at Ericson. Eventually Rumbaugh and Jacobson joined Booch at Rational, where they became known as the three amigos. During the late 1990s they unified (hence the name) their modeling languages into the Unified Modeling Language. The result was adopted by the Object Management Group (OMG), a consortium of companies devoted to industry standards.

Why do we need the UML? One reason is that in a large computer program it's often hard to understand, simply by looking at the code, how the parts of the program relate to each other. As we've seen, object-oriented programming is a vast improvement over procedural programs. Nevertheless, figuring out what a program is supposed to do requires, at best, considerable study of the program listings.

The trouble with code is that it's very detailed. It would be nice if there were a way to see a bigger picture, one that depicts the major parts of the program and how they work together. The UML answers this need.

The most important part of the UML is a set of different kinds of diagrams. Class diagrams show the relationships among classes, object diagrams show how specific objects relate, sequence diagrams show the communication among objects over time, use case diagrams show how a program's users interact with the program, and so on. These diagrams provide a variety of ways to look at a program and its operation.

The UML plays many roles besides helping us to understand how a program works. As we'll see in Chapter 16, it can help in the initial design of a program. In fact, the UML is useful throughout all phases of software development, from initial specification to documentation, testing, and maintenance.

The UML is not a software development process. Many such processes exist for specifying the stages of the development process. The UML is simply a way to look at the software being developed. Although it can be applied to any kind of programming language, the UML is espe cially attuned to OOP.

As we noted in the Introduction, we introduce specific features of the UML in stages through out the book.

- Chapter 1: (this section) introduction to the UML
- Chapter 8: class diagrams, associations, and navigability
- Chapter 9: generalization, aggregation, and composition
- Chapter 10: state diagrams and multiplicity
- Chapter 11: object diagrams
- Chapter 13: more complex state diagrams
- Chapter 14: templates, dependencies, and stereotypes
- Chapter 16: use cases, use case diagrams, activity diagrams, and sequence diagrams

Summary 1

OOP is a way of organizing programs. The emphasis is on the way programs are designed, not on coding details. In particular, OOP programs are organized around objects, which contain both data and functions that act on that data. A class is a tem plate for a number of objects.

Inheritance allows a class to be derived from an existing class without modifying it. The derived class has all the data and functions of the parent class, but adds new ones of its own. Inheritance makes possible reusability, or using a class over and over in different programs.

C++ is a superset of C. It adds to the C language the capability to implement OOP. It also adds a variety of other features. In addition, the emphasis is changed in C++ so that some features common to C, although still available in C++, are seldom used, while others are used far more frequently. The result is a surprisingly different language.

The Unified Modeling Language (UML) is a standardized way to visualize a program’s struc ture and operation using diagrams.

The general concepts discussed in this chapter will become more concrete as you learn more about the details of C++. You may want to refer back to this chapter as you progress further into this book.

Questions

Answers to these questions can be found in Appendix G. Note that throughout this book, multiple-choice questions can have more than one correct answer.

1. Pascal, BASIC, and C are p_____ languages, while C++ is an o_____ language.
2. A widget is to the blueprint for a widget as an object is to
   a. a member function.
   b. a class.
   c. an operator.
   d. a data item.
3. The two major components of an object are _____ and functions that _____.
4. In C++, a function contained within a class is called
   a. a member function.
   b. an operator.
   c. a class function.
   d. a method.

5. Protecting data from access by unauthorized functions is called _____. 6. Which of the following are good reasons to use an object-oriented language? a. You can define your own data types.
   b. Program statements are simpler than in procedural languages.
   c. An OO program can be taught to correct its own errors.
   d. It's easier to conceptualize an OO program.
7. _____ model entities in the real world more closely than do functions. 8. True or false: A C++ program is similar to a C program except for the details of coding.
9. Bundling data and functions together is called _____.
10. When a language has the capability to produce new data types, it is said to be
   a. reprehensible.
   b. encapsulated.
   c. overloaded.
   d. extensible.
11. True or false: You can easily tell, from any two lines of code, whether a pro gram is written in C or C++.
12. The ability of a function or operator to act in different ways on different data types is called __________.
13. A normal C++ operator that acts in special ways on newly defined data types is said to be
   a. glorified.

b. encapsulated.

c. classified.

d. overloaded.

14. Memorizing the new terms used in C++ is

a. critically important.

b. something you can return to later.

c. the key to wealth and success.

d. completely irrelevant.

15. The Unified Modeling Language is

a. a program that builds physical models. b. a way to look at the organization of a program. c. the combination of C++ and FORTRAN. d. helpful in developing software systems.

CHAPTER 2 C++ Programming Basics

IN THIS CHAPTER

In any language there are some fundamentals you need to know before you can write even the most elementary programs. This chapter introduces three such fundamentals: basic program construction, variables, and input/output (I/O). It also touches on a variety of other language features, including comments, arithmetic operators, the increment operator, data conversion, and library functions.

These topics are not conceptually difficult, but you may find that the style in C++ is a little austere compared with, say, BASIC or Pascal. Before you learn what it's all about, a C++ pro gram may remind you more of a mathematics formula than a computer program. Don't worry about this. You'll find that as you gain familiarity with C++, it starts to look less forbidding, while other languages begin to seem unnecessarily fancy and verbose.

Getting Started

As we noted in the Introduction, you can use either a Microsoft or a Borland compiler with this book. Appendixes C and D provide details about their operation. (Other compilers may work as well.) Compilers take source code and transform it into executable files, which your computer can run as it does other programs. Source files are text files (extension .CPP) that cor respond with the listings printed in this book. Executable files have the .EXE extension, and can be executed either from within your compiler, or, if you're familiar with MS-DOS, directly from a DOS window.

The programs run without modification on the Microsoft compiler or in an MS-DOS window. If you're using the Borland compiler, you'll need to modify the programs slightly before run ning them; otherwise the output won't remain on the screen long enough to see. Make sure to read Appendix D, "Borland C++Builder," to see how this is done.

Basic Program Construction

Let's look at a very simple C++ program. This program is called FIRST, so its source file is FIRST.CPP. It simply prints a sentence on the screen. Here it is:

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

int main()
    {
    cout << "Every age has a language of its own\n";
    return 0;
    }
```

Despite its small size, this program demonstrates a great deal about the construction of C++ programs. Let's examine it in detail.

Functions

Functions are one of the fundamental building blocks of C++. The FIRST program consists almost entirely of a single function called main(). The only parts of this program that are not part of the function are the first two lines—the ones that start with #include and using. (We'll see what these lines do in a moment.)

We noted in Chapter 1, "The Big Picture," that a function can be part of a class, in which case it is called a *member function*. However, functions can also exist independently of classes. We are not yet ready to talk about classes, so we will show functions that are separate standalone entities, as main() is here.

Function Name

The parentheses following the word main are the distinguishing feature of a function. Without the parentheses the compiler would think that main refers to a variable or to some other pro
gram element. When we discuss functions in the text, we'll follow the same convention that C++ uses: We'll put parentheses following the function name. Later on we'll see that the parentheses aren't always empty. They're used to hold function *arguments*: values passed from the calling program to the function.

The word int preceding the function name indicates that this particular function has a return value of type int. Don't worry about this now; we'll learn about data types later in this chapter and return values in Chapter 5, "Functions."

Braces and the Function Body

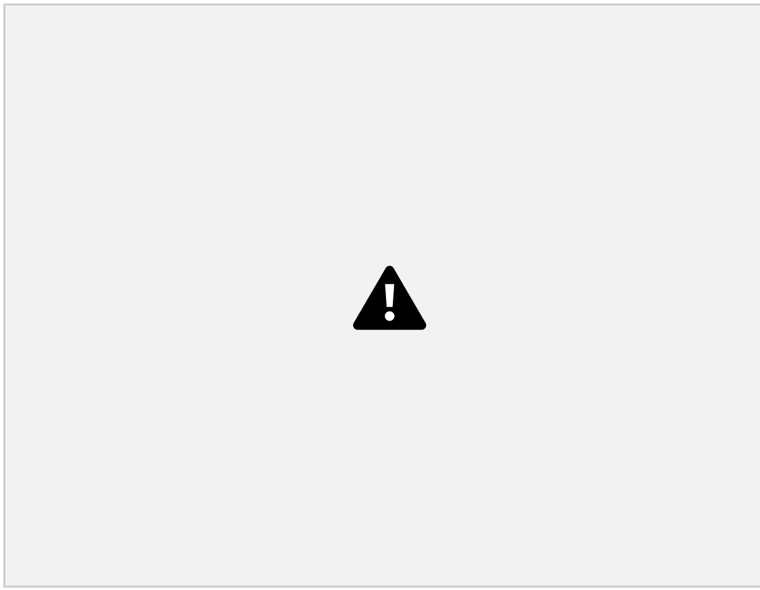
The *body* of a function is surrounded by *braces* (sometimes called *curly brackets*). These braces play the same role as the BEGIN and END keywords in some other languages: They sur
round or *delimit* a block of program statements. Every function must use this pair of braces around the function body. In this example there are only two statements in the function body: the line starting with cout, and the line starting with return. However, a function body can consist of many statements.

Always Start with main()

When you run a C++ program, the first statement executed will be at the beginning of a func
tion called main(). (At least that's true of the console mode programs in this book.) The pro
gram may consist of many functions, classes, and other program elements, but on startup, control always goes to main(). If there is no function called main() in your program, an error will be reported when you run the program.

In most C++ programs, as we'll see later, main() calls member functions in various objects to carry out the program's real work. The main() function may also contain calls to other stand
alone functions. This is shown in Figure 2.1.

FIGURE 2.1



Objects, functions, and main().

Program Statements

The program *statement* is the fundamental unit of C++ programming. There are two statements in the FIRST program: the line

```
cout << "Every age has a language of its own\n";
```

and the return statement

```
return 0;
```

The first statement tells the computer to display the quoted phrase. Most statements tell the computer to do something. In this respect, statements in C++ are similar to statements in other languages. In fact, as we've noted, the majority of statements in C++ are identical to state ments in C.

A semicolon signals the end of the statement. This is a crucial part of the syntax but easy to forget. In some languages (like BASIC), the end of a statement is signaled by the end of the line, but that's not true in C++. If you leave out the semicolon, the compiler will often (although not always) signal an error.

The last statement in the function body is return 0;. This tells main() to return the value 0 to whoever called it, in this case the operating system or compiler. In older versions of C++ you could give main() the return type of void and dispense with the return statement, but this is not considered correct in Standard C++. We'll learn more about return in Chapter 5.

Whitespace

We mentioned that the end of a line isn't important to a C++ compiler. Actually, the compiler ignores whitespace almost completely. *Whitespace* is defined as spaces, carriage returns, line feeds, tabs, vertical tabs, and formfeeds. These characters are invisible to the compiler. You can

put several statements on one line, separated by any number of spaces or tabs, or you can run a statement over two or more lines. It's all the same to the compiler. Thus the FIRST program

could be written this way:

```
#include <iostream>


using

namespace std;

int main () { cout
<<
"Every age has a language of its own\n"
; return
0;}
```

We don't recommend this syntax—it's nonstandard and hard to read—but it does compile cor rectly.

There are several exceptions to the rule that whitespace is invisible to the compiler. The first line of the program, starting with #include, is a preprocessor directive, which must be written on one line. Also, string constants, such as "Every age has a language of its own", can not be broken into separate lines. (If you need a long string constant, you can insert a back slash (\) at the line break or divide the string into two separate strings, each surrounded by quotes.)

Output Using cout

As you have seen, the statement

```
cout << "Every age has a language of its own\n";
```

causes the phrase in quotation marks to be displayed on the screen. How does this work? A complete description of this statement requires an understanding of objects, operator overload ing, and other topics we won't discuss until later in the book, but here's a brief preview.

The identifier cout (pronounced "C out") is actually an *object*. It is predefined in C++ to corre spond to the *standard output stream*. A *stream* is an abstraction that refers to a flow of data. The standard output stream normally flows to the screen display—although it can be redirected to other output devices. We'll discuss streams (and redirection) in Chapter 12, "Streams and Files."

The operator << is called the *insertion* or *put to* operator. It directs the contents of the variable on its right to the object on its left. In FIRST it directs the string constant "Every age has a language of its own\n" to cout, which sends it to the display.

(If you know C, you'll recognize << as the *left-shift* bit-wise operator and wonder how it can also be used to direct output. In C++, operators can be overloaded. That is, they can perform different activities, depending on the context. We'll learn about overloading in Chapter 8, "Operator Overloading.")

Although the concepts behind the use of cout and << may be obscure at this point, using them is easy. They'll appear in almost every example program. Figure 2.2 shows the result of using cout and the insertion operator <<.

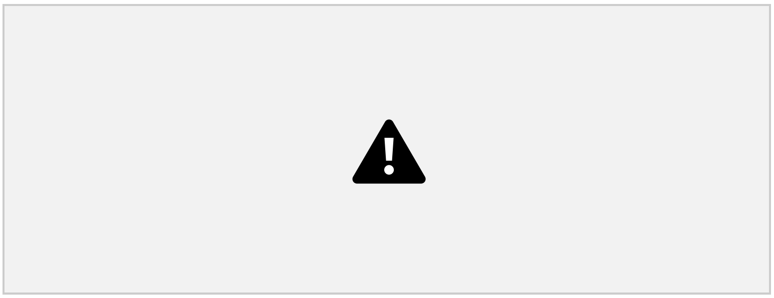


FIGURE 2.2
Output with cout.

String Constants

The phrase in quotation marks, "Every age has a language of its own\n", is an example of a *string constant*. As you probably know, a constant, unlike a variable, cannot be given a new value as the program runs. Its value is set when the program is written, and it retains this value throughout the program's existence.

As we'll see later, the situation regarding strings is rather complicated in C++. Two ways of handling strings are commonly used. A string can be represented by an array of characters, or it can be represented as an object of a class. We'll learn more about both kinds of strings in Chapter 7, "Arrays and Strings."

The '\n' character at the end of the string constant is an example of an *escape sequence*. It causes the next text output to be displayed on a new line. We use it here so that the phrases such as "Press any key to continue," inserted by some compilers for display after the program terminates, will appear on a new line. We'll discuss escape sequences later in this chapter.

Directives

The two lines that begin the FIRST program are *directives*. The first is a *preprocessor directive*, and the second is a using *directive*. They occupy a sort of gray area: They're not part of the basic C++ language, but they're necessary anyway

Preprocessor Directives

The first line of the FIRST program

```
#include <iostream>
```

might look like a program statement, but it's not. It isn't part of a function body and doesn't end with a semicolon, as program statements must. Instead, it starts with a number sign (#). It's called a *preprocessor directive*. Recall that program statements are instructions to the *com puter* to do something, such as adding two numbers or printing a sentence. A preprocessor directive, on the other hand, is an instruction to the *compiler*. A part of the compiler called the *preprocessor* deals with these directives before it begins the real compilation process.

The preprocessor directive #include tells the compiler to insert another file into your source file. In effect, the #include directive is replaced by the contents of the file indicated. Using an #include directive to insert another file into your source file is similar to pasting a block of text into a document with your word processor.

#include is only one of many preprocessor directives, all of which can be identified by the ini tial # sign. The use of preprocessor directives is not as common in C++ as it is in C, but we'll look at a few additional examples as we go along. The type file usually included by #include is called a *header file*.

Header Files

In the FIRST example, the preprocessor directive #include tells the compiler to add the source file IOSTREAM to the FIRST.CPP source file before compiling. Why do this? IOSTREAM is an exam ple of a *header file* (sometimes called an *include file*). It's concerned with basic input/output operations, and contains declarations that are needed by the cout identifier and the << operator. Without these declarations, the compiler won't recognize cout and will think << is being used incorrectly. There are many such include files. The newer Standard C++ header files don't have a file extension, but some older header files, left over from the days of the C language, have the extension .H.

If you want to see what's in IOSTREAM, you can find the include directory for your compiler and display it as a source file in the Edit window. (See the appropriate appendix for hints on how to do this.) Or you can look at it with the WordPad or Notepad utilities. The contents won't make much sense at this point, but you will at least prove to yourself that IOSTREAM is a source file, written in normal ASCII characters.

We'll return to the topic of header files at the end of this chapter, when we introduce library functions.

The using Directive

A C++ program can be divided into different *namespaces*. A namespace is a part of the pro gram in which certain names are recognized; outside of the namespace they're unknown. The directive

```
using namespace std;
```

says that all the program statements that follow are within the std namespace. Various program components such as cout are declared within this namespace. If we didn't use the using direc tive, we would need to add the std name to many program elements. For example, in the FIRST program we'd need to say

```
std::cout << "Every age has a language of its own.";
```

To avoid adding std:: dozens of times in programs we use the using directive instead. We'll discuss namespaces further in Chapter 13, "Multifile Programs."

Comments

Comments are an important part of any program. They help the person writing a program, and anyone else who must read the source file, understand what's going on. The compiler ignores comments, so they do not add to the file size or execution time of the executable program.

Comment Syntax

Let's rewrite our FIRST program, incorporating comments into our source file. We'll call the new program COMMENTS:

```
// comments.cpp
// demonstrates comments
#include <iostream> //preprocessor directive
using namespace std; //"using" directive
```

```
int main() //function name "main"
    { //start function body
    cout << "Every age has a language of its own\n"; //statement
    return 0; //statement
    } //end function body
```

Comments start with a double slash symbol (//) and terminate at the end of the line. (This is one of the exceptions to the rule that the compiler ignores whitespace.) A comment can start at the beginning of the line or on the same line following a program statement. Both possibilities are shown in the COMMENTS example.

When to Use Comments

Comments are almost always a good thing. Most programmers don't use enough of them. If you're tempted to leave out comments, remember that not everyone is as smart as you; they may need more explanation than you do about what your program is doing. Also, you may not be as smart next month, when you've forgotten key details of your program's operation, as you are today.

Use comments to explain to the person looking at the listing what you're trying to do. The details are in the program statements themselves, so the comments should concentrate on the big picture, clarifying your reasons for using a certain statement or group of statements.

Alternative Comment Syntax

There's a second comment style available in C++:

```
/* this is an old-style comment */
```

This type of comment (the only comment originally available in C) begins with the /* charac ter pair and ends with */ (not with the end of the line). These symbols are harder to type (since / is lowercase while * is uppercase) and take up more space on the line, so this style is not generally used in C++. However, it has advantages in special situations. You can write a multi line comment with only two comment symbols:

```
/* this
is a
potentially
very long
multiline
comment
*/
```

This is a good approach to making a comment out of a large text passage, since it saves insert ing the // symbol on every line.

You can also insert a /* */ comment anywhere within the text of a program line:

```
func1()
    { /* empty function body */ }
```

If you attempt to use the // style comment in this case, the closing brace won't be visible to the compiler—since a // style comment runs to the end of the line—and the code won't com pile correctly.

Integer Variables

Variables are the most fundamental part of any language. A variable has a symbolic name and can be given a variety of values. Variables are located in particular places in the computer's memory. When a variable is given a value, that value is actually placed in the memory space assigned to the variable. Most popular languages use the same general variable types, such as integers, floating-point numbers, and characters, so you are probably already familiar with the ideas behind them.

Integer variables represent integer numbers like 1, 30,000, and –27. Such numbers are used for counting discrete numbers of objects, like 11 pencils or 99 bottles of beer. Unlike floating point numbers, integers have no fractional part; you can express the idea of *four* using integers, but not *four and one-half*.

Defining Integer Variables

Integer variables exist in several sizes, but the most commonly used is type int. The amount of memory occupied by the integer types is system dependent. On a 32-bit system such as Windows, an int occupies 4 bytes (which is 32 bits) of memory. This allows an int to hold numbers in the range from –2,147,483,648 to 2,147,483,647. Figure 2.3 shows an integer vari able in memory.

While type int occupies 4 bytes on current Windows computers, it occupied only 2 bytes in MS-DOS and earlier versions of Windows. The ranges occupied by the various types are listed in the header file LIMITS; you can also look them up using your compiler's help system.

Here's a program that defines and uses several variables of type int:

```
// intvars.cpp
// demonstrates integer variables
#include <iostream>
using namespace std;

int main()
    {
    int var1; //define var1
    int var2; //define var2
```

```
var1 = 20; //assign value to var1 var2
= var1 + 10; //assign value to var2 cout
<< “var1+10 is “; //output text cout <<
var2 << endl; //output value of var2
return 0;
```

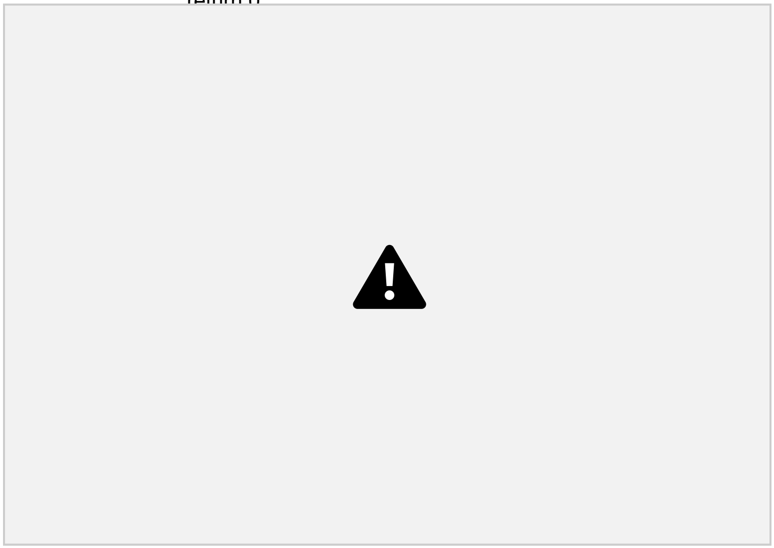


FIGURE 2.3

Variable of type int *in memory.*

Type this program into your compiler's edit screen (or load it from the Web site), compile and link it, and then run it. Examine the output window. The statements

```
int var1;
int var2;
```

define two integer variables, var1 and var2. The keyword int signals the type of variable. These statements, which are called *declarations*, must terminate with a semicolon, like other program statements.

You must declare a variable before using it. However, you can place variable declarations any where in a program. It's not necessary to declare variables before the first executable statement (as was necessary in C). However, it's probably more readable if commonly-used variables are located at the beginning of the program.

Declarations and Definitions

Let's digress for a moment to note a subtle distinction between the terms *definition* and *decla ration* as applied to variables.

A *declaration* introduces a variable's name (such as var1) into a program and specifies its type (such as int). However, if a declaration also sets aside memory for the variable, it is also called a *definition*. The statements

```
int var1;
int var2;
```

in the INTVARS program are definitions, as well as declarations, because they set aside memory for var1 and var2. We'll be concerned mostly with declarations that are also definitions, but later on we'll see various kinds of declarations that are not definitions.

Variable Names

The program INTVARS uses variables named var1 and var2. The names given to variables (and other program features) are called *identifiers*. What are the rules for writing identifiers? You can use upper- and lowercase letters, and the digits from 1 to 9. You can also use the under score (_). The first character must be a letter or underscore. Identifiers can be as long as you like, but most compilers will only recognize the first few hundred characters. The compiler dis tinguishes between upper- and lowercase letters, so Var is not the same as var or VAR.

You can't use a C++ keyword as a variable name. A *keyword* is a predefined word with a spe cial meaning. int, class, if, and while are examples of keywords. A complete list of key words can be found in Appendix B, “C++ Precedence Table and Keywords,” and in your compiler’s documentation.

Many C++ programmers follow the convention of using all lowercase letters for variable names. Other programmers use a mixture of upper- and lowercase, as in IntVar or dataCount. Still others make liberal use of underscores. Whichever approach you use, it’s good to be con
sistent throughout a program. Names in all uppercase are sometimes reserved for constants (see the discussion of const that follows). These same conventions apply to naming other pro
gram elements such as classes and functions.

A variable’s name should make clear to anyone reading the listing the variable’s purpose and how it is used. Thus boilerTemperature is better than something cryptic like bT or t.

Assignment Statements

The statements

```
var1 = 20;
var2 = var1 + 10;
```

assign values to the two variables. The equal sign (=), as you might guess, causes the value on the right to be assigned to the variable on the left. The = in C++ is equivalent to the := in Pascal or the = in BASIC. In the first line shown here, var1, which previously had no value, is given the value 20.

Integer Constants

The number 20 is an *integer constant*. Constants don’t change during the course of the pro
gram. An integer constant consists of numerical digits. There must be no decimal point in an integer constant, and it must lie within the range of integers.

In the second program line shown here, the plus sign (+) adds the value of var1 and 10, in which 10 is another constant. The result of this addition is then assigned to var2.

Output Variations

The statement

```
cout << “var1+10 is “;
```

displays a string constant, as we’ve seen before. The next statement

```
cout << var2 << endl;
```

displays the value of the variable var2. As you can see in your console output window, the out
put of the program is

```
var1+10 is 30
```

Note that cout and the << operator know how to treat an integer and a string differently. If we send them a string, they print it as text. If we send them an integer, they print it as a number. This may seem obvious, but it is another example of operator overloading, a key feature of C++. (C programmers will remember that such functions as printf() need to be told not only the variable to be displayed, but the type of the variable as well, which makes the syntax far less intuitive.)

As you can see, the output of the two cout statements appears on the same line on the output screen. No linefeed is inserted automatically. If you want to start on a new line, you must insert a linefeed yourself. We've seen how to do this with the '\n' escape sequence. Now we'll see another way: using something called a *manipulator*.

The endl Manipulator

The last cout statement in the INTVARS program ends with an unfamiliar word: endl. This causes a linefeed to be inserted into the stream, so that subsequent text is displayed on the next line. It has the same effect as sending the '\n' character, but is somewhat clearer. It's an

example of a *manipulator*. Manipulators are instructions to the output stream that modify the output in various ways; we'll see more of them as we go along. Strictly speaking, endl (unlike '\n') also causes the output buffer to be flushed, but this happens invisibly so for most pur poses the two are equivalent.

Other Integer Types

There are several numerical integer types besides type int. The two most common types are long and short. (Strictly speaking type char is an integer type as well, but we'll cover it sepa rately.) We noted that the size of type int is system dependent. In contrast, types long and short have fixed sizes no matter what system is used.

Type long always occupies four bytes, which is the same as type int on 32-bit Windows sys tems. Thus it has the same range, from –2,147,483,648 to 2,147,483,647. It can also be written as long int; this means the same as long. There's little point in using type long on 32-bit sys tems, since it's the same as int. However, if your program may need to run on a 16-bit system such as MS-DOS, or on older versions of Windows, specifying type long will guarantee a four-bit integer type. In 16-bit systems, type int has the same range as type short.

On all systems type short occupies two bytes, giving it a range of –32,768 to 32,767. There's probably not much point using type short on modern Windows systems unless it's important to save memory. Type int, although twice as large, is accessed faster than type short.

If you want to create a constant of type long, use the letter L following the numerical value, as in

```
longvar = 7678L; // assigns long constant 7678 to longvar
```

Many compilers offer integer types that explicitly specify the number of bits used. (Remember there are 8 bits to a byte.) These type names are preceded by two underscores. They are __int8, __int16, __int32, and __int64. The __int8 type corresponds to char, and (at least in 32-bit systems) the type name __int16 corresponds to short and __int32 corresponds to both int and long. The __int64 type holds huge integers with up to 19 decimal digits. Using these type names has the advantage that the number of bytes used for a variable is not implementa tion dependent. However, this is not usually an issue, and these types are seldom used.

Character Variables

Type char stores integers that range in value from –128 to 127. Variables of this type occupy only 1 byte (eight bits) of memory. Character variables are sometimes used to store numbers that confine themselves to this limited range, but they are much more commonly used to store ASCII characters.

As you may already know, the ASCII character set is a way of representing characters such as 'a', 'B', '$', '3', and so on, as numbers. These numbers range from 0 to 127. Most Windows systems extend this range to 255 to accommodate various foreign-language and graphics char acters. Appendix A, "ASCII Table," shows the ASCII character set.

Complexities arise when foreign languages are used, and even when programs are transferred between computer systems in the same language. This is because the characters in the range 128 to 255 aren't standardized and because the one-byte size of type char is too small to accommodate the number of characters in many languages, such as Japanese. Standard C++ provides a larger character type called wchar_t to handle foreign languages. This is important if you're writing programs for international distribution. However, in this book we'll ignore type wchar_t and assume that we're dealing with the ASCII character set found in current ver sions of Windows.

Character Constants

Character constants use single quotation marks around a character, like 'a' and 'b'. (Note that this differs from *string* constants, which use double quotation marks.) When the C++ compiler encounters such a character constant, it translates it into the corresponding ASCII code. The constant 'a' appearing in a program, for example, will be translated into 97, as shown in Figure 2.4.

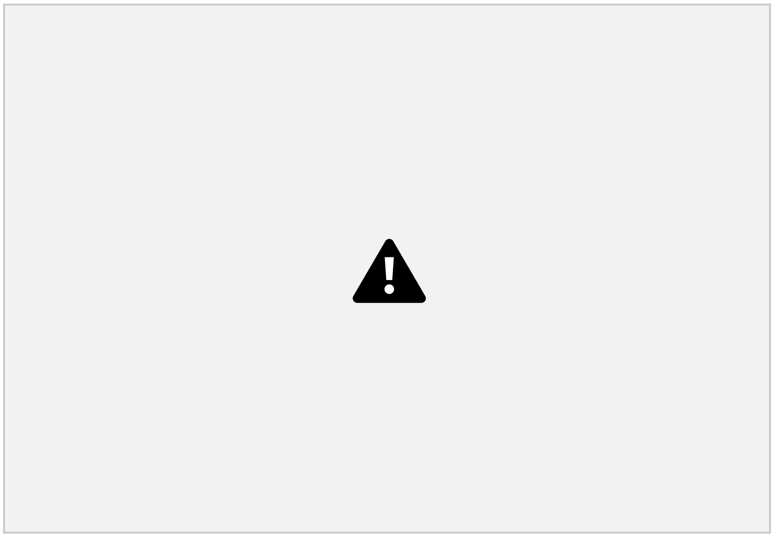


FIGURE 2.4

Variable of type char *in memory.*

Character variables can be assigned character constants as values. The following program shows some examples of character constants and variables.

```
// charvars.cpp
// demonstrates character variables
#include <iostream> //for cout, etc.
using namespace std;

int main()
   {
   char charvar1 = ‘A’; //define char variable as character
   char charvar2 = ‘\t’; //define char variable as tab

   cout << charvar1; //display character
   cout << charvar2; //display character
   charvar1 = ‘B’; //set char variable to char constant
   cout << charvar1; //display character
   cout << ‘\n’; //display newline character
   return 0;
   }
```

Initialization

Variables can be initialized at the same time they are defined. In this program two variables of type char—charvar1 and charvar2—are initialized to the character constants ‘A’ and ‘\t’.

Escape Sequences

This second character constant, ‘\t’, is an odd one. Like ‘\n’, which we encountered earlier, it’s an example of an *escape sequence*. The name reflects the fact that the backslash causes an “escape” from the normal way characters are interpreted. In this case the t is interpreted not as the character ‘t’ but as the tab character. A tab causes printing to continue at the next tab stop.

In console-mode programs, tab stops are positioned every eight spaces. Another character con stant, '\n', is sent directly to cout in the last line of the program.

Escape sequences can be used as separate characters or embedded in string constants. Table 2.1 shows a list of common escape sequences.

TABLE 2.1 Common Escape Sequences

Escape Sequence	*Character*
\ a	Bell (beep)
\ b	Backspace
\ f	Formfeed

TABLE 2.1 Continued

Escape Sequence	*Character*
\ n	Newline
\ r	Return
\ t	Tab
\ \	Backslash
\ ‘	Single quotation mark
\ “	Double quotation marks
\ xdd	Hexadecimal notation

Since the backslash, the single quotation marks, and the double quotation marks all have spe

cialized meanings when used in constants, they must be represented by escape sequences when

we want to display them as characters. Here's an example of a quoted phrase in a string con

stant:

```
cout << “\”Run, Spot, run,\” she said.”;
```

This translates to

```
“Run, Spot, run,” she said.
```

Sometimes you need to represent a character constant that doesn't appear on the keyboard, such as the graphics characters above ASCII code 127. To do this, you can use the '\xdd' rep resentation, where each d stands for a hexadecimal digit. If you want to print a solid rectangle, for example, you'll find such a character listed as decimal number 178, which is hexadecimal number B2 in the ASCII table. This character would be represented by the character constant '\xB2'. We'll see some examples of this later.

The CHARVARS program prints the value of charvar1 ('A') and the value of charvar2 (a tab). It then sets charvar1 to a new value ('B'), prints that, and finally prints the newline. The output looks like this:

```
A B
```

Input with cin

Now that we've seen some variable types in use, let's see how a program accomplishes input. The next example program asks the user for a temperature in degrees Fahrenheit, converts it to Celsius, and displays the result. It uses integer variables.

```
// fahren.cpp
// demonstrates cin, newline
#include <iostream>
using namespace std;

int main()
   {
   int ftemp; //for temperature in fahrenheit

   cout << "Enter temperature in fahrenheit: ";
   cin >> ftemp;
   int ctemp = (ftemp-32) * 5 / 9;
   cout << "Equivalent in Celsius is: " << ctemp << '\n';
   return 0;
   }
```

The statement

```
cin >> ftemp;
```

causes the program to wait for the user to type in a number. The resulting number is placed in the variable `ftemp`. The keyword `cin` (pronounced "C in") is an object, predefined in C++ to correspond to the standard input stream. This stream represents data coming from the keyboard (unless it has been redirected). The `>>` is the *extraction* or *get from* operator. It takes the value from the stream object on its left and places it in the variable on its right.

Here's some sample interaction with the program:

```
Enter temperature in fahrenheit: 212
Equivalent in Celsius is: 100
```

Figure 2.5 shows input using `cin` and the extraction operator `>>`.

FIGURE 2.5
Input with cin.

Variables Defined at Point of Use

The FAHREN program has several new wrinkles besides its input capability. Look closely at the listing. Where is the variable ctemp defined? Not at the beginning of the program, but in the next-to-the-last line, where it's used to store the result of the arithmetic operation. As we noted earlier, you can define variables throughout a program, not just at the beginning. (Many lan guages, including C, require all variables to be defined before the first executable statement.)

Defining variables where they are used can make the listing easier to understand, since you don't need to refer repeatedly to the start of the listing to find the variable definitions.

However, the practice should be used with discretion. Variables that are used in many places in a function are better defined at the start of the function.

Cascading <<

The insertion operator << is used repeatedly in the second cout statement in FAHREN. This is perfectly legal. The program first sends the phrase *Equivalent in Celsius is:* to cout, then it sends the value of ctemp, and finally the newline character '\n'.

The extraction operator >> can be cascaded with cin in the same way, allowing the user to enter a series of values. However, this capability is not used so often, since it eliminates the opportunity to prompt the user between inputs.

Expressions

Any arrangement of variables, constants, and operators that specifies a computation is called an *expression*. Thus, alpha+12 and (alpha-37)*beta/2 are expressions. When the computa tions specified in the expression are performed, the result is usually a value. Thus if alpha is 7, the first expression shown has the value 19.

Parts of expressions may also be expressions. In the second example, alpha-37 and beta/2 are expressions. Even single variables and constants, like alpha and 37, are considered to be expressions.

Note that expressions aren't the same as statements. Statements tell the compiler to do some thing and terminate with a semicolon, while expressions specify a computation. There can be several expressions in a statement.

Precedence

Note the parentheses in the expression

```
(ftemp-32) * 5 / 9
```

Without the parentheses, the multiplication would be carried out first, since * has higher prior ity than -. With the parentheses, the subtraction is done first, then the multiplication, since all operations inside parentheses are carried out first. What about the precedence of the * and / signs? When two arithmetic operators have the same precedence, the one on the left is exe cuted first, so in this case the multiplication will be carried out next, then the division. Precedence and parentheses are normally applied this same way in algebra and in other com puter languages, so their use probably seems quite natural. However, precedence is an impor tant topic in C++. We'll return to it later when we introduce different kinds of operators.

Floating Point Types

We've talked about type int and type char, both of which represent numbers as integers—that is, numbers without a fractional part. Now let's examine a different way of storing numbers— as floating-point variables.

Floating-point variables represent numbers with a decimal place—like 3.1415927, 0.0000625, and –10.2. They have both an integer part, to the left of the decimal point, and a fractional part, to the right. Floating-point variables represent what mathematicians call *real numbers*, which are used for measurable quantities such as distance, area, and temperature. They typically have a fractional part.

There are three kinds of floating-point variables in C++: type float, type double, and type long double. Let's start with the smallest of these, type float.

Type float

Type float stores numbers in the range of about $3.4\text{x}10^{-38}$ to $3.4\text{x}10^{38}$, with a precision of seven digits. It occupies 4 bytes (32 bits) in memory, as shown in Figure 2.6.

The following example program prompts the user to type in a floating-point number represent ing the radius of a circle. It then calculates and displays the circle's area.

```
// circarea.cpp
// demonstrates floating point variables
#include <iostream> //for cout, etc.
using namespace std;

int main()
    {
    float rad; //variable of type float
    const float PI = 3.14159F; //type const float

    cout << “Enter radius of circle: “; //prompt
    cin >> rad; //get radius
```

```
float area = PI * rad * rad; //find area
cout << “Area is “ << area << endl;
//display answer return 0;
}
```

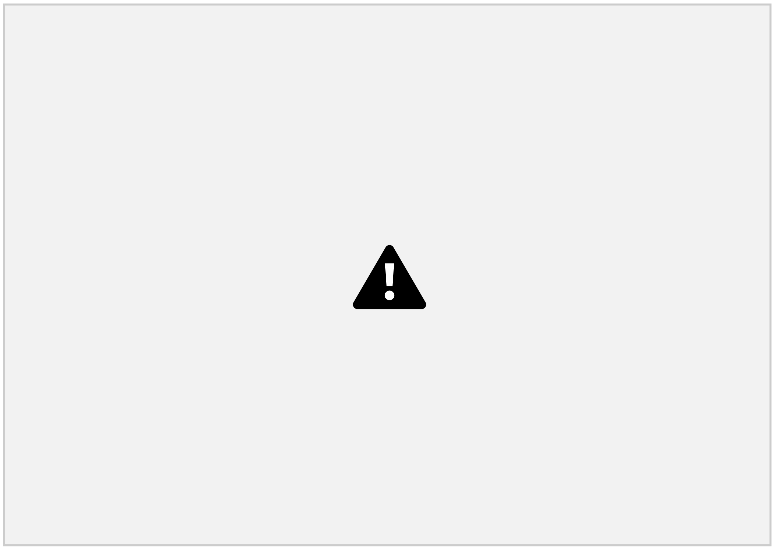


FIGURE 2.6
Variable of type float *in memory.*

Here's a sample interaction with the program:

```
Enter radius of circle: 0.5
Area is 0.785398
```

This is the area in square feet of a 12-inch LP record (which has a radius of 0.5 feet). At one time this was an important quantity for manufacturers of vinyl.

Type double and long double

The larger floating point types, double and long double, are similar to float except that they require more memory space and provide a wider range of values and more precision. Type double requires 8 bytes of storage and handles numbers in the range from $1.7x10^{-308}$ to $1.7x10^{308}$ with a precision of 15 digits. Type long double is compiler-dependent but is often the same as double. Type double is shown in Figure 2.7.

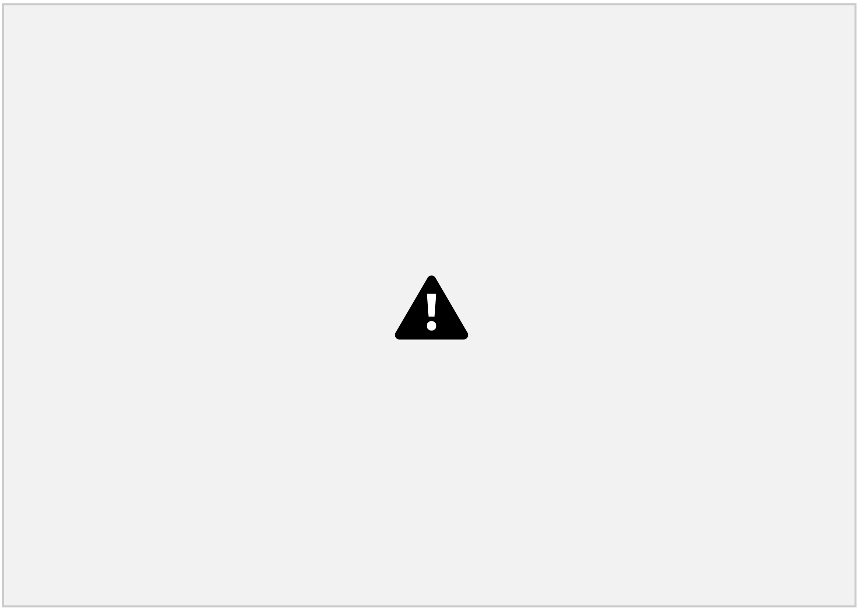


FIGURE 2.7
Variable of type double.

Floating-Point Constants

The number 3.14159F in CIRCAREA is an example of a *floating-point constant*. The decimal point signals that it is a floating-point constant, and not an integer, and the F specifies that it's type float, rather than double or long double. The number is written in normal decimal notation. You don't need a suffix letter with constants of type double; it's the default. With type long double, use the letter L.

You can also write floating-point constants using *exponential notation*. Exponential notation is a way of writing large numbers without having to write out a lot of zeros. For example, 1,000,000,000 can be written as 1.0E9 in exponential notation. Similarly, 1234.56 would be written 1.23456E3. (This is the same as 1.23456 times 10^3.) The number following the E is called the *exponent*. It indicates how many places the decimal point must be moved to change the number to ordinary decimal notation.

The exponent can be positive or negative. The exponential number 6.35239E–5 is equivalent to 0.0000635239 in decimal notation. This is the same as 6.35239 times 10^{-5}.

The const Qualifier

Besides demonstrating variables of type float, the CIRCAREA example also introduces the qual
ifier const. It's used in the statement

```
const float PI = 3.14159F; //type const float
```

The keyword const (for constant) precedes the data type of a variable. It specifies that the value of a variable will not change throughout the program. Any attempt to alter the value of a variable defined with this qualifier will elicit an error message from the compiler.

The qualifier const ensures that your program does not inadvertently alter a variable that you intended to be a constant, such as the value of PI in CIRCAREA. It also reminds anyone reading the listing that the variable is not intended to change. The const modifier can apply to other entities besides simple variables. We'll learn more about this as we go along.

The #define Directive

Although the construction is not recommended in C++, constants can also be specified using the preprocessor directive #define. This directive sets up an equivalence between an identifier and a text phrase. For example, the line

```
#define PI 3.14159
```

appearing at the beginning of your program specifies that the identifier PI will be replaced by the text 3.14159 throughout the program. This construction has long been popular in C. However, you can't specify the data type of the constant using #define, which can lead to pro
gram bugs; so even in C #define has been superseded by const used with normal variables. However, you may encounter this construction in older programs.

Type bool

For completeness we should mention type bool here, although it won't be important until we discuss relational operators in the next chapter.

We've seen that variables of type int can have billions of possible values, and those of type char can have 256. Variables of type bool can have only two possible values: true and false. In theory a bool type requires only one bit (not byte) of storage, but in practice compilers often store them as bytes because a byte can be quickly accessed, while an individual bit must be extracted from a byte, which requires additional time.

As we'll see, type bool is most commonly used to hold the results of comparisons. Is alpha less than beta? If so, a bool value is given the value true; if not, it's given the value false.

Type bool gets its name from George Boole, a 19th century English mathematician who invented the concept of using logical operators with true-or-false values. Thus such true/false values are often called *Boolean* values.

The setw Manipulator

We've mentioned that manipulators are operators used with the insertion operator (<<) to mod ify—or manipulate—the way data is displayed. We've already seen the endl manipulator; now we'll look at another one: setw, which changes the field width of output.

You can think of each value displayed by cout as occupying a field: an imaginary box with a certain width. The default field is just wide enough to hold the value. That is, the integer 567 will occupy a field three characters wide, and the string "pajamas" will occupy a field seven characters wide. However, in certain situations this may not lead to optimal results. Here's an example. The WIDTH1 program prints the names of three cities in one column, and their popula tions in another.

```
// width1.cpp
// demonstrates need for setw manipulator
#include <iostream>
using namespace std;

int main()
   {
   long pop1=2425785, pop2=47, pop3=9761;

   cout << "LOCATION " << "POP." << endl
        << "Portcity " << pop1 << endl
        << "Hightown " << pop2 << endl
        << "Lowville " << pop3 << endl;
   return 0;
   }
```

Here's the output from this program:

```
LOCATION POP.
Portcity 2425785
Hightown 47
Lowville 9761
```

Unfortunately, this format makes it hard to compare the numbers; it would be better if they lined up to the right. Also, we had to insert spaces into the names of the cities to separate them from the numbers. This is an inconvenience.

Here's a variation of this program, WIDTH2, that uses the setw manipulator to eliminate these problems by specifying field widths for the names and the numbers:

```
// width2.cpp
// demonstrates setw manipulator
#include <iostream>
#include <iomanip> // for setw
using namespace std;
```

```
int main()
    {

    long pop1=2425785, pop2=47, pop3=9761;

    cout << setw(8) << “LOCATION” << setw(12)

           << “POPULATION” << endl

           << setw(8) << “Portcity” << setw(12) << pop1 << endl

           << setw(8) << “Hightown” << setw(12) << pop2 << endl

           << setw(8) << “Lowville” << setw(12) << pop3 << endl;

    return 0;
    }
```

The setw manipulator causes the number (or string) that follows it in the stream to be printed within a field n characters wide, where n is the argument to setw(n). The value is right justified within the field. Figure 2.8 shows how this looks. Type long is used for the population figures, which prevents a potential overflow problem on systems that use 2-byte integer types, in which the largest integer value is 32,767.

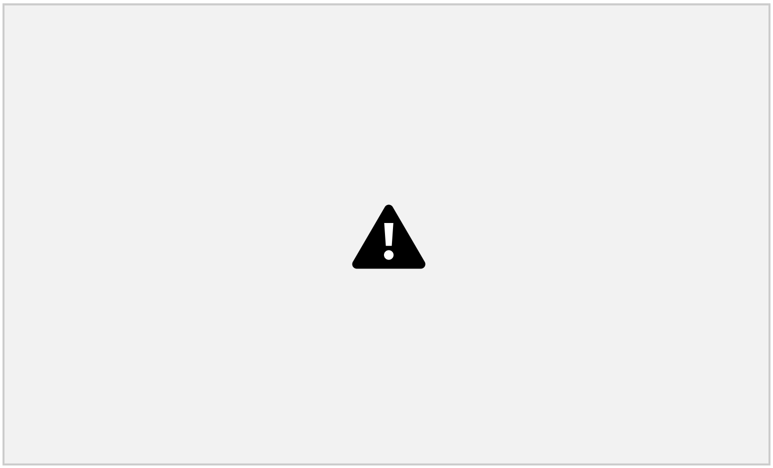


FIGURE 2.8

Field widths and setw.

Here’s the output of WIDTH2:

```
LOCATION POPULATION
Portcity 2425785
Hightown 47
Lowville 9761
```

Cascading the Insertion Operator

Note that there's only one cout statement in WIDTH1 and WIDTH2, although it's written on mul tiple lines. In doing this, we take advantage of the fact that the compiler ignores whitespace, and that the insertion operator can be cascaded. The effect is the same as using four separate statements, each beginning with cout.

Multiple Definitions

We initialized the variables pop1, pop2, and pop3 to specific values at the same time we defined them. This is similar to the way we initialized char variables in the CHARVARS example. Here, however, we've defined and initialized all three variables on one line, using the same long keyword and separating the variable names with commas. This saves space where a num ber of variables are all the same type.

The IOMANIP Header File

The declarations for the manipulators (except endl) are not in the usual IOSTREAM header file, but in a separate header file called IOMANIP. When you use these manipulators you must #include this header file in your program, as we do in the WIDTH2 example.

Variable Type Summary

Our program examples so far have used four data types—int, char, float, and long. In addition we've mentioned types bool, short, double, and long double. Let's pause now to summarize these data types. Table 2.2 shows the keyword used to define the type, the numerical range the type can accommodate, the digits of precision (in the case of floating point numbers), and the bytes of memory occupied in a 32-bit environment.

TABLE 2.2 Basic C++ Variable Types

	Numerical Range		*Digits of*	*Bytes of*
Keyword	*Low*	*High*	*Precision*	*Memory*
bool	false	true	n/a	1
char	–128	127	n/a	1
short	–32,768	32,767	n/a	2