Computer

Programming

A Beginner's Course

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Preface

This book attempts to teach computer programming to the complete beginner using the C language. As such, it assumes you have no knowledge whatsoever about programming. And if you are worried that you are not good at high-school mathematics, don't be. It is a myth that you must be good at mathematics to learn programming. In this book, a knowledge of primary school mathematics is all that is required—basic addition, subtraction, multiplication, division, finding the percentage of some quantity, finding an average or the larger of two quantities.

Some of our most outstanding students over the last thirty years have been people with little mathematics background from all walks of life—politicians, civil servants, sports people, housewives, secretaries, clerical assistants, artists, musicians and teachers. On the other hand, we've had mathematical folks who didn't do as well as might be expected.

What *will* be an asset is the ability to think logically or to follow a logical argument. If you are good at presenting convincing arguments, you will probably be a good programmer. Even if you aren't, programming is the perfect vehicle for teaching logical thinking skills. You should learn programming for these skills even if you never intend to become a serious programmer.

The main goal of this book is to teach fundamental programming principles using C, one of the most widely used programming languages in the world today. C is considered a 'modern' language even though its roots date back to the 1970s. Originally, C was designed for writing 'systems' programs—things like operating systems, editors, compilers, assemblers and input/output utility programs. But, today, C is used for writing all kinds of applications programs as well—wordprocessing programs, spreadsheet programs, database management programs, accounting programs, games, educational software—the list is endless.

However, this book is more about teaching programming basics than it is about teaching C. We discuss only those features and statements in C that are necessary to achieve our goal. Once you learn the *principles* well, they can be applied to any language.

Chapter 1 gives an overview of the programming process. Chapter 2 describes the basic building blocks needed to write programs. Chapter 3 explains how to write programs with the simplest kind of logic—sequence logic. Chapter 4 shows how to write programs which can make decisions. Chapter 5 explains the notion of 'looping' and how to use this powerful programming idea to solve more interesting problems. Chapter 6 deals with the oft-neglected, but important, topic of working with characters. Chapter 7 introduces functions—the key concept needed for writing large programs. And Chapter 8 tackles the nemesis of many would-be programmers—array processing.

The first step in becoming a good programmer is learning the syntax rules of the programming language. This is the easy part and many people mistakenly believe

that this makes them a programmer. They get carried away by the cosmetics—they learn the *features* of a language without learning how to use them to solve problems. Of course, you must learn *some* features. But it is far better to learn a few features and be able to use them to solve many problems rather than learn many features but can't use them to solve anything. For this reason, this book introduces a feature (like an **if** statement, say) and then discusses many examples to illustrate how the feature can be used to solve different problems.

This book is intended for anyone who is learning programming for the first time, regardless of age or institution. The material has been taught successfully to students preparing for high-school examinations in Computer Studies or Information Technology, students at college, university and other tertiary-level institutions.

The presentation is based on the experience that many people have difficulty in learning programming. To try and overcome this, we use an approach which provides clear examples, detailed explanations of very basic concepts and numerous interesting problems (not just artificial exercises whose only use is to illustrate some language feature).

While computer programming is essentially a mental activity and you *can* learn a fair amount of programming from just *reading* the book, it is important that you "get your hands dirty" by writing and running programs. One of life's thrills is to write your first program and get it to run successfully on a computer. Don't miss out on it.

But do not stop there. The only way to learn programming well is to write programs to solve new problems. The end-of-chapter exercises are a very rich source of problems, a result of the author's more than 30 years in the teaching of programming.

Thank you for taking the time to read this book. I hope your venture into programming is a successful and enjoyable one.

Noel Kalicharan

Contents

1 Elementary programming concepts

In this chapter, we will explain:

- how a computer solves a problem
- the various stages in the development of a computer program: from problem definition to finished program
- how a computer executes a program
- what is a 'data type' and its fundamental role in writing a program
- the role of characters—the basic building blocks of all programs
- the concepts of *constants* and *variables*
- the distinction between syntax and logic errors
- how to produce basic output in C using the **printf** statement
- what is an *escape sequence*
- how descriptive or explanatory comments can be included in your program
- what is an *assignment statement* and how to write one in C

We are all familiar with the computer's ability to perform a wide variety of tasks. For instance, we can use it to play games, write a letter or a book, perform accounting functions for a company, learn a foreign language, listen to music on a CD, send a fax or search for information on the Internet. How is this possible, all on the same machine? The answer lies with programming—the creation of a sequence of instructions which the computer can perform (we say "execute") to accomplish each task. This sequence of instructions is called a *program*. Each task requires a different program:

- to play a game, we need a game-playing program;
- to write a letter or a book, we need a word processing program;
- to do accounts, we need an accounting program;
- to learn Spanish, we need a program that teaches Spanish;
- to listen to a CD, we need a music-playing program;
- to send a fax, we need a fax-sending program;
- to use the Internet, we need a program called a 'Web browser';

For every task we want to perform, we need an appropriate program. And in order for the computer to run a program, the program must be stored (we sometimes say 'loaded') in the computer's memory.

But what is the nature of a program? First, we need to know that computers are built to execute instructions written in what is called *machine language*. In machine language, everything is expressed in terms of the binary number system —1's and 0's. Each computer has its own machine language and the computer can execute instructions written *in that language only*.

The instructions themselves are very simple, for example, add or subtract two numbers, compare one number with another or copy a number from one place to another. How, then, can the computer perform such a wide variety of tasks, solving such a wide variety of problems, with such simple instructions?

The answer is that no matter how complex an activity may seem, it can usually be broken down into a series of simple steps. It is the ability to analyze a complex problem and express its solution in terms of simple computer instructions that is one of the hallmarks of a good programmer.

We usually think of machine language, which uses binary instructions, as a *low-level* programming language. In the early days of computing (1940's and 50's) programmers had to write programs in machine language, that is, express all their instructions using 1's and 0's.

To make life a little easier for them, *assembly language* was developed. This was closely related to machine language but it allowed the programmer to use mnemonic[1] instruction codes (such as **ADD**) and names for storage locations (such as **sum**) rather than strings of binary digits (bits). For instance, a programmer could refer to a number by **sum** rather than have to remember that the number was stored in memory location 1000011101101011.

A program called an *assembler* is used to convert an assembly language program into machine language. Still, programming this way had several drawbacks:

- it was very tedious and error prone;
- it forced the programmer to think in terms of the machine rather than in terms of his problem;
- a program written in the machine language of one computer could not be run on a computer with a different machine language. Changing your computer could mean having to rewrite all your programs.

To overcome these problems, *high-level* or *problem-oriented* languages were developed in the late 1950's and 60's. The most popular of these were FORTRAN (FORmula TRANslation) and COBOL (COmmon Business-Oriented Language). FORTRAN was designed for solving scientific and engineering problems which involved a great deal of numerical computation. COBOL was designed to solve the data-processing problems of the business community.

The idea was to allow the programmer to think about a problem in terms familiar to him and relevant to the problem rather than have to worry about the machine.

[1] Meant to help to remember; e.g. DIV suggests what it means—divide

So, for instance, if he wanted to know the larger of two quantities, **A** and **B**, he could write

```
IF A IS GREATER THAN B THEN BIGGER = A ELSE BIGGER = B
```

rather than have to fiddle with several machine or assembly language instructions to get the same result. Thus high-level languages enabled the programmer to concentrate on solving the problem at hand, without the added burden of worrying about the idiosyncrasies[2] of a particular machine.

However, the computer *still* could only *execute* instructions written in machine language. A program called a *compiler* is used to translate a program written in a high-level language to machine language.

Thus we speak of a FORTRAN compiler or a COBOL compiler for translating FORTRAN and COBOL programs, respectively. But that's not the whole story. Since each computer has its own machine language, we must have, say, a FORTRAN compiler for an IBM Pentium computer and a FORTRAN compiler for a Macintosh PowerPC computer.

1.1 How a computer solves a problem

Solving a problem on a computer involves the following activities:

(1) Define the problem.
(2) Analyze the problem.
(3) Develop an *algorithm* (a method) for solving the problem.
(4) Write the computer program which *implements* the algorithm.
(5) Test and debug (find the errors in) the program.
(6) Document the program. (Explain how the program works and how to use it).
(7) Maintain the program.

There is normally some overlap of these activities. For example, with a large program, a portion may be written and tested before another portion is written. Also, documentation should be done at the same time as all the other activities; each activity produces its own items of documentation which will be part of the final program documentation.

1.1.1 Define the problem

Suppose we want to help a child work out the areas of squares. This defines a problem to be solved. However, a brief analysis reveals that the definition is not complete or specific enough to proceed with developing a program. Talking with the child might reveal that she needs a program which requests her to enter the length of a side of the square; the program then prints the area of the square.

[2] Distinguishing characteristics or features

1.1.2 Analyze the problem

We further analyze the problem to

(a) ensure that we have the clearest possible understanding of it;

(b) determine general requirements such as the main inputs to the program and the main outputs from the program. For more complex programs, we would, for instance, also need to decide on the kinds of *files*[3] which may be needed.

If there are several ways of solving the problem, we should consider the alternatives and choose the best or most appropriate one.

In this example, the input to the program is the length of one side of the square and the output is the area of the square. We only need to know how to calculate the area. If the side is **s**, then the area, **a**, is calculated by:

$$a = s \times s$$

1.1.3 Develop an algorithm for solving the problem

An *algorithm* is a set of instructions which, if faithfully followed, will produce a solution to a given problem or perform some specified task. When an instruction is followed, we say it is *executed*. We can speak of an algorithm for finding a word in a dictionary, for changing a punctured tyre or for playing a video game.

For any problem, there will normally be more than one algorithm to solve it. Each algorithm will have its own advantages and disadvantages. When we are searching for a word in the dictionary, one method would be to start at the beginning and look at each word in turn. A second method would be to start at the end and search backwards. Here, an advantage of the first method is that it would find a word faster if it were at the beginning, while the second method would be faster if the word were towards the end.

Another method for searching for the word would be one which used the fact that the words in a dictionary are in alphabetical order—this is the method we all use when looking up a word in a dictionary. In any situation, a programmer would usually have a choice of algorithms, and it is one of her more important jobs to decide which algorithm is the best, and why this is so.

In our example, we must write the instructions in our algorithm in such a way that they can be easily converted into a form which the computer can follow. Computer instructions fall into three main categories:

(1) *Input* instructions, used for supplying data from the 'outside world' to a program; this is usually done via the keyboard or a file.

[3] Think of a file as a place in the computer used for storing things like documents, pictures, programs, even songs and movies

(2) *Processing* instructions, used for manipulating data inside the computer. These instructions allow us to add, subtract, multiply and divide; they also allow us to compare two values, and act according to the result of the comparison. Also, we can move data from one location in the computer's memory to another location.

(3) *Output* instructions, used for getting information out of the computer to the outside world.

Data and variables

All computer programs, except the most trivial, are written to operate on *data*. For example:

- the data for an action game might be keys pressed or the position of the cursor when the mouse is clicked;
- the data for a word processing program are the keys pressed while you are typing a letter;
- the data for an accounting program would include, among other things, expenses and income;
- the data for a program that teaches Spanish could be an English word that you type in response to a question.

Recall that a program must be stored in the computer's memory for it to be run. When data is supplied to a program, that data is also stored in memory. Thus we think of memory as a place for holding programs and data. One of the nice things about programming in a high-level language (as opposed to machine language) is that you don't have to worry about which memory locations are used to store your data. But how do we refer to an item of data, given that there may be many data items in memory?

Think of memory as a set of boxes (or storage locations). Each box can hold one item of data, for example, one number. We can give a name to a box, and we will be able to refer to that box by the given name. In our example, we will need two boxes, one to hold the side of the square and one to hold the area. We will call these boxes `s` and `a`, respectively.

If we wish, we can change the value in a box at any time; since the values can vary, `s` and `a` are called variable names, or simply *variables.* Thus a variable is a name associated with a particular memory location or, if you wish, it is a *label* for the memory location. We can speak of giving a variable a value, or setting a variable to a specific value, `1`, say. Important points to remember are:

- a box can hold only one value at a time; if we put in a new value, the old one is lost;
- we must not assume that a box contains *any* value unless we specifically store a value in the box. In particular, we must not assume that the box contains 0.

Variables are a common feature of computer programs. It is very difficult to imagine what programming would be like without them. In everyday life, we often use variables. For example, we speak of an 'address'. Here, 'address' is a variable whose value depends on the person under consideration. Other common variables are telephone number, name of school, subject, size of population, type of car, television model, etc. (What are some possible values of these variables?)

Example – develop the algorithm

Using the notion of an algorithm and the concept of a variable, we develop the following algorithm for calculating the area of a square given one side:

Algorithm for calculating area of square given one side

(1) Ask the user for the length of a side
(2) Store the value in the box **s**
(3) Calculate the area of the square (**s** × **s**)
(4) Store the area in the box **a**
(5) Print the value in box **a**, appropriately labelled
(6) Stop

When an algorithm is developed, it must be checked to make sure that it is doing its intended job correctly. We can test an algorithm by 'playing computer', that is, we execute the instructions by hand, using appropriate data values. This process is called *dry running* or *desk checking* the algorithm. It is used to pinpoint any errors in logic before the computer program is actually written. We should *never* start to write programming code unless we are confident that the algorithm is correct.

1.1.4 Write the program for the algorithm

We have specified the algorithm using English statements. However, these statements are sufficiently 'computer-oriented' for a computer program to be written directly from them. Before we do this, let us see how we expect the program to work from the user's point of view.

First, the program will type the request for the length of a side; we say the program *prompts* the user to supply data. The screen display might look like this:

```
Enter length of side:
```

The computer will then wait for the user to type the length. Suppose the user types 12. The display will look like this:

```
Enter length of side: 12
```

The program will then accept (we say *read*) the number typed, calculate the area and print the result. The display may look like this:

```
Enter length of side: 12

Area of square is 144
```

Here we have specified what the *output* of the program should look like. For instance, there is a blank line between the prompt line and the line that gives the answer; we have also specified the exact form of the answer. This is a simple example of *output design*. This is necessary since the programmer cannot write the program unless he knows the precise output required.

In order to write the computer program from the algorithm, a suitable *programming language* must be chosen. We can think of a *program* as a set of instructions, *written in a programming language*, which, when executed, will produce a solution to a given problem or perform some specified task.

The major difference between an algorithm and a program is that an algorithm can be written using informal language without having to follow any special rules (though some *conventions* are usually followed) whereas a program is written in a programming language and *must* follow all the rules (the *syntax* rules) of the language. (Similarly, if we wish to write correct English, we must follow the syntax rules of the English language).

In this book, we will be showing you how to write programs in C, the programming language developed by Ken Thompson and Dennis Ritchie of Bell Laboratories, and one of the most popular and widely used today.

Here is the C program which requests the user to enter the length of a side and prints the area of the square:

```
#include <stdio.h>
main() {
  int a, s;
  printf("Enter length of side: ");
  scanf("%d", &s);        //store length in s
  a = s * s;              //calculate area; store in a
  printf("\nArea of square is %d\n", a);
}
```

It is not too important that you understand anything about this program at this time. But you can observe that a C program has something (a function) called **main** followed by opening and closing brackets. Between the left brace { and the right brace } we have what is called the *body* of the function. The statement

```
int a, s;
```

is called a *declaration*. The parts after // are *comments* which help to explain the program but have no effect when the program is run. And * is used to denote multiplication.

All of these terms will be explained in detail in due course.

Finally, a program written in a high-level language is usually referred to as a *source program* or *source code*.

1.1.5 Test and debug the program

Having written the program, the next job is to *test* it to find out whether it is doing its intended job. Testing a program involves the following steps:

1. *compile the program*: recall that a computer can execute a program written in *machine language only*. Before the computer can run our C program, the latter must be converted to machine language. We say that the *source code* must be converted to *object code* or *machine code*. The program which does this job is called a *compiler*. Appendix D tells you how you can acquire a C compiler for writing and running your programs.

   Among other things, a compiler will check the source code for *syntax errors*—errors which arise from breaking the rules for writing statements in the language. For example, a common syntax error in writing C programs is to omit a semicolon or to put one where it is not required.

   If the program contains syntax errors, these must be corrected before compiling it again. When the program is free from syntax errors, the compiler will convert it to machine language and we can go on to the next step.

2. *run the program*: here we request the computer to execute the program and we supply data to the program *for which we know the answer*. Such data is called *test data*. Some values we can use for the length of a side are 3, 12 and 20.

   If the program does not give us the answers 9, 144 and 400, respectively, then we know that the program contains at least one *logic* error. A logic error is one which causes a program to give incorrect results for valid data. A logic error may also cause a program to *crash* (come to an abrupt halt).

   If a program contains logic errors, we must *debug* the program; we must find and correct any errors that are causing the program to produce wrong answers.

To illustrate, suppose the statement which calculates the area was written (incorrectly) as:

```
a = s + s;
```

and when the program is run, 10 is entered for the length. Assume we *know* that the area should be 100. But when the program is run, it prints

```
Enter length of side: 10
Area of square is 20
```

Since this is **not** the answer we expect, we know that there is an error (perhaps more than one) in the program. Since the area is wrong, the logical place to start looking for the error is in the statement which calculates the area. If we look closely, we should discover that **+** was typed instead of *****. When this correction is made, the program works fine.

1.1.6 Document the program

The final job is to complete the documentation of the program. So far, our documentation includes:

- the statement of the problem;
- the algorithm for solving the problem;
- the program listing;
- test data and the results produced by the program.

These are some of the items that make up the *technical documentation* of the program. This is documentation that is useful to a programmer, perhaps for modifying the program at a later stage.

The other kind of documentation which must be written is *user documentation*. This enables a non-technical person to use the program without needing to know about the internal workings of the program. Among other things, the user needs to know how to load the program in the computer and how to use the various features of the program. If appropriate, the user will also need to know how to handle unusual situations which may arise while the program is being used.

1.1.7 Maintain the program

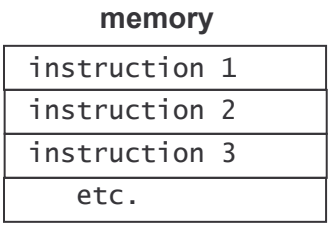
Except for things like class assignments, programs are normally meant to be used over a long period of time. During this time, errors may be discovered which previously went unnoticed. Errors may also surface because of conditions or data that never arose before. Whatever the reason, such errors must be corrected.

But a program may need to be modified for other reasons. Perhaps the assumptions made when the program was written have now changed due to changed company policy or even due to a change in government regulations (e.g. changes in income tax rates). Perhaps the company is changing its computer system and the program needs to be 'migrated' to the new system. We say the program must be 'maintained'.

Whether or not this is easy to do depends a lot on how the original program was written. If it was well-designed and properly documented, then the job of the *maintenance programmer* would be made so much easier.

1.2 How a computer executes a program

First, recall that a computer can execute a program written in machine language only. For the computer to execute the instructions of such a program, those instructions must be *loaded* into the computer's *memory* (also called *primary storage*), like this:



You can think of memory as a series of storage locations, numbered consecutively starting at `0`. Thus you can speak of memory location `27` or memory location `31548`. The number associated with a memory location is called its *address*.

A computer *runs* a program by executing its first instruction, then the second, then the third, and so on. It is possible that one instruction might say to jump over several instructions to a particular one and continue executing from there. Another might say to go back to a previous instruction and execute it again.

No matter what the instructions are, the computer faithfully executes them exactly as specified. That is why it is so important that programs specify precisely and exactly what must be done. The computer cannot know what you *intend*, it can only execute what you actually *write*. If you give the computer the wrong instruction, it will blindly execute it just as you specify.

1.3 Data types

Every day we meet names and numbers—at home, at work, at school or at play. A person's name is a type of data; so is a number. We can thus speak of the two *data types* called 'name' and 'number'. In the statement:

Caroline bought 3 dresses for $199.95

we can find:

- an example of a name: **Caroline**;
- two examples of numbers: `3` and `199.95`.

Usually, we find it convenient to divide numbers into two kinds:

(1) whole numbers, or *integers*;

(2) numbers with a decimal point, so-called *real* or *floating-point* numbers.

In the example, `3` is an integer and `199.95` is a real number.

Exercise: Identify the data types—names, integers and real numbers—in the following:

(a) Bill's batting average was 35.25 with a highest score of 75.

(b) Abigail, who lives at 41 Third Avenue, worked 36 hours at $11.50 per hour.

(c) In his 8 subjects, Richard's average grade was 68.75.

Generally speaking, programs are written to manipulate data of various types. We use the term *numeric* to refer to numbers (integer or floating-point). We use the term *string* to refer to non-numeric data such as a name, address, job description, title of a song or vehicle number (which is not really a number as far as the computer is concerned—it usually contains letters, e.g. **PAB6052**).

Programming languages in general, and C in particular, precisely define the various types of data which can be manipulated by programs written in those languages. Integer, real (or floating-point), character (data consisting of a single character such as **'K'** or **'%'**) and string data types are the most common.

Each data type defines *constants* of that type. For example,

- some integer constants are `3`, `-52`, `0` and `9813`;
- some real (or floating-point) constants are `3.142`, `-5.0`, `345.21` and `1.16`;
- some character constants are **'t'**, **'+'**, `'8'` and **'R'**;
- some string constants are **"Hi there"**, **"Wherefore art thou, Romeo?"** and **"C World"**.

Note that, in C, a *character* constant is delimited by single quotes and a *string* constant is delimited by double quotes.

When we use a variable in a program, we have to say what type of data (the kind of constants) we intend to store in that variable—we say we must *declare* the variable. It is usually an error if we try to store a type of data in a variable that is different from the type that the variable is declared to hold. For example, it would

be an error to attempt to store a string constant in an integer variable. C data types are discussed in detail in Chapter 2.

1.4 Characters

In computer terminology, we use the term *character* to refer to any one of the following:

- a digit from 0 to 9;
- an uppercase letter from **A** to **Z**;
- a lowercase letter from **a** to **z**;
- a special symbol like (,), $, =, <, >, +, -, /, *, etc.

The following are commonly used terms:

letter	–	one of **a** to **z** or **A** to **Z**
lowercase letter	–	one of **a** to **z**
uppercase letter	–	one of **A** to **Z**
digit	–	one of 0,1,2,3,4,5,6,7,8,9
special character	–	any symbol except a letter or a digit e.g. +, <, >, $, &, *, /, =
alphabetic	–	used to refer to a letter
numeric	–	used to refer to a digit
alphanumeric	–	used to refer to a letter or a digit

Characters are the basic building blocks used in writing programs;

we put characters together to form *variables* and *constants*;

we put variables, constants and special characters to form *expressions* such as **(a + 2.5) * c**;

we add special words such as **if**, **then** and **while** to form *statements* such as

```
if (a > 0) b = a + 2;
```

and we put statements together to form *programs*.

1.5 Welcome to C Programming

We take a quick peek at the C programming language by writing a program to print the message

Welcome to Trinidad & Tobago

One solution is Program P1.1.

Program P1.1

```
#include <stdio.h>
main() {
  printf("Welcome to Trinidad & Tobago");
}
```

The statement

```
#include <stdio.h>
```

is called a *compiler directive*. This simply means that it provides information the compiler needs to compile your program. In C, input/output instructions are provided by means of standard *functions* stored in a standard *library*. These functions use variable (and other) declarations stored in a special *header* file called **stdio.h**. *Any* program which uses an input/output instruction (such as **printf**) *must* inform the compiler to *include* the declarations in the file **stdio.h** with the program. If this is not done, the compiler will not know how to interpret the input/output statements used in the program.

A C program consists of one or more *functions* (or, *subprograms*), one of which must be called **main**. Our solution consists of just one function so it *must* be called **main**. The (round) brackets after **main** are necessary because, in C, a function name is followed by a list of *arguments*, enclosed in brackets. If there are no *arguments*, the brackets must still be present. Here, **main** has no arguments so the brackets alone are present.

Every function has a section called the *body* of the function. The body is where the work of the function is performed. The left and right braces, { and }, are used to define the start and end, respectively, of the body. In C, one or more statements enclosed by { and } is called a *block* or *compound statement*.

The body of **main** contains one statement:

```
printf("Welcome to Trinidad & Tobago");
```

printf is a standard output function which, in this example, takes one argument, a string constant **"Welcome to Trinidad & Tobago"**. Note that, as with all functions, the argument is enclosed in round brackets. The semicolon is used to indicate the end of the statement. We say the semicolon *terminates* the statement. When executed, this statement will print

```
Welcome to Trinidad & Tobago
```

on the 'standard output'. For now, take this to mean the screen.

1.5.1 Running the program

Having written the program on paper, the next task is to get it running on a real computer. How this is done varies somewhat from one computer system to the next but, in general, the following steps must be performed:

(1) type the program to a file. The file could be named **welcome.c**; it is good practice to use **.c** as the filename extension to those files which contain C source code.

(2) invoke your C compiler to compile the program in the file **welcome.c**. For instance, you may have to start up your C compiler and open the file **welcome.c** from the 'File' menu or you may simply have to double-click on the file **welcome.c** to start-up the compiler.

Once the file is open, typically there will be a menu command to 'Compile' or 'Run' the program. (Generally, 'Run' implies 'Compile' and 'Run'). If any (syntax) errors are detected during the compile phase, you must correct these errors and try again.

When all errors have been corrected and the program is 'Run', it will print:

```
Welcome to Trinidad & Tobago
```

1.5.2 A word on program layout

C does not require the program to be laid out as in the example. An equivalent program is

```
#include <stdio.h>
main()  { printf("Welcome to Trinidad & Tobago"); }
```

or

```
#include <stdio.h>
        main()
{
  printf("Welcome to Trinidad & Tobago");
}
```

For this small program, it probably does not matter which version we use. However, as program size increases, it becomes imperative that the *layout* of the program highlights the logical *structure* of the program.

This improves its readability and makes it easier to understand. Indentation and clearly indicating which { matches which } can help in this regard. We will see the value of this principle as our programs become more substantial.

1.6 Writing output with printf

Suppose we want to write a program to print the lines[4]:

```
Where the mind is without fear
And the head is held high
```

Our initial attempt might be:

```
#include <stdio.h>
main() {
  printf("Where the mind is without fear");
  printf("And the head is held high");
}
```

However, when run, this program would print:

```
Where the mind is without fearAnd the head is held high
```

Note that the two strings are joined together (we say the strings are *concatenated*). This happens because **printf** does not place output on a *new* line, unless this is specified explicitly. Put another way, **printf** does not automatically supply a *newline* character after printing its argument(s). A newline character would cause subsequent output to begin at the left margin of the next line.

In the example, a newline character is *not* supplied after **fear** is printed so that **And the head...** is printed on the same line as **fear** and immediately after it.

1.6.1 The newline character, \n (backslash n)

To get the desired effect, we must tell **printf** to supply a newline character after printing **...without fear**. We do this by using the character sequence **\n** (backslash **n**) as in Program P1.2.

Program P1.2

```
#include <stdio.h>
main() {
  printf("Where the mind is without fear\n");
  printf("And the head is held high\n");
}
```

The first **\n** says to terminate the current output line; subsequent output will start at the left margin of the next line. Thus, **And the...** will be printed on a new line.

[4] From *The Gitanjali* by Rabindranath Tagore

The second **\n** has the effect of terminating the second line. If it were not present, the output will still come out right, but only because this is the last line of output.

A program prints all pending output just before it terminates. (This is also the reason why our first program worked without **\n**).

As an embellishment, suppose we want to put a blank line between our two lines of output, like this:

```
Where the mind is without fear

And the head is held high
```

Each of the following sets of statements will accomplish this:

(1)
```
printf("Where the mind is without fear\n\n");
printf("And the head is held high\n");
```

(2)
```
printf("Where the mind is without fear\n");
printf("\nAnd the head is held high\n");
```

(3)
```
printf("Where the mind is without fear\n");
printf("\n");
printf("And the head is held high\n");
```

We just have to make sure we print two **\n**'s between **fear** and **And**. The first **\n** ends the first line; the second ends the second line, in effect, printing a blank line. C gives us a lot of flexibility in how we write statements to produce a desired effect.

Exercise: Write a program to print the lyrics of your favourite song.

1.6.2 Escape sequences

Within the string argument to **printf**, the backslash (\) signals that a special effect is needed at this point. The character following the backslash specifies what to do. This combination (\ followed by another character) is referred to as an *escape sequence*. The following are some escape sequences you can use in a string in a **printf** statement:

\n	issue a newline character
\f	issue a new page (formfeed) character
\t	issue a tab character
\"	print "
****	print \

For example, using an escape sequence is the only way to print a double quote as part of your output. Suppose we want to print the line

```
Use " to begin and end a string
```

If we typed

```
printf("Use " to begin and end a string\n");
```

then C would assume that the double quote *after* **Use** ends the string (causing a subsequent error when it can't figure out what to do with **to**). Using the escape sequence \", we can correctly print the line with:

```
printf("Use \" to begin and end a string\n");
```

Exercise: Write a statement to print the line:

```
An escape sequence starts with \
```

1.6.3 Printing the value of a variable

So far, we have used **printf** to print the *value* of a string constant (that is, the characters of the string excluding the quotes). We now show how we can print the *value* of a variable ignoring, for the moment, *how* the variable gets its value. (We will see how in Chapter 2). Suppose the integer variable **a** has the value 52. The statement:

```
printf("The number of students = %d\n", a);
```

will print:

```
The number of students = 52
```

This **printf** is a bit different from those we have seen so far. This one has *two* arguments—a string and a variable. The string, called the *format string*, contains a *format specification* %d. (In our previous examples, the format string contained no format specifications). The effect, in this case, is that the format string is printed as before, except that the %d is replaced by the value of the second argument, **a**. Thus, %d is replaced by 52, giving:

```
The number of students = 52
```

We will explain **printf** and format specifications in more detail in Chapter 2 but, for now, note that we use the specification %d if we want to print an integer value.

What if we want to print more than one value? This can be done provided that *each* value has a corresponding format specification. For example, suppose that **a** has the value 14 and **b** has the value 25. Consider,

```
printf("The sum of %d and %d is %d\n", a, b, a + b);
```

This **printf** has *four* arguments—the format string and three values to be printed: **a**, **b** and **a + b**. The format string *must* contain three format specifications: the first will correspond to **a**, the second to **b** and the third to **a + b**. When the format string is printed, each %d will be replaced by the *value* of its corresponding argument, giving:

```
The sum of 14 and 25 is 39
```

Exercise: What is printed by the following statement?

```
printf("%d + %d = %d\n", a, b, a + b);
```

1.7 Comments

All programming languages let you include *comments* in your programs. Comments can be used to remind yourself (and others) of what processing is taking place or what a particular variable is being used for. They can be used to explain or clarify any aspect of a program which may be difficult to understand by just reading the programming statements. This is very important since the easier it is to understand a program, the more confidence you will have that it is correct. It is worth adding anything which makes a program easier to understand.

Remember that a comment (or lack of it) has absolutely no effect on how the program runs. If you remove all the comments from a program, it will run exactly the same way as with the comments.

Each language has its own way of specifying how a comment must be written. In C, we write a comment by enclosing it within /* and */, for example:

```
/* This program prints a greeting */
```

A comment extends from /* to the next */ and may span one or more lines. The following is a valid comment:

```
/* This program reads characters one at a time
   and counts the number of letters found */
```

C also lets you use // to write one-line comments. The comment extends from // to the end of the line, for example:

```
a = s * s;      //calculate area; store in a
```

In this book, we will use mainly one-line comments.

1.8 Programming with variables

To reinforce the ideas discussed so far, let us write a program which adds the numbers 14 and 25 and prints the sum.

We would need storage locations for the two numbers and the sum. The values to

be stored in these locations are *integer* values. To refer to these locations, we make up the names **a**, **b** and **sum**, say. (Any other names would do. In C, as in all programming languages, there are rules to follow for making up variable names, for instance, a name must start with a letter and cannot contain spaces. We will see the C rules in the next chapter).

One possible algorithm might look like this:

```
set a to 14
set b to 25
set sum to a + b
print sum
```

The algorithm consists of four statements. The following explains the meaning of each statement:

- **set a to 14** — store the number 14 in memory location **a**; this is an example of an *assignment statement*.
- **set b to 25** — store the number 25 in memory location **b**.
- **set sum to a + b** — add the numbers in memory locations **a** and **b** and store the sum in memory location **sum**. The result is that 39 is stored in **sum**.
- **print sum** — print (on the screen) the value in **sum**, i.e. 39.

Program P1.3 shows how we can write this algorithm as a C program.

Program P1.3

```
// This program prints the sum of 14 and 25. It shows how
// to declare variables in C and assign values to them.
#include <stdio.h>
main() {
  int a, b, sum;
  a = 14;
  b = 25;
  sum = a + b;
  printf("%d + %d = %d\n", a, b, sum);
}
```

When run, this program will print

```
14 + 25 = 39
```

In C, variables are declared as *integer* using the required word **int**. (In programming terminology, we say that **int** is a *reserved* word). Thus, the statement:

```
int a, b, sum;
```

'declares' that **a**, **b** and **sum** are integer variables. In C, all variables must be declared before they are used in a program. Note that the variables are separated by commas, with a semicolon after the last one. If we were declaring just one variable (**a**, say), we would write:

```
int a;
```

The statement

```
a = 14;
```

is C's way of writing the *assignment statement*

```
set a to 14
```

It is sometimes pronounced "a becomes 14". In C, an assignment statement consists of a variable (**a** in the example), followed by an equals sign (**=**), followed by the value to be assigned to the variable (14 in the example), followed by a semicolon. In general, the value can be a constant (like 14), a variable (like **b**) or an expression (like **a + b**). Thus,

set b to 25 is written as

```
b = 25;
```

and **set sum to a + b** is written as

```
sum = a + b;
```

One final point: you may have gathered from page 18 that, for this problem, the variable **sum** is not really necessary. We *could*, for instance, have omitted **sum** from the program altogether and used:

```
int a, b;
a = 14;
b = 25;
printf("%d + %d = %d\n", a, b, a + b);
```

to give the same result since C lets us use an expression (e.g. **a + b**) as an argument to **printf**. However, if the program were longer and we needed to use the sum in other places, it would be wise to calculate and store the sum once (in **sum**, say). Whenever the sum is needed, we use **sum** rather than recalculate **a + b** each time.

Now that we have a general idea of what is involved in writing a program, we are ready to get down to the nitty-gritty of C programming.

Exercises 1

1. What makes it possible to do such a variety of things on a computer?
2. Computers can execute instructions written in what language?
3. Give two advantages of assembly language over machine language.
4. Give two advantages of a high-level language over assembly language.
5. Describe two main tasks performed by a compiler.
6. Describe the steps which must be performed for a problem to be solved by a computer.
7. Distinguish between an algorithm and a program.
8. Programming instructions fall into 3 main categories; what are they?
9. Distinguish between a syntax error and a logic error.
10. What is meant by "debugging a program"?
11. Name 5 data types commonly used in programming and give examples of constants of each type.
12. What are the different classes into which characters can be divided? Give examples in each class.
13. What is the purpose of comments in a program?
14. Write a program to print **Welcome to C** on the screen.
15. Write a program to print the following:

    There is a tide in the affairs of men
    Which, taken at the flood, leads on to fortune

16. Write a program to print any 4 lines of your favourite song or poem.
17. Same as exercise 16, but print a blank line after each line.
18. If **a** is 29 and **b** is 5, what is printed by each of the following statements?

```
printf("The product of %d and %d is %d\n", a, b, a * b);
printf("%d + %d = %d\n", a, b, a + b);
printf("%d - %d = %d\n", a, b, a - b);
printf("%d x %d = %d\n", a, b, a * b);
```

19. If **a** is 29 and **b** is 14, what is printed by the following statements?

```
printf("%d + \n", a);
printf("%d\n", b);
printf("--\n");
printf("%d\n", a + b);
```

20. If **rate** = 15, what is printed by (a) **printf("rate\n")**? (b) **printf("%d\n", rate)**?

2 C – the basics

In this chapter, we will explain:

- what is an alphabet, a character set and a token
- what is a syntax rule and a syntax error
- what is a reserved word
- how to create identifiers in C
- what is a symbolic constant
- the C data types—**int**, **float** and **double**
- how to write **int** and **double** expressions
- how to print an integer using a field width
- how to print a floating-point number to a required number of decimal places
- what happens when **int** and **double** values are mixed in the same expression
- what happens when we assign **int** to **double** and **double** to **int**
- how to declare a variable to hold a string
- how to assign a string value to a string variable
- some problems to avoid when using the assignment statement

In this chapter, we discuss some basic concepts you need to know in order to write programs in the C programming language.

A programming language is similar to speaking languages in many respects. It has an *alphabet* (more commonly referred to as a *character set*) from which everything in the language is constructed. It has rules for forming *words* (also called *tokens*), rules for forming statements and rules for forming programs. These are called the *syntax rules* of the language and *must* be obeyed when writing programs. If you violate a rule, your program will contain a *syntax error*. When you attempt to compile the program, the compiler will inform you of the error. You must correct it and try again.

The first step in becoming a good programmer is learning the syntax rules of the programming language. This is the easy part and many people mistakenly believe that this makes them a programmer. It is like saying that learning some rules of English grammar and being able to write some correctly formed sentences makes one a novelist. Novel-writing skills require much more than learning some rules of grammar. Among other things, it requires insight, creativity and a knack for using the right words in a given situation.

In the same vein, a good programmer must be able to creatively use the features of the language to solve a wide variety of problems in an elegant and efficient manner. This is the difficult part and can only be achieved by long, hard study of problem-solving algorithms and writing programs to solve a wide range of problems. But we must start with baby steps.

2.1 The C alphabet

In Section 1.4 we introduced the idea of a character. We can think of the C alphabet as consisting of all the characters one could type on a standard English keyboard, for example, the digits, uppercase and lowercase letters, and special characters such as **+**, **=**, **<**, **>**, **&** and **%**.

More formally, C uses the ASCII (American Standard Code for Information Interchange, pronounced **ass-key**) character set. This is a character standard which includes the letters, digits and special characters found on a standard keyboard. It also includes *control* characters such as backspace, tab, line feed, form feed and carriage return. Each character is assigned a numeric code. The ASCII codes run from 0 to 127.

The programs in this book will be written using the ASCII character set. The characters in the ASCII character set are shown in Appendix B.

Character handling will be discussed in detail in Chapter 6.

2.2 C tokens

The *tokens* of a language are the basic building blocks which can be put together to construct programs. A token can be a reserved word (such as **int** or **while**), an identifier (such as **b** or **sum**), a constant (such as **25** or **"Alice in Wonderland"**), a delimiter (such as **{** or **;**) or an operator (such as **+** or **=**).

For example, consider the following portion of the program given at the end of the last chapter:

```
main() {
  int a, b, sum;
  a = 14;
  b = 25;
  sum = a + b;
  printf("%d + %d = %d\n", a, b, sum);
}
```

Starting from the beginning, we can list the tokens in order:

`main`	identifier
`(`	left bracket, delimiter

)	right bracket, delimiter
{	left brace, delimiter
int	reserved word
a	identifier
,	comma, delimiter
b	identifier
,	comma, delimiter
sum	identifier
;	semicolon, delimiter
a	identifier
=	equals sign, operator
14	constant
;	semicolon, delimiter

and so on. Thus we can think of a program as a 'stream of tokens', which is precisely how the compiler views it. So that, as far as the compiler is concerned, the above could have been written:

```
main() { int a, b, sum;
  a = 14; b = 25; sum = a + b;
  printf("%d + %d = %d\n", a, b, sum); }
```

The order of the tokens is exactly the same; to the compiler, it *is* the same program. To the computer, only the order of the tokens is important. However, layout and spacing are important to make the program more readable to human beings.

A word on spacing

Generally speaking, C programs can be written using "free format". The language does not require us, for instance, to write one statement on a line. Even a simple statement like

```
a = 14;
```

can be written on four separate lines, like this:

```
a
  =
14
;
```

Only the order of the tokens is important. However, since `14` is one token, the `1` cannot be separated from the `4`. You are not even allowed to put a space between `1` and `4`.

Except within a string or character constant, spaces are not significant in C. However, judicious use of spaces can dramatically improve the readability of your program. A general 'rule of thumb' is that wherever you can put one space, you can put any number of spaces without affecting the meaning of your program. The statement

```
a = 14;
```

can be written as

```
a=14;
```

or

```
a  =  14  ;
```

or

```
a=   14;
```

The statement

```
sum = a + b;
```

can be written as

```
sum=a+b;
```

or

```
sum=  a  +  b  ;
```

or

```
sum = a+b;
```

Note, of course, that you cannot have spaces *within* the variable **sum**. It would be wrong to write **s um** or **su m**. In general, all the characters of a token must stay together.

2.2.1 Reserved words

The C language uses a number of *keywords* such as **int**, **char** and **while**. A keyword has a special meaning in the context of a C program and can be used for that purpose only. For example, **int** can be used only in those places where we need to specify that the type of some item is *integer*. All keywords are written in *lowercase letters* only. Thus **int** is a keyword but **Int** and **INT** are not. Keywords are reserved, that is, you cannot use them as *your* identifiers. As such, they are usually called *reserved words*. A list of C keywords is given in Appendix A.

2.2.2 Identifiers

The C programmer needs to make up names for things such as variables, function names (Chapter 7) and symbolic constants (see following page). A name that he makes up is called a *user identifier*. There are a few simple rules to follow in naming an identifier:

- it must start with a letter or underscore;
- if other characters are required, they can be any combination of letters, digits or underscore;
- the length of an identifier cannot exceed 31 characters[1].

[1] In C99, the latest C standard as of 2006, the limit is 63.

Examples of valid identifiers:

```
r
R
sumOfRoots1and2
_XYZ
maxThrowsPerTurn
TURNS_PER_GAME
R2D2
root1
```

Examples of invalid identifiers:

```
2hotToHandle        // does not start with a letter
Net Pay             // contains a space
ALPHA;BETA          //contains an invalid character ;
```

Important points to note:

- Spaces are not allowed in an identifier. If you need one which consists of two or more words, use a combination of uppercase and lowercase letters (as in **numThrowsThisTurn**) or use the underscore to separate the words (as in **num_throws_this_turn**). We prefer the uppercase/lowercase combination.
- In general, C is *case-sensitive* (an uppercase letter is considered different from the corresponding lowercase letter). Thus **r** is a different identifier from **R**. And **sum** is different from **Sum** is different from **SUM** is different from **SuM**.
- You cannot use a C reserved word as one of your identifiers.

Some naming conventions

Other than the rules for creating identifiers, C imposes no restriction on what names to use, or what format (uppercase or lowercase, for instance) to use. However, good programming practice dictates that some common-sense rules should be followed.

An identifier should be meaningful. For example, if it's a variable, it should reflect the value being stored in the variable; **netPay** is a much better variable than **x** for storing someone's net pay, even though both are valid. If it's a function (Chapter 7), it should give some indication of what the function is supposed to do; **playGame** is a better identifier than **plg**.

It is a good idea to use upper and lower case combinations to indicate the kind of item named by the identifier. In this book, we use the following conventions:

- A *variable* is normally written in lowercase, for example, **sum**. If we need a variable consisting of two or more words, we start the second and subsequent words with an uppercase letter, for example, **voteCount** or **sumOfSeries**.

- A *symbolic* (or *named*) *constant* is an identifier which can be used in place of a constant such as 100. Suppose 100 represents the maximum number of items we wish to process in some program. We would probably need to use the number 100 in various places in the program. But suppose we change our mind and want to cater for 500 items. We would have to change all occurrences of 100 to 500. However, we would have to make sure that we do *not* change an occurrence of 100 used for some purpose other than the maximum number of items (in a calculation like **principal*rate/100**, say).

  To make it easy to change our mind, we can set the identifier **MaxItems** to 100 and use **MaxItems** whenever we need to refer to the maximum number of items. If we change our mind, we would only need to set **MaxItems** to the new value. We will begin a symbolic constant with an uppercase letter. If it consists of more than one word, we will begin each word with uppercase, as in **MaxThrowsPerTurn.**

  We will see how to use symbolic constants in Section 4.5 (page 75).

2.3 Basic data types

In Section 1.3 we briefly touched on the concept of a data type. For most of this book, we will use the following data types:

int, double and **char**

(These, among others, are referred to as *primitive* data types). Each data type defines *constants* of that type. When we declare a variable to be of a particular type, we are really saying what kind of constants (values) can be stored in that variable. For example, if we declare the variable **num** to be **int**, we are saying that the value of num at any time can be an integer constant such as 25, -369 or 1024.

2.4 Integer numbers - int

An **int** variable is used to store an *integer* (whole number) value. An integer value is one of 0, ±1, ±2, ±3, ±4, etc. However, on a computer, the largest and smallest integers which can be stored are determined by the *number of bits* used to store an integer. Appendix C shows how integers can be represented on a computer.

Typically, an **int** variable occupies 16 bits (2 bytes) and can be used to store whole numbers in the range -32,768 to +32,767. Note, however, that on some machines, an **int** could occupy 32 bits, in which case it can store whole numbers from -2,147,483,648 to +2,147,483,647. In general, if n bits are used to store an **int**, the range of numbers which can be stored is -2^{n-1} to $+2^{n-1} - 1$.

As an exercise, find out the largest and smallest **int** values on your computer.

2.4.1 Declaring variables

In C, a variable is declared by specifying a type name followed by the variable. For example,

```
int j;
```

declares **j** to be a variable of type **int**.

You can declare several variables *of the same type* in one statement as in:

```
int a, b, c;  // declares 3 variables of type int
```

The variables are separated by commas, with a semicolon after the last one.

You can declare a variable and give it an initial value in one statement, as in:

```
int j = 14;
```

This declares **j** to be **int** *and* gives it a value of 14.

2.4.2 Integer expressions

An integer constant is written in the manner we are all accustomed to, for example, 354, -1, 30705 and -4802. Note that you can use only a possible sign followed by digits from 0 to 9. In particular, you *cannot* use commas as you might do to separate thousands; thus 32,732 is an *invalid* integer constant—you must write it as 32732.

An integer expression can be written using the following *arithmetic operators*:

+	add
-	subtract
*	multiply
/	divide
%	find remainder

For example, suppose we have the following declaration:

```
int a, b, c;
```

then the following are all valid expressions:

```
a + 39
a + b - c * 2
b % 10    //the remainder when b is divided by 10
c + (a * 2 + b * 2) / 2
```

The operators **+**, **-** and ***** all give the expected results. However, **/** performs *integer division*; if there is any remainder, it is thrown away. We say integer division *truncates*. Thus **19 div 5** gives the value 3; the remainder 4 is discarded.

But what is the value of **-19 div 5**? The answer here is −3. The rule is that, in C, integer division truncates *towards* zero. Since the exact value of −19 ÷ 5 is −3.8, truncating towards zero gives −3. (In the next section, we show how to get the precise value for the division of one integer by another).

The **%** operator gives the remainder when one integer is divided by another; for example,

```
19 % 5 evaluates to 4;
j % 7 gives the remainder when j is divided by 7;
```

You can use it to test, for instance, if a number **j** is even or odd. If **j % 2** is **0** then **j** is even, otherwise **j** is odd.

2.4.3 Precedence of operators

C evaluates an expression based on the usual *precedence* of operators: multiplication and division are done *before* addition and subtraction. We say that multiplication and division have *higher precedence* than addition and subtraction. For example, the expression

```
5 + 3 * 4
```

is evaluated by *first* multiplying 3 by 4 (giving 12) and *then* adding 5 to 12, giving 17 as the value of the expression.

As usual, we can use brackets to force the evaluation of an expression in the order we want. For example,

```
(5 + 3) * 4
```

first adds 5 and 3 (giving 8), and then multiplies 8 by 4, giving 32.

When two operators which have the *same* precedence appear in an expression, they are evaluated *from left to right*, unless specified otherwise by brackets. For example,

```
24 / 4 * 2
```

is evaluated as

```
(24 / 4) * 2
```

(giving 12) and

```
12 - 7 + 3
```

is evaluated as

```
(12 - 7) + 3
```

giving 8. However,

```
24 / (4 * 2)
```

is evaluated as expected, giving 3, and

```
12 - (7 + 3)
```

is evaluated as expected, giving 2.

In C, the remainder operator **%** has the same precedence as multiplication (*****) and division (/).

Exercise: What is printed by the following program? Verify your answer by typing and running the program.

```
#include <stdio.h>
main() {
  int a = 15;
  int b = 24;
  printf("%d  %d\n", b - a + 7,  b - (a + 7));
  printf("%d  %d\n", b - a - 4, b - (a - 4));
  printf("%d  %d\n", b % a / 2, b % (a / 2));
  printf("%d  %d\n", b * a / 2, b * (a / 2));
  printf("%d  %d\n", b / 2 * a, b / (2 * a));
}
```

2.4.4 Printing an integer using a "field width"

We have seen that we can print an integer value by specifying the value (either by a variable or an expression) in a **printf** statement. When we do so, C prints the value using as many "print columns" as needed. For instance, if the value is 782, it is printed using 3 print columns since 782 has 3 digits. If the value is -2345, it is printed using 5 print columns (one for the minus sign).

While this is usually sufficient for most purposes, there are times when it is useful to be able to tell C how many print columns to use. For example, if we want to print the value of **n** in 5 print columns, we can do this by specifying a *field width* of 5, as in:

```
printf("%5d", n);
```

Instead of the specification **%d**, we now use **%5d**. The field width is placed between **%** and **d**. The value of **n** is printed "in a field width of 5".

Suppose **n** is 279; there are 3 digits to print so 3 print columns are needed. Since the field width is 5, the number 279 is printed with 2 spaces before it, thus: ◇◇279 (◇ denotes a space). We also say "printed with 2 leading blanks/spaces" and "printed padded on the left with 2 blanks/spaces".

A more technical way of saying this is "**n** is printed *right-justified* in a field width of 5". "Right-justify" means that the number is placed as far right as possible in the field and spaces added in *front* of it to make up the field width. If the number is placed as far *left* as possible and spaces are added *after* it to make up the field

width, the number is *left-justified*. For example, 279◇◇ is left-justified in a field width of 5.

The minus sign can be used to specify *left-justification*; **%-wd** will print a value left-justified in a field width of **w**. For example, to print an integer value left-justified in field width of 5, we use **%-5d**.

For another example, suppose **n** is -7 and the field width is 5. Printing **n** requires two print columns (one for - and one for 7); since the field width is 5, it is printed with 3 leading spaces, thus: ◇◇◇-7.

You may ask, what will happen if the field width is too small? Suppose the value to be printed is 23456 and the field width is 3. Printing this value requires 5 columns which is greater than the field width 3. In this case, C ignores the field width and simply prints the value using as many columns as needed (5, in this example).

In general, suppose the integer value **v** is printed with the format specification **%wd** where **w** is an integer, and suppose **n** columns are needed to print **v**. There are 2 cases to consider:

- If **n** is less than **w** (the field width is bigger), the value is padded on the left with (**w - n**) spaces. For example, if **w** is 7 and **v** is -345 so that **n** is 4, the number is padded on the left with (7-4) = 3 spaces and printed as ◇◇◇-345.
- If **n** is greater than or equal to **w** (field width is the same or smaller), the value is printed using **n** print columns. In this case, the field width is ignored.

A field width is useful when we want to line up numbers one below the other. Suppose we have three **int** variables **a**, **b** and **c** with values 9876, -3 and 501, respectively. The statements

```
printf("%d\n", a);
printf("%d\n", b);
printf("%d\n", c);
```

will print

```
9876
-3
501
```

Each number is printed using just the number of columns required. Since this varies from one number to the next, they do not line up. If we want to, we could get the numbers lined up using a field width of 5, say. The statements

```
printf("%5d\n", a);
printf("%5d\n", b);
printf("%5d\n", c);
```

will print (◇ denotes a space)

```
◇9876
◇◇◇-3
◇◇501
```

which will look like (without ◇)

```
 9876
   -3
  501
```

all nicely lined up.

As a matter of interest, we don't really need 3 **printf** statements. We can replace the last 3 **printf** statements with

```
printf("%5d\n%5d\n%5d\n", a, b, c);
```

Each **\n** forces the following output onto a new line.

2.5 Floating-point numbers – the types float and double

A floating-point number is one which may have a fractional part. A *floating-point constant* can be written in one of two ways:

- the normal way, with an optional sign, and including a decimal point; for example, `-3.75`, `0.537`, `47.0`;
- using *scientific* notation, with an optional sign, including a decimal point and including an 'exponent' part; for example, `-0.375E1` meaning "-0.375 multiplied by 10 to the power 1", that is, `-3.75`. Similarly, `0.537` can be written as `5.37e-1`, that is, "5.37 x 10^{-1}". The exponent can be specified using either **e** or **E**.

  Note that there are several ways to write the same number. For example, the following all represent the same number `27.96`:

```
27.96E00 2.796E1 2.796E+1 2.796E+01 0.2796E+02 279.6E-1
```

In C, we can declare a floating-point variable using either **float** or **double**. A **float** value is normally stored as a 32-bit floating-point number, giving about 6 or 7 significant digits. A **double** value is stored as a 64-bit floating-point number, giving about 15 significant digits.

A floating-point constant is of type **double** unless it is followed by **f** or **F**, in which case it is of type **float**. Thus `3.75` is of type **double** but `3.75f` (or `3.75F`) is of type **float**. Most calculations are done using **double** precision. The type **float** is useful if you need to store lots of floating-point numbers and you wish to use as little storage as possible (and do not mind living with 6 or 7 digits of precision).

In this book, we will mostly use **double** for working with floating-point numbers.

2.5.1 *Printing the values of* double *and* float *variables*

We have been using the *format specification* **%d** in a **printf** statement to print the value of an integer variable. If we wish to print the value of a **double** or **float** variable, we can use the **%f** specification. For example, consider:

```
double d = 987.654321;
printf("%f \n", d);
```

The value of **d** will be printed to a pre-defined number of decimal places (usually 6, but could vary from one compiler to the next). In this case, the value printed will be `987.654321`. However, if **d** were assigned `987.6543215`, the value printed would be `987.654322` (rounded to 6 decimal places).

Similarly, if **x** was of type **float**, its value could be printed using:

```
printf("%f \n", x);
```

We just saw that the specification **%f** prints the number to a pre-defined number of decimal places. Most times, though, we want to say how many decimal places to print and, sometimes, how many columns to use. For example, if we want to print **d**, above, to 2 decimal places in a field width of 6, we can use:

```
printf("%6.2f \n", d);
```

Between **%** and **f**, we write **6.2**, that is, the field width, followed by a **.** (point), followed by the number of decimal places. The value is *rounded* to the stated number of decimal places and then printed. Here, the value printed will be `987.65`, which occupies exactly 6 print columns. If the field width were bigger, the number will be padded on the left with spaces. If the field width were smaller, it is ignored, and the number printed using as many columns as necessary.

As another example, consider

```
b = 245.75;
printf("%6.1f \n", d);
```

In the specification **%6.1f**, `1` says to *round* the number to 1 decimal place; this gives `245.8`, which requires 5 columns for printing.

`6` says to print `245.8` in 6 columns; since only 5 columns are needed for printing the number, one space is added at the beginning to make up 6 columns, so the number is printed as ◇`245.8` (◇ denotes a space).

Similarly,

```
printf("%6.0f \n", d);
```

will print **b** as ◇◇◇`246` (rounded to `0` decimal places and printed in a field width of `6`).

If the specification were **%3.1f** and the value to be printed is `245.8`, it would be printed using 5 print columns, even though the field width is 3. Again, when the field width specified is *smaller* than the number of print columns required, C ignores the field width and prints the value using as many columns as needed.

We can sometimes use this to our advantage. If we do not know how big a value might be, we can deliberately use a small field width to ensure it is printed using the exact number of print columns required for printing the value.

In general, suppose the **float** or **double** value **v** is to be printed with the specification **%w.df** where **w** and **d** are integers. Firstly, the value **v** is *rounded* to **d** decimal places; suppose the number of print columns required to print **v**, including a possible point[2] and a possible sign, is **n**. There are 2 cases to consider:

- If **n** is less than **w** (the field width is bigger), the value is padded on the left with (**w - n**) spaces. For example, if **w** is 7 and the value to be printed is `-3.45` so that **n** is 5, the number is padded on the left with (7-5) = 2 spaces and printed as ◇◇`-3.45`.
- If **n** is greater than or equal to **w** (field width is the same or smaller), the value is printed using **n** print columns. In this case, the field width is ignored.

As with integers, a field width is useful when we want to line up numbers one below the other. Assume we have three **double** variables **a**, **b** and **c** with values `419.563`, `-8.7` and `3.25`, respectively. Suppose we want to print the values to 2 decimal places, lined up on the decimal point, like this:

```
419.56
 -8.70
  3.25
```

Since the biggest number requires 6 print columns, we can line them up using a field width of at least 6. The following statements will line them up as above:

```
printf("%6.2f \n", a);
printf("%6.2f \n", b);
printf("%6.2f \n", c);
```

If we use a field width bigger than 6, the numbers will still line up but with leading spaces.

For example, if we use a field width of 8, we will get (◇ denotes a space)

```
◇◇419.56
◇◇◇-8.70
◇◇◇◇3.25
```

Again, we can use one **printf** instead of three to achieve the same effect:

```
printf("%6.2f \n%6.2f \n%6.2f \n", a, b, c);
```

Each **\n** forces the following output onto a new line.

---

[2] There will be no point if d = 0 (the value is to be rounded to a whole number)

2.5.2 Assignment between *double* and *float*

As expected, you can store a **float** value in a **float** variable and a **double** value in a **double** variable. Since **float** is smaller than **double**, C allows you to store a **float** value in a **double** variable without any problems. However, if you assign a **double** to a **float**, some precision may be lost. Consider the following:

```
double d = 987.654321;
float x = d;
printf("%f \n", x);
```

Since a **float** variable allows only about 7 digits of precision, we should expect that the value of **d** may not be assigned precisely to **x**. Indeed, when run using one compiler, the value `987.654297` was printed for **x**. When **d** was changed to `987654321.12345`, the value printed was `987654336.000000`. In both cases, about 6 or 7 digits of precision were retained.

As an exercise, see what values would be printed on your compiler.

2.5.3 Floating-point expressions

Floating-point expressions can be written using the following operators:

+	addition
-	subtraction
*****	multiplication
/	division

These operate as expected; in particular, division is performed in the usual way so that, for example, `19.0/5.0` gives the value `3.8`.

If **op1** and **op2** are the two operands of an operator, the following shows the type of calculation performed:

op1	op2	type of calculation
float	float	float
float	double	double
double	float	double
double	double	double

Thus **float** is performed only if both operands are **float**; otherwise **double** is performed.

2.5.4 Expressions with integer and floating-point values

It is quite common to use expressions involving both integer and floating-point values, for example,

```
a / 3     where a is float
n * 0.25   where n is int
```

In C, the rule for such expressions is:

> If either operand of an arithmetic operator is floating-point, the calculation is done in floating-point arithmetic. The calculation is done in **float** unless at least one operand is **double**, in which case the calculation is done in **double**.

In the first example above, the integer `3` is converted to **float** and the calculation is done in **float**. In the second example, **n** is converted to **double** (since `0.25` is **double**) and the calculation is done in **double**.

How do we get the exact value of an integer division, `19/5`, say? We can force a double precision calculation by writing one or both constants as **double**, thus: `19/5.0`, `19.0/5` or `19.0/5.0`. We can also use a *cast*, as in

```
(double) 19 / 5
```

A *cast* consists of a type name enclosed in brackets and allows us to force the conversion of one type to another. Here, `19` is cast to **double**, forcing `5` to be converted to **double** and a double precision division is performed.

However, we must be careful with a construct like

```
(double) (19 / 5)
```

since it may not do what we think. This does NOT do a floating-point division. Since both constants are integer, the expression inside the brackets is evaluated as an integer division, giving `3`; *this* value is converted to **double**, giving `3.0`.

2.5.5 *Assigning* double/float *to* int

Consider:

```
double d = 987.654321;
int n = d;
printf("%d \n", n);
```

The value `987` is printed. When we assign a floating-point value to an **int**, the fractional part, if any, is dropped (not rounded) and the resulting integer value is assigned. It is up to us to ensure that the integer obtained is small enough to fit in an **int**. If not, the resulting value is unpredictable.

On one compiler, where the largest value of an **int** was 32767, when **d** was changed to 987654.321, the value printed was 4614, a far cry from what might be expected, certainly unpredictable[3]. This is because the truncated value of **d** is 987654 which is too big to fit in an **int** variable.

As an exercise, see what value would be printed on your compiler.

If we want the *rounded* value of **d** stored in **n**, we could do this with

```
n = d + 0.5;
```

If the first digit after the point in **d** is 5 or more, adding 0.5 would add 1 to the whole number part. If the first digit after the point is less than 5, adding 0.5 would not change the whole number part.

For example, if **d** is 245.75, adding 0.5 would give 246.25 and 246 would be assigned to **n**. But if **d** were 245.49, adding 0.5 would give 245.99 and 245 would be assigned to **n**.

2.6 Strings

So far, we have seen several examples of string constants in **printf** statements.

A *string constant* is any sequence of characters enclosed in double quotes. Examples are:

```
"Once upon a time"
"645-2001"
"Are you OK?"
"c:\data\castle.in"
```

The opening and closing quotes *must* appear *on the same line*. In other words, C does not allow a string constant to continue on to another line. However, a long string can be broken up into pieces, with each piece on one line. When the program is compiled, C will join the pieces, making one string. For example,

```
printf("Part of a long string can be placed on one line and "
       "the other part placed on the next line. The pieces are "
       "separated by whitespace, not commas or semicolons.\n");
```

The *value* of a string constant is the sequence of characters without the beginning and ending quotes. Thus, the value of **"Are you OK?"** is **Are you OK?**.

If you want the double quote to be part of a string, you must write it using the escape sequence **\"**, as in

```
"\"Don't move!\", he commanded"
```

[3] Not quite unpredictable; the value assigned is **987654 %32768** which is **4614**. In general, if **big** represents a value that is too big to be stored, the value actually stored is **big % 32768** for integers stored in 16 bits.

The value of this string is **"Don't move!", he commanded**. Each \" is replaced by " and the beginning and ending quotes are dropped.

The C language does not have a predefined **string** type. This presents difficulties for the beginning programmer since he cannot work with string variables the way he can with numeric variables.

In C, a string is stored in an "array of characters". Since we discuss characters in Chapter 6 and arrays in Chapter 8, we *could* be patient and wait until then to understand what is an array, how strings are stored and how we can use them to store a name, for instance. Or, we could accept a few things on faith and reap the benefit of being able to work with strings, in a limited way, much sooner than we normally would. We'll be impatient and choose the latter. Here goes.

Suppose we wish to store a person's name in some variable **name**. We can declare **name** as follows:

```
char name[50];
```

This declares **name** to be a "character array" of size 50. As we will explain in Chapter 8, this allows us to store a maximum of 49 characters in **name**. If you find this is too much (or too little) for your purposes, you can use a different number.

If we want to, we can assign a string constant to **name** *in the declaration*, thus:

```
char name[50] = "Alice Wonder";
```

This stores the characters from **A** to **r**, including the space, in **name**. The quotes are *not* stored. Once this is done, we could print the value of **name** using the specification **%s** in **printf**, thus:

```
printf("Hello, %s\n", name);
```

This will print

```
Hello, Alice Wonder
```

The *value* of **name** replaces **%s**.

Unfortunately, we cannot assign a string constant to **name**, other than in the declaration. C does not permit us to write an assignment statement such as

```
name = "Alice in Wonderland";  // this is not valid
```

to assign a value to **name**. What we *can* do is use the standard function **strcpy** (for string copy), as in:

```
strcpy(name, "Alice in Wonderland");  // this is valid
```

But in order to use **strcpy** (and other string functions), we must precede our program with the directive:

```
#include <string.h>
```

We summarize all of this in Program P2.1 (next page).

Program P2.1

```
#include <stdio.h>  //needed for printf
#include <string.h>  // needed for strcpy
main() {
   char name[50];
   strcpy(name, "Alice in Wonderland");
   printf("Hello, %s\n", name);
}
```

When run, this program will print

```
Hello, Alice in Wonderland
```

In Sections 3.3 (page 50) and 5.9 (page 106), we will see how to read a string value into a variable.

Joining two strings is an operation we sometimes want to perform. We say we want to *concatenate* the two strings. We can do this with the standard string function **strcat** (**str**ing con**cat**enation). For example, suppose we have:

```
char name[30] = "Alice";
char last[15] = "Wonderland";
```

The statement

```
strcat(name, last);
```

will *add* the string in **last** to the one in **name**. It is up to us to ensure that **name** is big enough to hold the joined strings. The result is that **name** will now hold **AliceWonderland**; the value in **last** does not change. The two statements

```
strcat(name, " in ");  //one space before and after 'in'
strcat(name, last);
```

will set **name** to **Alice in Wonderland**.

2.7 The assignment statement

In Section 1.8, we introduced the *assignment statement*. Recall that an assignment statement consists of a *variable* followed by an equals sign (**=**) followed by the *value* to be assigned to the variable, followed by a semicolon. We could write this as:

```
<variable> = <value>;
```

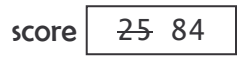
<value> must be *compatible* with **<variable>** otherwise we will get an error. For example, if **<variable>** is **int**, we must be able to derive an integer from **<value>**. And if **<variable>** is **double**, we must be able to derive a floating-point value from **<value>**. If **n** is **int** and **x** is **double**, we cannot, for instance, write

```
n = "Hi there";        //cannot assign string to int
x = "Be nice";         //cannot assign string to double
```

It is useful to think of the assignment statement being executed as follows: the value on the right-hand side of **=** is evaluated. The value obtained is stored in the variable on the left-hand side. The old value of the variable, if any, is lost. For example, if **score** had the value 25, then after the statement

```
score = 84;
```

the value of **score** would be 84; the old value 25 is lost. We can picture this as:



A variable can take on any of several values, but *only one at a time*. As another example, consider

```
score = score + 5;
```

and suppose **score** has the value 84 before this statement is executed. What is the value after execution?

First, the right-hand side **score + 5** is evaluated using the current value of **score**, 84. The calculation gives 89—this value is then stored in the variable on the left-hand side; it happens to be **score**. The end result is that the value of **score** is increased by 5 to 89. The old value 84 is lost.

It is possible that even though an assignment statement is *valid*, it could produce an error when the program is run. Consider the following (**a**, **b**, **c**, **d** and **e** are **int**):

```
a = 12;
b = 5;
c = (a - b) * 2;
d = c + e;
```

Each of these is a correctly formed assignment statement. However, when these statements are executed, an error will result. Can you see how?

The first statement assigns 12 to **a**; the second assigns 5 to **b**; the third assigns 14 to **c**; no problem so far. However, when the computer attempts to execute the fourth statement, it runs into a problem: there is no value for **e**, so the expression **c + e** cannot be evaluated. We say that **e** is *undefined*—it has no value.

Before we can use any variable in an expression, it must have been assigned a value by some previous statement. If not, we will get an "undefined variable" error and our program will halt.

The moral of the story is: a *valid* program is not necessarily a *correct* program.

Exercise: What is printed by the following?

```
a = 13;
b = a + 12;
printf("%d %d\n", a, b);
c = a + b;
a = a + 11;
printf("a = %d b = %d c = %d\n", a, b, c);
```

2.8 printf

We have seen several examples of the **printf** statement. We have used it to print string constants, integer values and floating-point values. And we have printed values with and without field widths. We have also seen how to use the escape sequence **\n** to force output onto a new line.

It is worth emphasizing that the characters in the format string are printed exactly as they appear except that a format specification is replaced by its corresponding value. For example, if **a** is 25 and **b** is 847, the statement

```
printf("%d%d\n", a, b);
```

will print

```
25847
```

The numbers are stuck together and we cannot tell what is **a** and what is **b**! This is so because the specification **%d%d** says to print the numbers next to each other. If we want them separated by one space, say, we must put a space between **%d** and **%d**, like this:

```
printf("%d %d\n", a, b);
```

This will print

```
25 847
```

If we want more spaces between the numbers, we simply put how many we want between **%d** and **%d**.

Exercise: What is printed by the following?

```
printf("%d\n %d\n", a, b);
```

The following are some useful things to know about format specifications.

Suppose **num** is **int** and its value is 75:

- the specification **%d** will print 75 using 2 print columns: **75**
- the specification **%5d** will print 75 with 3 leading spaces: **◇◇◇75**
- the specification **%-5d** will print 75 with 3 trailing spaces: **75◇◇◇**
- the specification **%05d** will print 75 with 3 leading zeroes: **00075**

For an example in which leading 0's might be useful, the statement

```
printf("Pay this amount: $%04d\n", num);
```

will print

```
Pay this amount: $0075
```

This is better than printing

```
Pay this amount: $  75
```

since someone can insert numbers between **$** and **7**.

In general, the minus sign specifies left-justification and a 0 in front of the field width specifies 0 (zero, rather than a space) as the padding character.

Exercises 2

1. In the ASCII character set, what is the range of codes for (a) the digits (b) the uppercase letters and (c) the lowercase letters?
2. What is a token? Give examples.
3. Spaces are normally not significant in a program. Give an example showing where spaces *are* significant.
4. What is a reserved word? Give examples.
5. Give the rules for making up an identifier.
6. What is a symbolic constant and why is it useful?
7. Give examples of integer constants, floating-point constants and string constants.
8. Name 5 operators which can be used for writing integer expressions and give their precedence in relation to each other.
9. Give the value of (a) **39 % 7** (b) **88 % 4** (c) **100 % 11** (d) **-25 % 9**
10. Give the value of (a) **39 / 7** (b) **88 / 4** (c) **100 / 11** (d) **-25 / 9**
11. Write a statement which prints the value of the **int** variable **sum**, right justified in a field width of 6.
12. You are required to print the values of the **int** variables **b**, **j** and **n**. Write a statement which prints **b** with its rightmost digit in column 10, **j** with its rightmost digit in column 20 and **n** with its rightmost digit in column 30.
13. Write statements which print the values of **b**, **j** and **n** lined up one below the other with their rightmost digits in column 8.
14. Using scientific notation, write the number 345.72 in 4 different ways.

15. Write a statement which prints the value of the **double** variable **total** to 3 decimal places, right justified in a field width of 9.
16. You need to print the values of the **float** variables **a**, **b** and **c** to 1 decimal place. Write a statement which prints **a** with its rightmost digit in column 12, **b** with its rightmost digit in column 20 and **c** with its rightmost digit in column 32.
17. What kind of variable would you use to store a telephone number? Explain.
18. Write statements to print the values of 3 **double** variables **a**, **b** and **c**, to 2 decimal places, The values must be printed one below the other, with their rightmost digits in column 12.
19. How can you print the value of a **double** variable, rounded to the nearest whole number?
20. What happens if you try to print a number (**int**, **float** or **double**) with a field width and the field width is too small? What if the field width is too big?
21. Name some operators which can be used for writing floating-point expressions.
22. Describe what happens when we attempt to assign an **int** value to a **float** variable.
23. Describe what happens when we attempt to assign a **float** value to an **int** variable.
24. Write a statement to print **Use \n to end a line of output**.
25. Write a statement to increase the value of the **int** variable **quantity** by 10.
26. Write a statement to decrease the value of the **int** variable **quantity** by 5.
27. Write a statement to double the value of the **int** variable **quantity**.
28. Write a statement to set **a** to **2** times **b** plus **3** times **c**.
29. The **double** variable **price** holds the price of an item. Write a statement to increase the price by (a) $12.50 (b) 25%.
30. What will happen when the computer attempts to execute the following:

```
p = 7;
q = 3 + p;
p = p + r;
printf("%d\n", p);
```

31. Suppose **rate = 15**. What is printed by each of the following?

    (a) `printf("Maria earns rate dollars an hour\n");`

    (b) `printf("Maria earns %d dollars an hour\n", rate);`

32. If **m** is 3770 and **n** is 123, what is printed by each of the following?

    (a) `printf("%d%d\n", n, m);`

    (b) `printf("%d\n%d\n", n, m);`

3 Writing programs using sequence logic

In this chapter, we will explain:

- the idea of reading data supplied by a user
- how the **scanf** statement works
- how to read numeric data using **scanf**
- how to read string data using **gets**
- important principles of program writing using several examples

In the last chapter, we introduced some of C's basic data types—**int**, **double** and **float**—and used simple statements to illustrate their use. We now go a step further and introduce several programming concepts by writing programs using these types.

The programs in this chapter will be based on *sequence* logic—that simply means that the statements in the programs are executed one after the other, from the first to the last. This is the simplest kind of logic, also called *straight-line* logic. In the next chapter we will write programs which use *selection* logic—the ability of a program to test some *condition* and take different courses of action based on whether the condition is true or false.

3.1 How to read data supplied by a user

Consider, again, Program P1.3 from page 19.

Program P1.3

```
// This program prints the sum of 14 and 25. It shows how
// to declare variables in C and assign values to them.
#include <stdio.h>
main() {
   int a, b, sum;
   a = 14;
   b = 25;
   sum = a + b;
   printf("%d + %d = %d\n", a, b, sum);
}
```

Since C allows us to declare a variable and give it an initial value in one statement, we could write the program more concisely (without the comment) as Program P3.1:

Program P3.1

```
#include <stdio.h>
main() {
   int a = 14;
   int b = 25;
   int sum = a + b;
   printf("%d + %d = %d\n", a, b, sum);
}
```

And since, as discussed on page 20, we do not really need the variable **sum**, this program can be written as Program P3.2:

Program P3.2

```
#include <stdio.h>
main() {
   int a = 14;
   int b = 25;
   printf("%d + %d = %d\n", a, b, a + b);
}
```

This program is very restrictive. If we wish to add two other numbers, we will have to change the numbers 14 and 25 in the program to the ones required. We would then have to re-compile the program. And each time we want to add two different numbers, we would have to change the program. This can become very tedious.

It would be nice if we could write the program in such a way that when we *run* the program, we will have the opportunity to tell the program which numbers we wish to add. In this way, the numbers would not be tied to the program, and the program would be more *flexible*. When we 'tell' the program the numbers, we say we are supplying *data* to the program. But how do we get the program to 'ask' us for the numbers and how do we 'tell' the program what the numbers are?

We can get the program to *prompt* us for a number by printing a message such as:

```
Enter first number:
```

using a **printf** statement. The program must then wait for us to type the number and, when it is typed, *read* it. This can be done with the **scanf** statement[1]. Before we look at this statement, let us rewrite the algorithm using these new ideas:

[1] Strictly speaking, **printf** and **scanf** are *functions*, but the distinction is not too important for us

```
prompt for the first number
read the number
prompt for the second number
read the number
find the sum
print the sum
```

We can *implement* this algorithm in C as Program P3.3.

Program P3.3

```
//prompt for two numbers and find their sum
#include <stdio.h>
main() {
  int a, b;
  printf("Enter first number: ");
  scanf("%d", &a);
  printf("Enter second number: ");
  scanf("%d", &b);
  printf("%d + %d = %d\n", a, b, a + b);
}
```

When run, the first **printf** statement will print:

```
Enter first number:
```

The **scanf** statement, explained shortly, will cause the computer to wait for the user to type a number.

Suppose she types 23; the screen will look like this:

```
Enter first number: 23
```

When she presses the "Enter" or "Return" key on the keyboard, **scanf** *reads* the number and stores it in the variable **a**.

The next **printf** statement then prompts:

```
Enter second number:
```

Again, **scanf** causes the computer to wait for the user to enter a number. Suppose she enters 18; **scanf** reads the number and stores it in the variable **b**. At this stage, the number 23 is stored in **a** and 18 is stored in **b**. We can picture this as:

The program then executes the last **printf** statement and prints:

```
23 + 18 = 41
```

At the end, the screen will look as follows. Underlined items are typed by the user, everything else is printed by the computer:

```
Enter first number: 23
Enter second number: 18
23 + 18 = 41
```

Since the user is free to enter *any* numbers, the program will work for whatever numbers are entered[2].

3.2 scanf

In Program P3.3, the statement

```
scanf("%d", &a);
```

causes the computer to wait for the user to type a number. Since **a** is an integer variable, **scanf** expects the next item in the data to be an integer. If it is not (for example, if it is a letter or it contains a decimal point) the program will give an error message such as "Invalid numeric format" and stop. We say the program will *crash*. If the data *is* valid, the number will be stored in the variable **a**. The statement **scanf("%d", &b);** works in a similar manner.

The statement consists of:

- the word **scanf**
- left and right brackets
- two items (called *arguments*) inside the brackets, separated by a comma

As with **printf**, the first item is a string called the *format string*. In this example, the string consists of the *format specification* **%d** only. It specifies the *type* of data to be read. Here, **%d** is used to indicate that an *integer* value is to be read.

The second argument specifies *where* to store the value read. Even though we want the value stored in **a**, **scanf** *requires* us to specify this by writing **&a**[3]. You will need to take it on faith that in order to *read* a value into a variable using **scanf**, the variable must be preceded by **&**, as in **&a** and **&b**. Note that this applies *only* to the **scanf** statement. Other than this, the variable is used in its normal form (without **&**) as in:

```
printf("%d + %d = %d\n", a, b, a + b);
```

We can use **scanf** to read more than one value at a time. For example, suppose we want to read 3 integer values for variables **a**, **b** and **c**. To do so, we would need to

[2] Provided the numbers entered and their sum are within the range of numbers which can be stored in an **int** variable. If they are not, strange results will be printed.

[3] The quick explanation is that we must tell **scanf** the *address* of the memory location where the value is to be stored; **&a** stands for "address of **a**".

write **%d** three times in the format specification, thus:

```
scanf("%d %d %d", &a, &b, &c);
```

When this statement is executed, it will look for three integers. The first one is stored in **a**, the second in **b** and the third in **c**. It is up to the user to ensure that the next three items in the data are integers. If this is not so, an "Invalid numeric format" message will be printed and the program will crash.

When entering the data, the numbers must be separated by one or more spaces, like this:

```
42  -7  18
```

When using **scanf**, data can be supplied in flexible ways. The *only* requirement is that the data be supplied *in the correct order*. In this example, the three numbers could be supplied as above or as

```
42
-7
18
```

or as

```
42   -7
  18
```

or even with a blank line as

```
  42

-7    18
```

Spaces, tabs and blank lines (so-called *whitespace*) do not matter; **scanf** will simply keep reading data, ignoring spaces, tabs and blank lines, until it finds the three integers. Again, we emphasize that if any invalid character is encountered, the program will crash. For instance, if the user types

```
42 -7 18.0
```

or

```
42 = 18  24
```

the program will crash. In the first case, the decimal point is invalid since an integer is expected and, in the second case, **=** is not a valid character for an integer.

3.2.1 Reading data into a float *variable*

If we wish to read a floating-point number into a **float** variable **x**, we can use

```
scanf("%f", &x);
```

The specification **%f** is used to read a value into a **float** (but not **double**, see next)

variable. When executed, **scanf** expects to find a valid floating-point constant in the data. For example, any of the following will be acceptable:

```
4.265
-707.96
2.345E+1
```

In the last case, there must be no spaces, for instance, between the `5` and the `E` or between the `E` and the `+` or between the `+` and the `1`. The following will all be invalid for reading the number `23.45`:

```
2.345 E+1
2.345E +1
2.345E+ 1
```

3.2.2 Reading data into a double variable

If we wish to read a floating-point number into a **double** variable **y**, we can use

```
scanf("%lf", &y);
```

The specification **%lf** (percent ell f) is used to read a value into a **double** variable. Apart from the specification, data is entered the same way for **float** and **double** variables. Be careful—you *cannot* use `%f` for *reading* data into a **double** variable. If you do, your variable will contain nonsense. However, as you have seen, you *can* use **%f** for *printing* the value of a **double** variable.

When entering data for a **float/double** variable, an integer is acceptable. If you enter `42`, say, it will be interpreted as `42.0`. But, as discussed above, you cannot enter a floating-point constant for an **int** variable; if you do, your program will crash or give you incorrect results.

If you need to, you can read values into more than one variable using one **scanf** statement. If **x** and **y** are **double** variables, you can use

```
scanf("%lf %lf", &x, &y);
```

to read values into **x** and **y**. When executed, **scanf** expects to find two valid floating-point (or integer) constants next in the data. The first is stored in **x** and the second in **y**. Any number of spaces or blank lines can come before, between or after the numbers.

We can also read values for **int**, **double** or **float** variables in the same **scanf** statement. We just have to ensure that we use the correct specification for each variable. Suppose **item** and **quantity** are **int**, and **price** is **double**. The statement

```
scanf("%d %lf %d", &item, &price, &quantity);
```

expects to find 3 numbers next in the data.

- The first must be an **int** constant which will be stored in **item**.

- The second must be a **double** (or **int**) constant which will be stored in **price**.
- The third must be an **int** constant which will be stored in **quantity**.

The following are all valid data for this **scanf** statement:

```
4000  7.99  8
3575  10  44        price will be interpreted as 10.00
5600  25.0 1
```

As usual, any amount of whitespace may be used to separate the numbers.

The following are all invalid data for this **scanf** statement:

```
4000  7.99  8.5     8.5 is not an integer constant
35.75  10  44       35.75 is not an integer constant
560 25 amt = 7      a is not a valid numeric character
```

When **scanf** fetches a number, it remains poised just after the number; a subsequent **scanf** will continue to read data from that point. To illustrate, suppose some data is typed as

```
4000 7.99 8
```

and consider the statements

```
scanf("%d", &item);
scanf("%lf", &price);
scanf("%d", &quantity);
```

The first **scanf** will store 4000 in **item**. On completion, it remains poised at the space after 4000. The next **scanf** will continue reading from that point and will store 7.99 in **price**. This **scanf** will stop at the space after 7.99. The third **scanf** will continue reading from that point and store 8 in **quantity**. This **scanf** will stop at the character after 8; this may be a space or the *end-of-line* character. Any subsequent **scanf** will continue reading from that point.

It is useful to imagine a "data pointer" moving through the data as data items are read. At any time, it marks the position in the data from which the next **scanf** will start looking for the next item of data.

3.3 Reading strings

In Section 2.6 (page 37), we saw how to declare a variable to hold a string value. For example, the declaration

```
char item[50];
```

lets us store a string value (of maximum length 49) in **item**. We also saw how we can assign a string value to **item** using the standard string function, **strcpy**.

Now we show you how to read a value from the input into **item**. There are several ways to do this in C. We will use the **gets**[4] statement (more precisely, a function), as in:

```
gets(item);
```

This reads characters and stores them in **item** starting from the current position of the data pointer until the end-of-line is reached. The end-of-line character is *not* stored. The data pointer is positioned at the beginning of the next line.

For example, if the data line is

```
Right front headlamp
```

then the string **Right front headlamp** is stored in **item**. The *effect* is the same as if we had written

```
strcpy(item, "Right front headlamp");
```

The alert reader will notice that we did not put an **&** before **item**, as we have been doing for reading numbers with **scanf**. For now, just note that **item** is a "character array" and the rule in C is that we must not put **&** before an *array name* when reading data into it. You may understand this better after we discuss arrays in Chapter 8[5]. If not, just think of it as a rule that you need to follow.

Consider the following statements (assume the declaration **char name[50]**):

```
printf("Hi, what's your name? ");
gets(name);
printf("Delighted to meet you, %s\n", name);
```

When executed,

- the **printf** statement will ask for your name
- **gets** will wait for you to type your name. When typed, the name will be stored in the variable **name**
- **printf** will then print a greeting using your name

Your computer screen will look as follows (assuming **Birdie** is typed as the name):

```
Hi, what's your name? Birdie
Delighted to meet you, Birdie
```

[4] Usually pronounced "get s", not "gets"

[5] The quick explanation is that an *array name* denotes the "address of the first element of the array" so there is no need for **&** to get the address.

3.4 Examples

We now write programs to solve a few problems. You should try solving the problems before looking at the solutions. In the sample runs, the underlined items are typed by the user; everything else is printed by the computer.

Problem 1

Write a program to request 3 integers and print their average to 1 decimal place. The program should work as follows:

```
Enter 3 integers: 23 7 10

Their average is 13.3
```

A solution is shown as Program P3.4.

Program P3.4

```
//request 3 integers; print their average
#include <stdio.h>
main() {
  int a, b, c;
  double average;
  printf("Enter 3 integers: ");
  scanf("%d %d %d", &a, &b, &c);
  average = (a + b + c) / 3.0;
  printf("\nTheir average is %3.1f\n", average);
}
```

Points to note about Program P3.4:

- The variable **average** is declared as **double** since the average may not be a whole number.
- If whole numbers are not entered in the data, the program will crash or, at least, give incorrect results.
- We use `3.0` instead of `3` in calculating the average. This forces a floating-point division to be performed. If we had used 3, an integer division would be performed, giving `13.0` as the answer for the sample data, above.
- In the last **printf**, the first **\n** is used to print the blank line in the output.
- We could have declared average *and* assigned to it in one statement, thus:

```
double average = (a + b + c) / 3.0;
```

- The variable **average** is not really necessary in this program. We could calculate and print the average in the **printf** statement with

```
printf("\nTheir average is %3.1f\n", (a + b + c) / 3.0);
```

Problem 2

Write a program to request a whole number and print the number and its square. The program should work as follows:

```
Enter a whole number: 6

Square of 6 is 36
```

A solution is shown as Program P3.5.

Program P3.5

```
//request a whole number; print its square
#include <stdio.h>
main() {
   int num, numSq;
   printf("Enter a whole number: ");
   scanf("%d", &num);
   numSq = num * num;
   printf("\nSquare of %d is %d\n", num, numSq);
}
```

Points to note about Program P3.5:

- To make the output readable, note the space after **f** and the spaces around **is**. If these spaces are omitted, the sample output will be

  ```
  Square of6is36
  ```

- The variable **numSq** is not really necessary. It can be omitted altogether and the same output printed with

  ```
  printf("\nSquare of %d is %d\n", num, num * num);
  ```

- The program assumes an integer will be entered; if anything other than an integer is entered, the program will crash or give incorrect results. To cater for numbers with a point, declare **num** (and **numSq**, if used) as **double**.

Problem 3

The following data are given for a customer in a bank: name, account number, average balance and number of transactions made during the month. It is required to calculate the interest earned and service charge.

The interest is calculated by

```
interest = 6% of average balance
```

and the service charge is calculated by

```
service charge = 50 cents per transaction
```

Write a program to read the data for the customer, calculate the interest and service charge, and print the customer's name, average balance, interest and service charge.

The following is a sample run of the program:

```
Name? Alice Wonder
Account number? 4901119250056048
Average balance? 2500
Number of transactions? 13

Name: Alice Wonder
Average balance: $2500.00
Interest: $150.00
Service charge: $6.50
```

A solution is shown as Program P3.6 (next page).

This problem is more complicated than those we have seen so far. It involves more data and more processing. But we can simplify its solution if we tackle it in small steps.

Firstly, let us outline an algorithm for solving the problem. This can be:

```
prompt for and read each item of data
calculate interest earned
calculate service charge
print required output
```

The logic here is fairly straightforward and a little thought should convince us that these are the steps required to solve the problem.

Next, we must choose variables for the data items we need to store.

- For the customer's name, we need a string variable—we call it **customer**.
- We may be tempted to use an integer variable for the account number but this is not a good idea for two reasons: an account number may contain letters (as in CD55887700) or it may be a very long integer, too big to fit in an **int** variable. For these reasons, we use a string variable which we call **acctNum**.

Program P3.6

```
//calculate interest and service charge for bank customer
#include <stdio.h>
main() {
  char customer[30], acctNum[30];
  double  avgBalance, interest, service;
  int  numTrans;

  printf("Name? ");
  gets(customer);
  printf("Account number? ");
  gets(acctNum);
  printf("Average balance? ");
  scanf("%lf", &avgBalance);
  printf("Number of transactions? ");
  scanf("%d", &numTrans);

  interest = avgBalance * 0.06;
  service = numTrans * 0.50;

  printf("\nName: %s\n", customer);
  printf("Average balance: $%3.2f\n", avgBalance);
  printf("Interest: $%3.2f\n", interest);
  printf("Service charge: $%3.2f\n", service);
}
```

- The average balance may contain a decimal point and must be stored in a **double** variable; we call it **avgBalance**.
- The number of transactions is a whole number so we use an **int** variable, **numTrans**.

Next, we need variables to store the interest and service charge. Since these may contain a decimal point, we must use **double** variables—we call them **interest** and **service**.

Prompting for and reading the data are fairly straightforward, given what we have covered so far. We need only emphasize that when numeric data is being entered, it must be a numeric constant. We cannot, for instance, enter the average balance as `$2500` or as `2,500`. We must enter it as `2500` or `2500.0` or `2500.00`.

The calculation of the interest and service charge presents the biggest challenge. We must specify the calculation in a form which the computer can understand and execute.

We cannot, for instance, write

```
interest = 6% of avgBalance;
```

or even

```
interest = 6% * avgBalance;
```

or

```
service = 50 cents per transaction;
```

We must express each right-hand side as a proper arithmetic expression, using appropriate constants, variables and operators. Hence,

"6% of average balance" must be expressed as **avgBalance * 0.06** or **0.06 * avgBalance** and

"50 cents per transaction" must be expressed as **0.50 * numTrans** or **numTrans * 0.5** or something similar, even **numTrans / 2.0**.

Printing the output is fairly straightforward. Even though, for example, we cannot use $ when entering data for average balance, we can print a dollar sign in front of it when we print its value. All we need to do is print $ as part of a string. How this is done is shown in the program. Similarly, we print the interest and service charge labelled with a dollar sign.

We use the specification `%3.2f` for printing **avgBalance**. We intentionally use a small field width of 3 so that **avgBalance** is printed using only the exact number of print columns needed for printing its value. This ensures that its value is printed right next to the dollar sign. Similar remarks apply to **interest** and **service**.

Problem 4

At a football match, tickets are sold in 3 categories: reserved, stands and grounds. For each of these categories, you are given the ticket price and the number of tickets sold. Write a program to prompt for these values and print the amount of money collected from each category of tickets. Also print the total number of tickets sold and the total amount of money collected.

We will write the program to operate as follows when run:

```
Reserved price and tickets sold? 100 500
Stands price and tickets sold? 75 4000
Grounds price and tickets sold? 40 8000

Reserved sales: $50000.00
Stands sales: $300000.00
Grounds sales: $320000.00

12500 tickets were sold
Total money collected: $670000.00
```

As shown, we prompt for and read two values at a time, the price and the number of tickets sold.

For each category, the sales is calculated by multiplying the ticket price by the number of tickets sold.

The total number of tickets sold is calculated by adding the number of tickets sold for each category.

The total money collected is calculated by adding the sales for each category.

An outline of the algorithm for solving the problem is:

```
prompt for and read reserved price and tickets sold
calculate reserved sales
prompt for and read stands price and tickets sold
calculate stands sales
prompt for and read grounds price and tickets sold
calculate grounds sales
calculate total tickets
calculate total sales
print required output
```

A solution is shown as Program P3.7. The price can be entered as an integer or **double** constant; the number of tickets *must* be entered as an integer constant.

Program P3.7

```
//calculate ticket sales for football match
#include <stdio.h>
main() {
  double rPrice, sPrice, gPrice;
  double  rSales, sSales, gSales, tSales;
  int  rTickets, sTickets, gTickets, tTickets;

  printf("Reserved price and tickets sold? ");
  scanf("%lf %d", &rPrice, &rTickets);
  rSales = rPrice * rTickets;
  printf("Stands price and tickets sold? ");
  scanf("%lf %d", &sPrice, &sTickets);
  sSales = sPrice * sTickets;
  printf("Grounds price and tickets sold? ");
  scanf("%lf %d", &gPrice, &gTickets);
  gSales = gPrice * gTickets;

  tTickets = rTickets + sTickets + gTickets;
  tSales = rSales + sSales + gSales;

  printf("\nReserved sales: $%3.2f\n", rSales);
  printf("Stands sales: $%3.2f\n", sSales);
  printf("Grounds sales: $%3.2f\n", gSales);
  printf("\n%d tickets were sold\n", tTickets);
  printf("Total money collected: $%3.2f\n", tSales);
}
```

Exercises 3

1. For each of the following, give examples of data which will be read correctly and examples of data which will cause the program to crash: (assume the declarations **int i**, **j** ; **double x**, **y**;)

   (a) `scanf("%d %d", &i, &j);`
   (b) `scanf("%lf %lf", &x, &y);`
   (c) `scanf("%d %lf %d", &i, &x, &j);`

2. For 1(c), state what will be stored in **i**, **x** and **j** for each of the following sets of data:

   (a) `14 11 52`
   (b) `-7 2.3 52`
   (c) `0 6.1 7.0`
   (d) `1.0 8 -1`

3. Write a program which requests a user to enter a weight in kilograms, and converts it to pounds. (1 kilogram = 2.2 pounds).
4. Write a program which requests a length in centimetres and converts it to inches. (1 inch = 2.54 cm).
5. Assuming that `12` and `5` are entered as data, identify the logic error in the following statements (**a**, **b**, **c**, **d** and **e** are **int**):

```
scanf("%d %d", &a, &b);
c = (a - b) * 2;
d = e + a;
e = a / (b + 1);
printf("%d %d %d\n", c, d, e);
```

   When the error is corrected, what is printed?

6. What is printed by the following (**a**, **b**, and **c** are **int**)?

```
a = 13;
b = a + 12;
printf("%d %d\n", a, b);
c = a + b;
a = a + 11;
printf("%d %d %d\n", a, b, c);
```

7. Write a program which requests a price and a discount percent. The program prints the original price, the discount amount and the amount the customer must pay.
8. Same as 7, but assume that 15% tax must be added on to the amount the customer must pay.
9. Write a program to calculate electricity charges for a customer. The program requests a name, previous meter reading and current meter reading. The difference in the two readings gives the number of units of electricity used. The customer pays a fixed charge of $25 plus 20 cents for each unit used.

   Print all the data, the number of units used and the amount the customer must pay, appropriately labelled.

10. Modify 9 so that the program requests the fixed charge and the rate per unit.

11. Write a program to request a student's name and marks in 4 subjects. The program must print the name, total marks and average mark, appropriately labelled.
12. Write a program which requests a person's gross salary, deductions allowed and rate of tax (e.g. 25, meaning 25%) and calculates his net pay as follows:

    tax is calculated by applying the rate of tax to the gross salary minus the deductions;

    net pay is calculated by gross salary minus tax.

    Print the gross salary, tax deducted and net pay, appropriately labelled.

    Also print the percentage of the gross salary that was paid in tax.

    Make up appropriate sets of data for testing the program.
13. Write a program which, when run, works as follows:

    Hi, what's your name? Alice
    Welcome to our show, Alice
    How old are you? 27
    Hmm, you don't look a day over 22
    Tell me, Alice, where do you live? Princes Town
    Oh, I've heard Princes Town is a lovely place
14. A ball is thrown vertically upwards with an initial speed of **U** metres per second. Its height **H** after time **T** seconds is given by

    $$H = UT - 4.9T^2$$

    Write a program which requests **U** and **T** and prints the height of the ball after **T** seconds.
15. Write a program to calculate the cost of carpeting a rectangular room in a house. The program must
    - request the length and breadth of the room (assume they are in metres)
    - request the cost per square metre of the carpet
    - calculate the area of the room
    - calculate the cost of the carpet for the room
    - print the area and the cost, appropriately labelled
16. Write a program which, given a length in inches, converts it to yards, feet and inches. (1 yard = 3 feet, 1 foot = 12 inches). For example, given 100 inches, the program should print **2 yd 2 ft 4 in**.

4 Writing programs using selection logic

In this chapter, we will explain:

- what are Boolean expressions
- how C represents Boolean values
- how to write programs using **if**
- how to write programs using **if...else**
- where semicolons are required, where they are optional and where they must *not* be put
- how a program should be tested
- why symbolic constants are useful and how to use them in a C program

In the last chapter, we showed how to write programs using sequence logic—programs whose statements are executed "in sequence" from the first to the last.

In this chapter, the programs will use *selection* logic—they will *test* some *condition* and take different courses of action based on whether the condition is true or false. In C, selection logic is implemented using the **if** and the **if...else** statements.

4.1 Boolean expressions

A *Boolean expression*[1] is one that is either true or false. The simplest kinds of Boolean expressions are those that compare one value with another. Examples are

j is equal to 999
a is greater than 100
$a^2 + b^2$ is equal to c^2
b^2 is greater than or equal to 4ac
s is not equal to 0

Each of these can be either true or false. These are examples of a special kind of Boolean expression called *relational expressions*. Such expressions simply check if one value is equal to, not equal to, greater than, greater than or equal to, less than and less than or equal to another value. We write them using *relational operators*.

[1] Named after the famous English mathematician George Boole

The C relational operators (with examples) are:

==	equal to	j == 999, a*a + b*b == c*c
!=	not equal to	s != 0, a != b + c
>	greater than	a > 100
>=	greater than or equal to	b*b >= 4.0*a *c
<	less than	n < 0
<=	less than or equal to	score <= 65

Boolean expressions are normally used to control the flow of program execution. For example, we may have a variable (**j**, say) which starts off with a value of 0. We keep increasing it by 1 and we want to know when its value reaches 100. We say we wish to know when the *condition* **j == 100** is true. A condition is the common name for a Boolean expression.

The real power of programming lies in the ability of a program to *test* a *condition* and decide whether it is true or false. If it is true, the program can perform one set of actions and if it is false, it can perform another set, or simply do nothing at all.

For example, suppose the variable **score** holds the score obtained by a student in a test, and the student passes if her score is 50 or more and fails if it is less than 50. A program can be written to *test* the *condition*

```
score >= 50
```

If it is true, the student passes; if it is false, the student fails. In C, this can be written as:

```
if (score >= 50) printf("Pass\n");
else printf("Fail\n");
```

When the computer gets to this statement, it compares the current value of **score** with 50. If the value is greater than or equal to 50, we say that the condition **score >= 50** is true. In this case the program prints **Pass**. If the value of **score** is less than 50, we say that the condition **score >= 50** is false. In this case, the program prints **Fail**.

In this chapter, we will see how Boolean expressions are used in **if** and **if...else** statements and, in the next chapter, we will see how they are used in **while** statements.

With the relational operators, we can create *simple* conditions. But sometimes, we need to ask if one thing is true AND another thing is true. We may also need to know if one of two things is true. For these situations, we need *compound* conditions. To create compound conditions, we use the *logical operators* AND, OR and NOT.

For example, suppose we want to know if the value of **h** lies between 1 and 99, inclusive. We want to know if **h** is greater than or equal to 1 AND if **h** is less than or equal to 99. In C, we express this as:

```
(h >= 1) && (h <= 99)
```

In C, the symbol for AND is **&&**.

Note the following:

- the variable **h** *must be repeated* in both conditions. It is tempting, but wrong, to write

```
h >= 1 && <= 99  //this is wrong
```

- The brackets around **h >= 1** and **h <= 99** are not *required*, but it is not wrong to put them. This is so since **&&** (and **||**, see next) have lower precedence than the relational operators. Without the brackets,

```
h >= 1 && h <= 99
```

  would be interpreted by C as

```
(h >= 1) && (h <= 99)
```

  the same as with the brackets.

If **n** is an integer representing a month of the year, we can check if **n** is invalid by testing if **n** is less than 1 OR **n** is greater than 12. In C, we express this as:

```
(n < 1) || (n > 12)
```

In C, the symbol for OR is **||**. As discussed above, the brackets are not required and we could write the expression as

```
n < 1 || n > 12
```

This tests if **n** is invalid. Of course, we can test if **n** is valid by testing if

```
n >= 1 && n <= 12
```

Which test we use depends on how *we* wish to express our logic. Sometimes it's convenient to use the valid test, sometimes the invalid one.

If **p** is some Boolean expression, then **NOT p** reverses the truth value of p. In others words, if **p** is true then **NOT p** is false; if **p** is false, **NOT p** is true. In C, the symbol for NOT is the exclamation mark, **!**. Using the above example, since

```
n >= 1 && n <= 12
```

tests for valid **n**, the condition **NOT (n >=1 && n <= 12)** tests for invalid **n**. This is written in C as

```
! (n >= 1 && n <= 12)
```

This is equivalent to **n < 1 || n > 12**.

In general, if **p** and **q** are Boolean expressions, then:

- **p && q** is **true** when both **p** and **q** are **true** and **false**, otherwise;
- **p || q** is **true** when either **p** or **q** is **true** and **false** only when both **p** and **q** are **false**;
- **!p** is true when **p** is **false** and **false** when **p** is **true**.

Most of the programs in this book will use simple conditions. A few will use compound conditions.

Important note

The original C standard and the later ANSI C standard did not define a Boolean data type. Traditionally, C has used the concept of the *value of an expression* to denote **true**/**false**. A numeric expression can be used in any context where a **true**/**false** value is required. The expression is considered **true** if its value is *non-zero* and **false** if its value is 0.

The latest C99 standard defines the type **bool**. However, in this book, we will use the traditional approach mainly because most of the easily available C compilers do not support the C99 standard. Also, as we will see, we can easily live without **bool**. The vast majority of our Boolean expressions would be relational expressions used in **if** and **while** statements. If we ever need a 'Boolean' variable, we can use an **int** variable with 1 representing **true** and 0 representing **false**.

4.2 The if construct

Let us write a program for the following problem:

> A computer repair shop charges $100 per hour for labour plus the cost of any parts used in the repair. However, the minimum charge for any job is $150. Prompt for the number of hours worked and the cost of parts (which could be $0) and print the charge for the job.

We will write the program assuming it works as follows:

```
Hours worked? 2.5
Cost of parts? 20

Charge for the job: $270.00
```

or

```
Hours worked? 1
Cost of parts? 25

Charge for the job: $150.00
```

The following algorithm describes the steps required to solve the problem:

```
prompt for and read the hours worked
prompt for and read the cost of parts
calculate charge = hours worked * 100 + cost of parts
if charge is less than 150 then set charge to 150
print charge
```

This is another example of an algorithm written in *pseudocode*—an informal way of specifying programming logic.

The algorithm introduces a new statement—the **if** statement. The expression **charge is less than 150** is an example of a *condition*. If the condition is **true**, the statement after **then** (called the *then part*) is executed; if it is **false**, the statement after **then** is *not* executed.

Program P4.1 shows how to express this algorithm as a C program.

Program P4.1

```
//print job charge based on hours worked and cost of parts
#include <stdio.h>
main() {
  double hours, parts, jobCharge;
  printf("Hours worked? ");
  scanf("%lf", &hours);
  printf("Cost of parts? ");
  scanf("%lf", &parts);
  jobCharge = hours * 100 + parts;
  if (jobCharge < 150) jobCharge = 150;
  printf("\nCharge for the job: $%3.2f\n", jobCharge);
}
```

For this program, we choose to use 3 variables—**hours**, **parts** and **jobCharge**, all of type **double** since we may need to enter floating-point values for hours worked and cost of parts.

It is very important that you make an extra effort to understand the **if** statement since it is one of the most important statements in programming. It is the **if** statement that can make a program appear to think.

The condition **charge is less than 150** of the pseudocode algorithm is expressed in our program as **jobCharge < 150**. When the program is executed, the job charge is calculated in the normal way (**hours * 100 + parts**). The **if** statement then tests if this value, **jobCharge**, is less than 150; if it is, then **jobCharge** is set to 150. If it is not less than 150, **jobCharge** remains as it is. The statement

```
if (jobCharge < 150) jobCharge = 150;
```

is a simple example of the **if** *construct*. Observe that the word **then** is *not* used in C. In general, the construct takes the following form in C:

```
if (<condition>) <statement>
```

The word **if** and the brackets around **<condition>** are *required* by C. You must supply **<condition>** and **<statement>** where **<condition>** is a **Boolean** expression and **<statement>** can be either a one-line statement or a block[2]. If **<condition>** is **true**, **<statement>** is executed; if **<condition>** is **false**, **<statement>** is **not** executed. In either case, the program continues with the statement, if any, after **<statement>**.

In the program, **<condition>** is **jobCharge < 150** and **<statement>** is **jobCharge = 150;**.

To give an example where **<statement>** is a block, suppose we want to exchange the values of two variables **a** and **b** but only if **a** is bigger than **b**. This can be done with (using as an example **a** = 15, **b** = 8):

```
if (a > b)
{
  c = a;    //store a in a temporary variable c; c becomes 15
  a = b;   //store b in a; a becomes 8
  b = c;   //store c, the old value of a, in b; b becomes 15
}
```

Here, **<statement>** is the part from **{** to **}**, a block containing 3 assignment statements. If **a** is greater than **b**, the block is executed (and the values are exchanged); if **a** is **not** greater than **b**, the block is **not** executed (and the values remain as they are). In passing, be aware that exchanging the values of two variables requires *three* assignment statements; it cannot be done with *two*. If you are not convinced, try it.

In general, if there are several things that we want to do if a condition is true, we must enclose them within **{** and **}** to create a block. This will ensure that we satisfy C's rule that **<statement>** is a single statement or a block.

It is good programming practice to *indent* the statements in the block. This makes it easy to see at a glance which statements are in the block. If we had written the above as

```
if (a > b)
{
c = a;    //store a in a temporary variable c; c becomes 15
a = b;   //store b in a; a becomes 8
b = c;   //store c, the old value of a, in b; b becomes 15
}
```

[2] One or more statements enclosed by { and }

the structure of the block is not so easy to see.

When we are writing *pseudocode*, we normally use the following format:

```
if <condition> then
  <statement1>
  <statement2>
  etc.
endif
```

The construct is terminated with **endif**, a convention used by many programmers. Note, again, that we indent the statements to be executed if **<condition>** is true. We emphasize that **endif** is not a C word but merely a convenient word used by programmers in writing pseudocode.

The example illustrates one style of writing a block in an **if** statement. This style matches **{** and **}** as follows:

```
if (<condition>)
{
  <statement1>;
  <statement2>;
    etc.
}
```

Here, **{** and **}** line up with **if** and the statements are indented. This makes it easy to recognize what's in the body. For a small program, it probably doesn't matter, but as program size increases, it will become more important for the layout of the code to reflect its structure. In this book, we will use the following style[3]:

```
if (<condition>) {
  <statement1>;
  <statement2>;
    etc.
}
```

We will put **{** on the first line after the right bracket and let **}** match up with **if**; the statements in the block are indented. We believe this is as clear as the first style and it's one less line in the program! Which style you use is a matter of personal preference; choose one and use it consistently.

[3] As you would know by now, the *compiler* doesn't care which style is used.

Example – finding the sum of two lengths

Suppose that a length is given in metres and centimetres, for example, 3m 75cm. You are given two pairs of integers representing two lengths. Write a program to prompt for two lengths and print their sum such that the centimetre value is less than 100.

For example, the sum of 3m 25cm and 2m 15cm is 5m 40cm, but the sum of 3m 75cm and 5m 50cm is 9m 25cm.

Assume the program works as follows:

```
Enter values for m and cm: 3 75
Enter values for m and cm: 5 50

Sum is 9m 25cm
```

Observe that the data must be entered with digits only. If, for instance, we type 3m 75cm we will get an error since 3m is not a valid integer constant. Our program will assume that the first number entered is the metre value and the second number is the centimetre value.

We find the sum by adding the two metre values and adding the two centimetre values. If the centimetre value is less than 100, there is nothing more to do. But if it is not, we must subtract 100 from it and add 1 to the metre value. This logic is expressed by

```
m = sum of metre values
cm = sum of centimetre values
if cm >= 100 then
  subtract 100 from cm
  add 1 to m
endif
```

As a 'boundary' case, we must check that our program works if **cm** is exactly 100. As an exercise, verify that it does.

Program P4.2 (next page) solves the problem as described.

We use the variables **m1** and **cm1** for the first length, **m2** and **cm2** for the second length, and **mSum** and **cmSum** for the sum of the two lengths.

The program assumes that the centimetre part of the given lengths is less than 100 and it works correctly if this is so. But what if the lengths were 3m 150cm and 2m 200cm?

The program will print 6m 250cm. (As an exercise, follow the logic of the program to see why.) While this is correct, it is not in the correct format since we require the centimetre value to be less than 100. We can modify our program to work in these cases as well by using integer division and % (remainder operator).

Program P4.2

```
//find the sum of two lengths given in metres and cm
#include <stdio.h>
main() {
  int m1, cm1, m2, cm2, mSum, cmSum;
  printf("Enter values for m and cm: ");
  scanf("%d %d", &m1, &cm1);
  printf("Enter values for m and cm: ");
  scanf("%d %d", &m2, &cm2);

  mSum = m1 + m2;  //add the metres
  cmSum = cm1 + cm2;  //add the centimetres
  if (cmSum >= 100) {
    cmSum = cmSum - 100;
    mSum = mSum + 1;
  }
  printf("\nSum is %dm %dcm\n", mSum, cmSum);
}
```

The following pseudocode shows how:

```
m = sum of metre values
cm = sum of centimetre values
if cm >= 100 then
  add cm / 100 to m
  set cm to cm % 100
endif
```

Using the above example, **m** is set to 5 and **cm** is set to 350. Since **cm** is greater than 100, we work out **350 / 100**[4] which is 3, using integer division; this is added to **m**, giving 8. The next line sets **cm** to **350 % 100** which is 50. So the answer we get is 8m 50cm, which is correct *and* in the correct format.

Note that the statements in the 'then part' *must* be written in the order shown. We must use the (original) value of **cm** to work out **cm / 100** before changing it in the next statement to **cm % 100**. As an exercise, work out what value will be computed for the sum if these statements are reversed. (The answer will be 5m 50cm, which is wrong. Can you see why?)

These changes are reflected in Program P4.3 (next page).

[4] Essentially, this finds how many 100's there are in cm

Program P4.3

```
//find the sum of two lengths given in metres and cm
#include <stdio.h>
main() {
  int m1, cm1, m2, cm2, mSum, cmSum;
  printf("Enter values for m and cm: ");
  scanf("%d %d", &m1, &cm1);
  printf("Enter values for m and cm: ");
  scanf("%d %d", &m2, &cm2);

  mSum = m1 + m2;  //add the metres
  cmSum = cm1 + cm2;  //add the centimetres
  if (cmSum >= 100) {
    mSum = mSum + cmSum / 100;
    cmSum = cmSum % 100;
  }
  printf("\nSum is %dm %dcm\n", mSum, cmSum);
}
```

The following is a sample run of this program:

```
Enter values for m and cm: 3 150
Enter values for m and cm: 2 200

Sum is 8m 50cm
```

The astute reader may recognize that we do not even need the **if** statement.

Consider:

```
mSum = m1 + m2;   //add the metres
cmSum = cm1 + cm2;  //add the centimetres
mSum = mSum + cmSum / 100;
cmSum = cmSum % 100;
```

where the last two statements come from the **if** statement.

We know therefore that this will work if **cmSum** is greater than or equal to 100 since, when that is the case, these four statements are executed.

What if **cmSum** is less than 100? Originally, the last two statements would not have been executed since the **if** condition would have been false. *Now* they are executed. Let us see what happens. Using the example of 3m 25cm and 2m 15cm, we get **mSum** as 5 and **cmSum** as 40.

In the next statement **40 / 100** is 0 so **mSum** does not change and in the last statement **40 % 100** is 40 so **cmSum** does not change. So the answer will be

printed correctly as

```
Sum is 5m 40cm
```

You should begin to realize by now that there is usually more than one way to express the logic of a program. With experience and study, you will learn which ways are better and why.

4.3 The if...else construct

Let us write a program for the following problem:

> A student is given 3 tests, each marked out of 100. The student passes if his average mark is greater than or equal to 50 and fails if his average mark is less than 50. Prompt for the 3 marks and print **Pass** if the student passes and **Fail** if he fails.

We will write the program assuming it works as follows:

```
Enter 3 marks: 60 40 56
Average is 52.0 Pass
```

or

```
Enter 3 marks: 40 60 36
Average is 45.3 Fail
```

The following algorithm describes the steps required to solve the problem:

```
prompt for the 3 marks
calculate the average
if average is greater than or equal to 50 then
  print "Pass"
else
  print "Fail"
endif
```

The part from **if** to **endif** is an example of the **if...else** *construct*.

The condition **average is greater than or equal to 50** is another example of a relational expression. If the condition is **true**, the statement after **then** (the *then part*) is executed; if it is **false**, the statement after **else** (the *else part*) is executed.

The whole *construct* is terminated with **endif**.

When you write pseudocode, what is important is that the logic intended is unmistakably clear. Note again how indentation can help by making it easy to identify the **then** part and the **else** part.

In the end, though, you must express the code in some programming language for it to be run on a computer. Program P4.4 shows how to do this for the above algorithm.

Program P4.4

```
//request 3 marks; print their average and Pass/Fail
#include <stdio.h>
main() {
  int mark1, mark2, mark3;
  double average ;
  printf("Enter 3 marks: ");
  scanf("%d %d %d", &mark1, &mark2, &mark3);
  average = (mark1 + mark2 + mark3) / 3.0;
  printf("\nAverage is %3.1f", average);
  if (average >= 50) printf(" Pass\n");
  else printf(" Fail\n");
}
```

Study carefully the **if...else** construct in the program. It reflects the logic expressed on the previous page. Note, again, that the word **then** is omitted in C.

In general, the **if...else** construct in C takes the form shown below.

```
if (<condition>) <statement1> else <statement2>
```

The words **if** and **else**, and the brackets, are *required* by C. You must supply **<condition>**, **<statement1>** and **<statement2>**. Each of **<statement1>** and **<statement2>** can be a one-line statement or a block. If **<condition>** is **true**, **<statement1>** is executed and **<statement2>** is skipped; if **<condition>** is **false**, **<statement1>** is skipped and **<statement2>** is executed. Note that when the **if** construct is executed, *either* **<statement1>** *or* **<statement2>** is executed, but not both.

If **<statement1>** and **<statement2>** are one-line statements, you can use the layout

```
if (<condition>) <statement1>
else <statement2>
```

If **<statement1>** and **<statement2>** are blocks, you can use the layout

```
if (<condition>) {
  ...
}
else {
  ...
}
```

In describing the various constructs in C, we normally use the phrase "where **<statement>** can be a one-line statement or a block".

It is useful to remember that, in C, for one-line statements, the semicolon is considered *part of* the statement. Examples are:

```
a = 5;
printf("Pass\n");
scanf("%d", &n);
```

So, in those cases where one-line statements are used, the semicolon, being part of the statement, must be present. In Program P4.4, in the **if...else** statement, **<statement1>** is **printf("Pass\n");** and **<statement2>** is **printf("Fail\n");** (semicolon included in both cases).

However, for a block or compound statement, the right brace, **}**, ends the block. So, in those cases where a block is used, there is no need for an additional semicolon to end the block.

It is sometimes useful to remember that the entire **if...else** construct (from **if** to **<statement2>**) is considered by C to be *one* statement and can be used in any place where one statement is required.

Example – calculating pay

For an example requiring blocks, suppose we have values for hours worked and rate of pay (the amount paid per hour) and wish to calculate a person's regular pay , overtime pay and net pay based on the following:

> if hours worked is less than or equal to 40, regular pay is calculated by multiplying hours worked by rate of pay and overtime pay is 0. If hours worked is greater than 40, regular pay is calculated by multiplying 40 by the rate of pay and overtime pay is calculated by multiplying the hours *in excess of* 40 by the rate of pay by 1.5. Net pay is calculated by adding regular pay and overtime pay.

For example, if hours is 36 and rate is 20 dollars per hour, regular pay is $720 (36 times 20) and overtime pay is $0. Net pay is $720.

And if hours is 50 and rate is 12 dollars per hour, regular pay is $480 (40 times 12) and overtime pay is $180 (excess hours 10 times 12 times 1.5). Net pay is $660 (480 + 180).

The above description could be expressed in pseudocode as:

```
if hours is less than or equal to 40 then
  set regular pay to hours x rate
  set overtime pay to 0
else
  set regular pay to 40 x rate
  set overtime pay to (hours – 40) x rate x 1.5
endif
set net pay to regular pay + overtime pay
```

We use indentation to highlight the statements to be executed if the condition "hours is less than or equal to 40" is true and those to be executed if the condition is false. The whole *construct* is terminated with **endif**.

The next step is to convert the pseudocode to C. When we do, we have to make sure that we stick to C's rules for writing an **if...else** statement. In this example, we have to ensure that both the **then** and **else** parts are written as blocks since they both consist of more than one statement.

Using the variables **hours** (hours worked), **rate** (rate of pay), **regPay** (regular pay), **ovtPay** (overtime pay) and **netPay** (net pay), we write

```
if (hours <= 40) {
  regPay = hours * rate;
  ovtPay = 0;
}   //no semicolon here; } ends the block
else {
  regPay = 40 * rate;
  ovtPay = (hours - 40) * rate * 1.5;
}   //no semicolon here; } ends the block
netPay = regPay + ovtPay;
```

Note the two comments. It would be wrong to put a semicolon after the first **}** since the **if** statement continues with an **else** part. If we were to put one, it effectively ends the **if** statement and C assumes there is no **else** part. When it finds the word **else**, there will be no **if** with which to match it and the program will give a "misplaced else" error.

There is no need for a semicolon after the second **}** but putting one would do no harm.

Problem: write a program to prompt for hours worked and rate of pay. The program then calculates and prints regular pay, overtime pay and net pay, based on the above description.

The following algorithm outlines the overall logic of the solution:

```
prompt for hours worked and rate of pay
if hours is less than or equal to 40 then
  set regular pay to hours x rate
  set overtime pay to 0
else
  set regular pay to 40 x rate
  set overtime pay to (hours – 40) x rate x 1.5
endif
set net pay to regular pay + overtime pay
print regular pay, overtime pay and net pay
```

This algorithm is implemented as Program P4.5. All the variables are declared as **double** so that fractional values can be entered for hours worked and rate of pay.

Program P4.5

```
#include <stdio.h>
main() {
  double hours, rate, regPay, ovtPay, netPay;
  printf("Hours worked? ");
  scanf("%lf", &hours);
  printf("Rate of pay? ");
  scanf("%lf", &rate);

  if (hours <= 40) {
    regPay = hours * rate;
    ovtPay = 0;
  }
  else {
    regPay = 40 * rate;
    ovtPay = (hours - 40) * rate * 1.5;
  }
  netPay = regPay + ovtPay;

  printf("\nRegular pay: $%3.2f\n", regPay);
  printf("Overtime pay: $%3.2f\n", ovtPay);
  printf("Net pay: $%3.2f\n", netPay);
}
```

A sample run of this program is shown on the next page. You should verify that the results are indeed correct.

Note that even though **hours** and **rate** are **double**, *data* for them can be supplied in any valid numeric format—here we use the integers `50` and `12`. These values would be converted to **double** format before being stored in the variables. We could, if we wished, have typed `50.0` and `12.00`, for example.

```
Hours worked? 50
Rate of pay? 12

Regular pay: $480.00
Overtime pay: $180.00
Net pay: $660.00
```

Sample run of P4.5

4.4 On program testing

When we write a program we should test it thoroughly to ensure that it is working correctly. As a minimum, we should test *all paths* through the program. This means that our *test data* must be chosen so that each statement in the program is executed at least once.

For Program P4.5, the sample run tests only when the hours worked is greater than 40. Based on this test alone, we cannot be sure that our program will work correctly if the hours worked is less than or equal to 40. To be sure, we must run another test in which the hours worked is less than or equal to 40. The following is such a sample run:

```
Hours worked? 36
Rate of pay? 20

Regular pay: $720.00
Overtime pay: $0.00
Net pay: $720.00
```

These results are correct which gives us greater assurance that our program is correct. We should also run a test when the hours is exactly `40`; we must always test a program at its 'boundaries'. For this program, `40` is a boundary—it is the value at which overtime begins to be paid.

What if the results are incorrect? For example, suppose overtime pay is wrong. We say the program contains a *bug* (an error), and we must *debug* (remove the error from) the program. In this case, we can look at the statement(s) which calculate the overtime pay to see if we have specified the calculation correctly. If this fails to uncover the error, we must painstakingly 'execute' the program by hand using the test data which produced the error. If done properly, this will usually reveal the cause of the error.

4.5 Using symbolic constants in C

In Program 4.1, we used two constants—`100` and `150`—denoting the labour charge per hour and the minimum job cost, respectively. What if these values change after the program has been written? We would have to find all occurrences of them in the program and change them to the new values.

This program is fairly short so this would not be too difficult to do. But imagine what the task would be like if the program contained hundreds or even thousands of lines of code. It would be difficult, time-consuming and error-prone to make all the required changes.

We can make life a little easier by using *symbolic constants*[5]—identifiers which we set to the required constants in one place. If we need to change the value of a constant, the change would have to be made in one place only. For example, in Program P4.1, we could use the symbolic constants **ChargePerHour** and **MinJobCost**. We would set **ChargePerHour** to 100 and **MinJobCost** to 150.

In C, we use the **#define** directive to define symbolic constants, among other uses. We show how by rewriting Program P4.1 as Program P4.6.

Program P4.6

```
//This program illustrates the use of symbolic constants
//Print job charge based on hours worked and cost of parts
#include <stdio.h>
#define ChargePerHour 100
#define MinJobCost 150
main() {
  double hours, parts, jobCharge;
  printf("Hours worked? ");
  scanf("%lf", &hours);
  printf("Cost of parts? ");
  scanf("%lf", &parts);
  jobCharge = hours * ChargePerHour + parts;
  if (jobCharge < MinJobCost) jobCharge = MinJobCost;
  printf("\nCharge for the job: $%3.2f\n", jobCharge);
}
```

The #define *directive*

In general, directives in C normally come at the top of the program. For our purposes, the **#define** directive takes the following form:

#define followed by an identifier, followed by the "replacement text"

In the program, we used

```
#define ChargePerHour 100
```

Note that this is not a normal statement and a semicolon is not needed to end it. Here, the identifier is **ChargePerHour** and the replacement text is the constant 100. In the body of the program, we use the identifier instead of the constant.

[5] Some people use the term *manifest constant* or *named constant*

When the program is compiled, C performs what is called a "pre-processing" step. It replaces all occurrences of the identifier by its replacement text. In this case, it replaces all occurrences of **ChargePerHour** by 100 and all occurrences of **MinJobCost** by 150 . After this is done, the program is compiled. It is up to the programmer to ensure that, when the identifier is replaced, the resulting statement makes sense.

Effectively, the directives say that the identifier **ChargePerHour** is equivalent to the constant 100 and the identifier **MinJobCost** is equivalent to 150.

For example, the pre-processing step changes

```
if (jobCharge < MinJobCost) jobCharge = MinJobCost;
```

to

```
if (jobCharge < 150) jobCharge = 150;
```

Suppose, for instance, that the minimum job cost changes from 150 to 180. We would just need to change the value in the **#define** directive, thus:

```
#define MinJobCost 180
```

No other changes would be needed.

In this book, we will use the *convention* of starting a symbolic constant identifier with an uppercase letter. Note, however, that C allows you to use any valid identifier.

For a slightly bigger example, consider Program P4.5 (page 74). Here, we used two constants—40 and 1.5—denoting the maximum regular hours and the overtime rate factor, respectively. We rewrite Program P4.5 as Program P4.7 (next page) using the symbolic constants **MaxRegularHours** (set to 40) and **OvertimeFactor** (set to 1.5).

Suppose, for instance, the maximum regular hours changes from 40 to 35. Program P4.7 would be easier to change than Program P4.5, since we would need to change the value in the **#define** directive only, thus:

```
#define MaxRegularHours 35
```

No other changes would be needed.

The numbers 40 and 1.5 used in Program P4.5 are referred to as *magic numbers*—they appear in the program for no apparent reason, as if by magic. Magic numbers are a good sign that a program may be restrictive, tied to those numbers. As far as possible, we must write our programs without magic numbers. Using symbolic constants can help to make our programs more flexible and easier to maintain.

Program P4.7

```
#include <stdio.h>
#define MaxRegularHours 40
#define OvertimeFactor 1.5
main() {
  double hours, rate, regPay, ovtPay, netPay;
  printf("Hours worked? ");
  scanf("%lf", &hours);
  printf("Rate of pay? ");
  scanf("%lf", &rate);

  if (hours <= MaxRegularHours) {
    regPay = hours * rate;
    ovtPay = 0;
  }
  else {
    regPay = MaxRegularHours * rate;
    ovtPay = (hours - MaxRegularHours) * rate * OvertimeFactor;
  }
  netPay = regPay + ovtPay;

  printf("\nRegular pay: $%3.2f\n", regPay);
  printf("Overtime pay: $%3.2f\n", ovtPay);
  printf("Net pay: $%3.2f\n", netPay);
}
```

4.6 More examples

We now write programs to solve two more problems. Their solutions will illustrate how to use **if...else** statements to determine which of several alternatives to take. In the sample runs, the underlined items are typed by the user; everything else is printed by the computer.

Example – printing a letter grade

Write a program to request a score in a test and print a letter grade based on the following:

```
score < 50          F
50 ≤ score < 75     B
score ≥  75         A
```

The program should work as follows:

```
Enter a score: 70
Grade B
```

A solution is shown as Program P4.8.

Program P4.8

```
//request a score; print letter grade
#include <stdio.h>
main() {
  int score;
  printf("Enter a score: ");
  scanf("%d", &score);
  printf("\nGrade ");
  if (score < 50) printf("F\n");
  else if (score < 75) printf("B\n");
  else printf("A\n");
}
```

The second **printf** prints a blank line followed by the word **Grade** followed by one space but does not end the line. When the letter grade *is* determined, it will be printed on this same line.

We saw that the **if...else** statement takes the form

```
if (<condition>) <statement1> else <statement2>
```

where **<statement1>** and **<statement2>** can be any statements. In particular, either one (or both) can be an **if...else** statement. This allows us to write so-called *nested if* statements. This is especially useful when we have several related conditions to test, as in this example. In the program, we can think of the part:

```
if (score < 50) printf("F\n");
else if (score < 75) printf("B\n");
else printf("A\n");
```

as

```
if (score < 50) printf("F\n");
else <statement>
```

where **<statement>** is the **if...else** statement

```
  if (score < 75) printf("B\n");
else printf("A\n");
```

If **score** is less than 50, the program prints **F** and ends. If not, it follows that **score** must be greater than or equal to 50.

Knowing this, the first **else** part checks if **score** is less than 75. If it is, the program prints **B** and ends. If not, it follows that **score** must be greater than or equal to 75.

Knowing this, the second **else** part (which matches the second **if**) prints **A** and ends.

To make sure the program is correct, you should run it with at least 3 different scores (e.g. 70, 45, 83) to verify that each of the 3 grades is printed correctly.

Note the preferred style for writing **else if**'s. If we had followed our normal indenting style, we would have written

```
if (score < 50) printf("F\n");
else
  if (score < 75) printf("B\n");
  else printf("A\n");
```

which would, of course, still be correct. However, if we had more cases, the indentation would go too deep and would look awkward. Also, since the different ranges for **score** are really *alternatives* (rather than one being within the other), it is better to keep them at the same indentation level.

The statements here were all one-line **printf** statements so we chose to write them on the same line as **if** and **else**. However, if they were blocks, it would be better to write it like this:

```
if (score < 50) {
  ...
}
else if (score < 75) {
  ...
}
else {
  ...
}
```

As an exercise, extend the program to print the correct grade based on:

```
score < 50          F
50 ≤ score < 65     C
65 ≤ score < 80     B
score ≥  80         A
```

Example – classifying a triangle

Given three integer values representing the sides of a triangle, print:

- **Not a triangle** if the values cannot be the sides of any triangle. This is so if any value is negative or zero, or if the length of any side is greater than or equal to the sum of the other two;
- **Scalene** if the triangle is scalene (all sides different);
- **Isosceles** if the triangle is isosceles (two sides equal);
- **Equilateral** if the triangle is equilateral (three sides equal).

The program should work as follows:

```
Enter 3 sides of a triangle: 7 4 7

Isosceles
```

A solution is shown as Program P4.9.

Program P4.9

```
//request 3 sides; determine type of triangle
#include <stdio.h>
main() {
  int a, b, c;
  printf("Enter 3 sides of a triangle: ");
  scanf("%d %d %d", &a, &b, &c);
  if (a <= 0 || b <= 0 || c <= 0) printf("\nNot a triangle\n");
  else if (a >= b + c || b >= c + a || c >= a + b)
    printf("\nNot a triangle\n");
  else if (a == b && b == c) printf("\nEquilateral\n");
  else if (a == b || b == c || c == a) printf("\nIsosceles\n");
  else printf("\nScalene\n");
}
```

The first task is to establish that we, in fact, have a valid triangle. The first **if** checks if any of the sides is negative or zero. If so, **Not a triangle** is printed. If they are all positive, we go to the **else** part which itself consists of an **if...else** statement.

Here, the **if** checks if any one side is greater than or equal to the sum of the other two. If so, **Not a triangle** is printed. If not, then we have a valid triangle and must determine its type by executing the **else** part beginning **if (a == b ...**

It is easiest to do this by first checking if it is equilateral. If two different *pairs of sides* are equal—**if (a == b && b == c)**—then all three are equal and we have an equilateral triangle.

If it is not equilateral, then we check if it is isosceles. If any two sides are equal—**if (a == b || b == c || c == a)**—we have an isosceles triangle.

If it is not isosceles, then it must be scalene.

As an exercise, extend the program to determine if the triangle is right-angled. It is right-angled if the sum of the squares of two sides is equal to the square of the third side.

Exercises 4

1. An auto repair shop charges as follows. Inspecting the vehicle costs $75. If no work needs to be done, there is no further charge. Otherwise, the charge is $75 per hour for labour plus the cost of parts, with a minimum charge of $120. If any work is done, there is no charge for inspecting the vehicle.

   Write a program to read values for hours worked and cost of parts (either of which could be 0) and print the charge for the job.
2. Write a program which requests two weights in kilograms and grams and prints the sum of the weights. For example, if the weights are 3kg 500g and 4kg 700g, your program should print 8kg 200g.
3. Write a program which requests two lengths in feet and inches and prints the sum of the lengths. For example, if the lengths are 5 ft. 4 in. and 8 ft. 11 in., your program should print 14ft. 3 in. (1 ft. = 12 in.)
4. A variety store give a 15% discount on sales totalling $300 or more. Write a program to request the cost of 3 items and print the amount the customer must pay.
5. Write a program to read two pairs of integers. Each pair represents a fraction. For example, the pair 3 5 represents the fraction 3/5. Your program should print the sum of the given fractions. For example, give the pairs 3 5 and 2 3, your program should print 19/15, since

   $$\frac{3}{5} + \frac{2}{3} = \frac{19}{15}$$

   Modify the program so that it prints the sum with the fraction reduced to a proper fraction; for this example, your program should print 1 4/15.

6. Write a program to read a person's name, hours worked, hourly rate of pay and tax rate (a number representing a percentage, e.g. 25 meaning 25%). The program must print the name, gross pay, tax deducted and net pay.

   Gross pay is calculated as described for net pay on page 72. The tax deducted is calculated by applying the tax rate to 80% of gross pay. And the net pay is calculated by subtracting the tax deducted from the gross pay.

   For example, if the person works 50 hours at $20/hour and the tax rate is 25%, his gross pay would be (40 × 20) + (10 × 20 × 1.5) = $1100. He pays 25% tax on 80% of $1100, that is, 25% of $880 = $220. His net pay is 1100 - 220 = $880.

7. In an English class, a student is given 3 term tests (marked out of 25) and an end-of-term test (marked out of 100). The end-of-term test counts the same as the 3 term tests in determining the final mark (out of 100). Write a program to read marks for the 3 term tests followed by the mark for the end-of-term test. The program then prints the final mark and an indication of whether the student passes or fails. To pass, the final mark must be 50 or more.

   For example, given the data 20 10 15 56, the final mark is calculated by

   $$\frac{(20+10+15)}{75} \times 50 + \frac{56}{100} \times 50 = 58$$

8. Write a program to read integer values for **month** and **year** and print the number of days in the month. For example, 4 2005 (April 2005) should print 30; 2 2004 (February 2004) should print 29 and 2 1900 (February 1900) should print 28.

   A leap year, *n*, is divisible by 4; however, if *n* is divisible by 100 then it is a leap year only if it is also divisible by 400. So 1900 is not a leap year but 2000 is.

9. Write a program to request two times given in 24-hour clock format and find the time (in hours and minutes) that has elapsed between the first time and the second time. You may assume that the second time is later than the first time. Each time is represented by two numbers: e.g. `16 45` means the time `16:45`, that is 4:45 p.m.

   For example, if the two given times are `16 45` and `23 25` your answer should be `6` hours `40` minutes.

   Modify the program so that it works as follows: if the second time is sooner than the first time, take it to mean a time for the *next* day. For example, given the times `20:30` and `6:15`, take this to mean 8.30 p.m. to 6.15 a.m. of the next day. Your answer should be `9` hours `45` minutes.

10. For any **year** between 1900 and 2099, inclusive, the **month** and **day** on which Easter Sunday falls can be determined by the following algorithm:

```
set a to year minus 1900
set b to the remainder when a is divided by 19
set c to the integer quotient when 7b + 1 is divided by 19
set d to the remainder when 11b + 4 - c is divided by 29
set e to the integer quotient when a is divided by 4
set f to the remainder when a + e + 31 - d is divided by 7
set g to 25 minus the sum of d and f
if g is less than or equal to 0 then
  set month to 'March'
  set day to 31 + g
else
  set month to 'April'
  set day to g
endif
```

   Write a program which requests a year between 1900 and 2099, inclusive, and checks if the year is valid. If it is, print the day on which Easter Sunday falls in that year. For example, if the year is `1999`, your program should print **April 4**.

11. A bank pays interest based on the amount of money deposited. If the amount is less than $5,000, the interest is 4% per annum. If the amount is $5,000 or more but less than $10,000, the interest is 5% per annum. If the amount is $10,000 or more but less than $20,000, the interest is 6% per annum. If the amount is $20,000 or more, the interest is 7% per annum.

    Write a program to request the amount deposited and print the interest earned for one year.

12. Write a program to prompt for the name of an item, its previous price and its current price. Print the percentage increase or decrease in the price. For example, if the previous price is $80 and the current price is $100, you should print **increase of 25%**; if the previous price is $100 and the current price is $80, you should print **decrease of 20%**.

13. A country charges income tax as follows based on one's gross salary. No tax is charged on the first 20% of salary. The remaining 80% is called *taxable income*. Tax is paid as follows:

- 10% on the first $15,000 of taxable income;
- 20% on the *next* $20,000 of taxable income;
- 25% on all taxable income in excess of $35,000;

    Write a program to read a value for a person's salary and print the amount of tax to be paid. Also print the *average tax rate*, that is, the percentage of salary that is paid in tax. For example, on a salary of $20,000, a person pays $1700 in tax. The average tax rate is `1700/20000*100 = 8.5%`.

5 Writing programs using repetition logic

In this chapter, we will explain:

- how to use the **while** construct to perform 'looping' in a program
- how to find the sum and average of an arbitrary set of numbers
- how to get a program to 'count'
- how to find the largest and smallest of an arbitrary set of numbers
- how to read data from a file
- how to write output to a file
- how to use the **for** construct to perform 'looping' in a program
- how to produce tables using **for**

In Chapter 3, we showed you how to write programs using *sequence* logic—programs whose statements are executed "in sequence" from the first to the last. In Chapter 4, we showed you how to write programs for problems which require *selection* logic. These programs used the **if** and the **if...else** statements.

In this chapter, we discuss problems which require *repetition* logic. The idea is to write statements once and get the computer to execute them repeatedly as long as some condition is true. We will see how to express repetition logic using the **while** and **for** statements.

5.1 The while construct

Consider the problem of writing a program to find the sum of some numbers which the user enters one at a time. The program will prompt the user to enter numbers as follows:

```
Enter a number: 13
Enter a number: 8
Enter a number: 16
```

and so on. We want to let the user enter as many number as he wishes. Since we can have no idea how many that will be, and the amount could vary from one run of the program to the next, we must let the user 'tell' us when he wishes to stop entering numbers.

How does he 'tell' us? Well, the only time the user 'talks' to the program is when he types a number in response to the prompt. If he wishes to stop entering

numbers, he can enter some 'agreed upon' value; when the program reads this value, it will know that the user wishes to stop.

In this example, we can use 0 as the value which tells the program that the user wishes to stop. When a value is used this way, it is referred to as a *sentinel* or *end-of-data* value. It is sometimes called a *rogue* value—the value is not to be taken as one of the actual data values.

What can we use as a sentinel value? Any value that cannot be confused with an actual data value would be okay. For example, if the data values are all positive numbers, we can use 0 or -1 as the sentinel value. When we prompt the user, it is a good idea to remind him what value to use as the sentinel value.

Assume we want the program to run as follows:

```
Enter a number (0 to end): 24
Enter a number (0 to end): 13
Enter a number (0 to end): 55
Enter a number (0 to end): 32
Enter a number (0 to end): 19
Enter a number (0 to end): 0

The sum is 143
```

How do we get the program to run like that? We want to be able to express the following logic

> As long as the user does not enter 0, keep prompting him for another number and add it to the sum

It seems obvious that we must, at least, prompt him for the first number. If this number is 0, we must print the sum (which, of course, would be 0 at this time). If the number is not 0, we must add it to the sum and prompt for another number. If *this* number is 0, we must print the sum. If this number is not 0, we must add it to the sum and prompt for another number. If *this* number is 0..., and so on.

The process will come to an end when the user enters 0.

This logic is expressed quite neatly using a **while** construct[1] shown on the next page.

Note, particularly, that we get a number *before* we enter the **while** loop. This is to ensure that the **while** condition makes sense the first time. (It would not make sense if **num** had no value).

[1] Informally, we say the **while** statement or the **while** loop

```
//Algorithm for finding sum
set sum to 0
get a number, num
while num is not 0 do
  add num to sum
  get another number, num
endwhile
print sum
```

To find the sum, we need to:

- Choose a variable to hold the sum; we will use **sum**.
- Initialize **sum** to 0 (before the **while** loop).
- Add a number to **sum** (inside the **while** loop). One number is added each time through the loop.

On exit from the loop, **sum** contains the sum of all the numbers entered.

The **while** construct lets us execute one or more statements repeatedly as long as some condition is true. Here, the two statements

```
add num to sum
get another number, num
```

are executed repeatedly as long as the condition **num is not 0** is true.

In *pseudocode*, the **while** construct is usually written as follows:

```
while <condition> do
  statements to be executed repeatedly
endwhile
```

The statements to be executed repeatedly are called the *body* of the **while** construct. The construct is executed as follows:

(1) **<condition>** is tested;

(2) if **true**, the body is executed and we go back to step (1);
if **false**, we continue with the statement, if any, after **endwhile**.

On the next page, we show how the algorithm is executed using the sample data entered above. For easy reference, the data was entered in the order:

```
24  13  55  32  19  0
```

When a **while** construct is being executed, we say the program is *looping* or the **while** *loop* is being executed.

It remains to show how to express this algorithm in C. Program P5.1 (page 89) shows how.

Execution of algorithm for finding sum with data: 24 13 55 32 19 0

Initially, **num** is undefined and **sum** is 0. We show this as:

24 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (24) is added to **sum** (0), giving:

13 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (13) is added to **sum** (24), giving:

55 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (55) is added to **sum** (37), giving:

32 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (32) is added to **sum** (92), giving:

19 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (19) is added to **sum** (124), giving:

0 is entered and stored in **num**;
num *is* 0 so we exit the **while** loop and go to **print sum** with

sum is now 143 so the algorithm prints 143.

Program P5.1

```
//print the sum of several numbers entered by a user
#include <stdio.h>
main() {
  int num, sum = 0;
  printf("Enter a number (0 to end): ");
  scanf("%d", &num);
  while (num != 0) {
    sum = sum + num;
    printf("Enter a number (0 to end): ");
    scanf("%d", &num);
  }
  printf("\nThe sum is %d\n", sum);
}
```

Of particular interest is the **while** statement. The pseudocode

```
while num is not 0 do
  add num to sum
  get another number, num
endwhile
```

is expressed in C as

```
while (num != 0) {
  sum = sum + num;
  printf("Enter a number (0 to end): ");
  scanf("%d", &num);
}
```

When the program is run, what would happen if the very first number entered was 0? Since **num** *is* 0, the **while** condition is immediately **false** so we drop out of the **while** loop and continue with the **printf** statement. The program will print the correct answer:

```
The sum is 0
```

In general, if the **while** condition is **false** the first time it is tested, the body is not executed at all.

Formally, the **while** construct in C is defined as follows:

while (<condition>) <statement>

The word **while** and the brackets are required; you must supply **<condition>** and **<statement>**; **<statement>** must be a single statement or a block[2]. First, **<condition>** is tested; if **true**, **<statement>** is executed and **<condition>** is tested again. This is repeated until **<condition>** becomes **false**. When **<condition>** becomes **false**, execution continues with the statement, if any, after **<statement>**. If **<condition>** is **false** the first time, **<statement>** is *not* executed and execution continues with the following statement, if any.

In Program P5.1, **<condition>** is **num != 0** and **<statement>** is the block

```
{
  sum = sum + num;
  printf("Enter a number (0 to end): ");
  scanf("%d", &num);
}
```

Whenever we want to execute several statements if **<condition>** is true, we must enclose the statements by **{** and **}**; effectively, this makes them into one statement, a *compound* statement, satisfying C's syntax rule which requires one statement as the body.

Example – finding the highest common factor

Let us write a program to find the highest common factor[3] (HCF) of two numbers. The program will run as follows:

```
Enter two numbers: 42 24
Their HCF is 6
```

We will use Euclid's algorithm for finding the **HCF** of two integers, **m** and **n**. The algorithm is as follows:

1. if n is 0, the HCF is m—stop
2. set r to the remainder when m is divided by n
3. set m to n
4. set n to r
5. go to step 1

[2] Recall that a block, also called a compound statement, is one or more statements enclosed by **{** and **}**.
[3] Also known as the greatest common divisor (GCD)

Using **m** as 42 and **n** as 24, step through the algorithm and verify that it gives the correct answer, 6.

Steps 2, 3 and 4 are executed as long as **n** is not 0. Hence, this algorithm can be expressed using a **while** loop as follows:

```
while n is not 0 do
  set r to m % n
  set m to n
  set n to r
endwhile
HCF is m
```

We can now write Program P5.2 which finds the highest common factor of two numbers entered.

Program P5.2

```
//find the HCF of two numbers entered by a user
#include <stdio.h>
main() {
  int m, n, r;
  printf("Enter two numbers: ");
  scanf("%d %d", &m, &n);
  while (n != 0) {
    r = m % n;
    m = n;
    n = r;
  }
  printf("\nTheir HCF is %d\n", m);
}
```

Note that the **while** condition is **n != 0** and the **while** body is the block

```
{
  r = m % n;
  m = n;
  n = r;
}
```

The algorithm and, hence, the program, works whether **m** is bigger than **n** or not. Using the example above, if **m** is 24 and **n** is 42, when the loop is executed the first time, it will set **m** to 42 and **n** to 24. In general, if **m** is smaller than **n**, the first thing the algorithm does is swap their values.

5.2 Keeping a count

Program P5.1 finds the sum of a set of numbers entered. Suppose we want to *count* how many numbers were entered, not counting the end-of-data 0. We could use an integer variable **n** to hold the count. To get the program to keep a count, we need to do the following:

- Choose a variable to hold the count; we choose **n**.
- Initialize **n** to 0.
- Add 1 to **n** in the appropriate place. Here, we need to add 1 to **n** each time the user enters a non-zero number.
- Print the count.

Program P5.3 is the modified program for counting the numbers.

Program P5.3

```
//print the sum and count of several numbers entered by a user
#include <stdio.h>
main() {
  int num, sum = 0, n = 0;
  printf("Enter a number (0 to end): ");
  scanf("%d", &num);
  while (num != 0) {
    n = n + 1;
    sum = sum + num;
    printf("Enter a number (0 to end): ");
    scanf("%d", &num);
  }
  printf("\n%d numbers were entered\n", n);
  printf("The sum is %d\n", sum);
}
```

The following is a sample run of the program:

```
Enter a number (0 to end): 24
Enter a number (0 to end): 13
Enter a number (0 to end): 55
Enter a number (0 to end): 32
Enter a number (0 to end): 19
Enter a number (0 to end): 0

5 numbers were entered
The sum is 143
```

Comments on Program P5.3

- We declare and initialize **n** and **sum** to 0 *before* the **while** loop.
- The statement

  ```
  n = n + 1;
  ```

  adds 1 to **n**. We say that **n** is *incremented* by 1. Suppose **n** has the value 3. When the right hand side is evaluated, the value obtained is 3 + 1 = 4. This value is stored in the variable on the left hand side, i.e. **n**. The net result is that 4 is stored in **n**.

  This statement is placed *inside* the loop so that **n** is incremented each time the loop body is executed. Since the loop body is executed when **num** is not 0, the value of **n** is always the amount of numbers entered so far.
- When we exit the **while** loop, the value in **n** will be the amount of numbers entered, not counting 0. This value is then printed.
- Observe that if the first number entered were 0, the **while** condition would be immediately false and control will go directly to the first **printf** statement with **n** and **sum** both having the value 0. The program will print, correctly:

  ```
  0 numbers were entered
  The sum is 0
  ```

Finding the average

Program P5.3 can be easily modified to find the average of the numbers entered. As we saw above, on exit from the **while** loop, we know the sum (**sum**) and how many numbers were entered (**n**). We can add a **printf** statement to print the average to 2 decimal places, thus:

```
printf("The average is %3.2f\n", (double) sum/n);
```

For the data in the sample run, the output will be

```
5 numbers were entered
The sum is 143
The average is 28.60
```

As explained on page 36, note the use of the cast **(double)** to force a floating-point calculation. Without it, since **sum** and **n** are **int**, an integer division would be performed, giving 28. Alternatively, we could declare **sum** as **double**, and print the sum and average with:

```
printf("The sum is %3.0f\n", sum);
printf("The average is %3.2f\n", sum/n);
```

However, there is still a problem. If the user enters 0 as the first number, execution will reach the last **printf** statement with **sum** having the value 0 and **n** having the value 0. The program will attempt to divide 0 by 0, giving the error "Attempt to divide by 0". This is an example of a *run-time* (or *execution*) error.

To cater for this situation, we could use the following after the **while** loop:

```
if (n == 0) printf("\nNo numbers entered\n");
else {
  printf("\n%d numbers were entered\n", n);
  printf("The sum is %d\n", sum);
  printf("The average is %3.2f\n", (double) sum/n);
}
```

The moral of the story is that, whenever possible, you should try to anticipate the ways in which your program might fail and cater for them. This is an example of what is called *defensive programming*.

5.3 Increment and decrement operators

There are a number of operators that originated with C and give C its unique flavour. The best known of these is the increment operator, **++**. In the last program, we used

```
n = n + 1;
```

to add 1 to **n**. The statement

```
n++;
```

does the same thing. The operator **++** adds 1 to its argument, which *must* be a variable. It can be written as a prefix (**++n**) or as a suffix (**n++**).

Even though **++n** and **n++** both add 1 to **n**, in certain situations, the *side-effect* of **++n** is different from **n++**. This is so because **++n** increments **n** *before* using its value, whereas **n++** increments **n** *after* using its value. As an example, suppose **n** has the value 7. The statement

```
a = ++n;
```

first increments **n** and *then assigns* the value (8) to **a**. But the statement

```
a = n++;
```

first assigns the value 7 to **a** and *then increments* **n** to 8. In both cases, though, the end result is that **n** is assigned the value 8.

As an exercise, what is printed by the following?

```
n = 5;
printf("Suffix: %d\n", n++);
printf("Prefix: %d\n", ++n);
```

The decrement operator **--** is similar to **++** except that it *subtracts* 1 from its variable argument. For example, **--n** and **n--** are both equivalent to

```
n = n - 1;
```

As explained above, **--n** *subtracts* 1 and *then uses* the value of **n**; **n--** *uses* the value of **n** and *then subtracts* 1 from it. It would be useful to do the above exercise with **--** replaced by **++**.

5.4 Assignment operators

So far, we have used the assignment operator, **=**, to assign the value of an expression to a variable, as in:

```
c = a + b
```

The entire construct consisting of the variable, **=** and the expression is referred to as an *assignment expression*. When the expression is followed by a semicolon, it becomes an *assignment statement*. The *value* of an assignment expression is simply the value assigned to the variable. For example, if **a** is 15 and **b** is 20, then the assignment expression

```
c = a + b
```

assigns the value 35 to **c**. The value of the (entire) assignment expression is also 35.

Multiple assignments are possible, as in

```
a = b = c = 13
```

The operator **=** evaluates from right to left, so the above is equivalent to

```
a = (b = (c = 13))
```

The rightmost assignment is done first, followed by the one to the left, and so on.

C provides other assignment operators, of which **+=** is the most widely used. In Program P5.3, above, we used the statement

```
sum = sum + num;
```

to add the value of **num** to **sum**. This can be written more neatly using **+=** as:

```
sum += num;  //add num to sum
```

To add 3 to **n**, we could write **n += 3**, which is the same as **n = n + 3**.

Other assignment operators include **-=**, ***=**, **/=** and **%=**. If **op** represents any of **+**, **-**, *****, **/** or **%**, then

```
variable op= expression
```

is equivalent to

```
variable = variable op expression
```

We point out that we could write all our programs without using increment, decrement or the special assignment operators. However, sometimes, they permit us to express certain operations more concisely or more conveniently.

5.5 Finding the largest

Suppose we want to write a program which works as follows: the user will type some numbers and the program will find the largest number typed. The following is a sample run of the program (underlined items are typed by the user):

```
Enter a number (0 to end): 36
Enter a number (0 to end): 17
Enter a number (0 to end): 43
Enter a number (0 to end): 52
Enter a number (0 to end): 50
Enter a number (0 to end): 0

The largest is 52
```

The user will be prompted to enter numbers, one at a time. We will assume that the numbers entered are all positive integers. We will let the user enter as many numbers as she likes. However, in this case, she will need to tell the program when she wishes to stop entering numbers. To do so, she will type 0.

Finding the largest number involves the following steps:

- Choose a variable to hold the largest number; we choose **bigNum**.
- Initialize **bigNum** to a very small value. The value chosen should be such that no matter what number is entered, *its* value would be greater than this initial value. Since we are assuming that the numbers entered would be positive, we can initialize **bigNum** to 0.
- As each number (**num**, say) is entered, it is compared with **bigNum**; if **num** is greater than **bigNum**, then we have a bigger number and **bigNum** is set to this new number.
- When all the numbers have been entered and checked, **bigNum** will contain the largest one.

These ideas are expressed in the following algorithm:

```
set bigNum to 0
get a number, num
while num is not 0 do
  if num is bigger than bigNum, set bigNum to num
  get a number, num
endwhile
print bigNum
```

Like before, we get the first number *before* we enter the **while** loop. This is to ensure that the **while** condition makes sense (*is defined)* the first time. It would not make sense if **num** had no value. If it is not 0, we enter the loop. Inside the loop, we process the number (compare it with **bigNum**, etc.) after which we get another number. *This* number is then used in the next test of the **while** condition.

When the **while** condition is **false** (**num** *is* 0), the program continues with the **print** statement *after* the loop.

This algorithm is implemented as shown in Program P5.4.

Program P5.4

```
//find the largest of a set of numbers entered
#include <stdio.h>
main() {
  int num, bigNum = 0;
  printf("Enter a number (0 to end): ");
  scanf("%d", &num);
  while (num != 0) {
    if (num > bigNum) bigNum = num; //is this number bigger?
    printf("Enter a number (0 to end): ");
    scanf("%d", &num);
  }
  printf("\nThe largest is %d\n", bigNum);
}
```

Let us 'step through' this program using the sample data entered at the beginning of this section. For easy reference, the data was entered in the order:

36 17 43 52 50 0

Initially, **num** is undefined and **bigNum** is 0. We show this as:

num [ ] **bigNum** [0]

36 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (36) is compared with **bigNum** (0);
36 is bigger so **bigNum** is set to 36, giving:

num [36] **bigNum** [36]

17 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (17) is compared with **bigNum** (36);
17 is not bigger so **bigNum** remains at 36, giving:

num [17] **bigNum** [36]

43 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (43) is compared with **bigNum** (36);
43 is bigger so **bigNum** is set to 43, giving:

num 43 bigNum 43

52 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (52) is compared with **bigNum** (43);
52 is bigger so **bigNum** is set to 52, giving:

num 52 bigNum 52

50 is entered and stored in **num**;
num is not 0 so we enter the **while** loop;
num (50) is compared with **bigNum** (52);
50 is not bigger so **bigNum** remains at 52, giving:

num 50 bigNum 52

0 is entered and stored in **num**;
num *is* 0 so we exit the **while** loop and go to **printf** with

num 0 bigNum 52

bigNum is now 52 and the **printf** statement prints

```
The largest is 52
```

5.6 Finding the smallest

In addition to finding the largest of a set of items, we are sometimes interested in finding the smallest. We will find the smallest of a set of integers. To do so involves the following steps:

- Choose a variable to hold the smallest number; we choose **smallNum**.
- Initialize **smallNum** to a very big value. The value chosen should be such that no matter what number is entered, *its* value would be *smaller* than this initial value. If we have an idea of the numbers we will get, we can choose an appropriate value.

  For instance, if we know that the numbers will contain at most 4 digits, we can use an initial value such as 10000. If we do not know this, we can set **smallNum** to the largest integer value defined by the compiler (32767 for 16-bit integers). Similarly, when we are finding the largest, we can initialize **bigNum** (say) to a very small number like -32767.

  Another possibility is to read the first number and set **smallNum** (or **bigNum**) to it. For our program, we will set **smallNum** to 32767.

- As each number (**num**, say) is entered, it is compared with **smallNum**; if **num** is smaller than **smallNum**, then we have a smaller number and **smallNum** is set to this new number.
- When all the numbers have been entered and checked, **smallNum** will contain the smallest one.

These ideas are expressed in the following algorithm:

```
set smallNum to 32767
get a number, num
while num is not 0 do
  if num is smaller than smallNum, set smallNum to num
  get a number, num
endwhile
print smallNum
```

This algorithm is implemented as shown in Program P5.5.

Program P5.5

```
//find the smallest of a set of numbers entered
#include <stdio.h>
main() {
  int num, smallNum = 32767;
  printf("Enter a number (0 to end): ");
  scanf("%d", &num);
  while (num != 0) {
    if (num < smallNum) smallNum = num;
    printf("Enter a number (0 to end): ");
    scanf("%d", &num);
  }
  printf("\nThe smallest is %d\n", smallNum);
}
```

When run, if numbers are entered in the following order:

```
36  17  43  52  50  0
```

the program will print

```
The smallest is 17
```

and if the numbers entered are

```
36  -17  43  -52  50  0
```

the program will print

```
The smallest is -52
```

5.7 Reading data from a file

So far, we have written our programs assuming that data to be supplied is typed at the keyboard. We have fetched the data using **scanf** for reading numbers and **gets** for reading strings. Typically, the program prompts the user for the data and waits for the user to type the data. When the data is typed, the program reads it, stores it in a variable (or variables) and continues with its execution. This mode of supplying data is called *interactive* since the user is interacting with the program.

We say we have been reading data from the "standard input". C uses the predefined identifier **stdin** to refer to the standard input. When your program starts up, C assumes that **stdin** refers to the keyboard. Similarly, the predefined identifier **stdout** refers to the standard output, the screen. So far, our programs have written output to the screen.

We can also supply data to a program by storing the data in a file. When the program needs data, it fetches it directly from the file, without user intervention. Of course, we have to ensure that the appropriate data has been stored in the file in the correct order and format. This mode of supplying data is normally referred to as *batch*[4] mode.

For example, suppose we need to supply an item number (**int**) and a price (**double**) for several items. If the program is written assuming that the data file contains several pairs of numbers (an **int** constant followed by a **double** constant) then we must ensure that the data in the file conforms to this.

Suppose we create a file called **input.txt** and type data in it. This file is a *file of characters* or a *text* file. Depending on the programming environment provided by your C compiler, it may be possible to assign **stdin** to **input.txt**—we say *redirect* the standard input to **input.txt**. Once this is done, your program will read data from the file rather than the keyboard. Similarly, it may be possible to redirect the standard output to a file, **output.txt**, say. If done, your **printf**'s will write output to the file, rather than the screen.

We will take a slightly different approach, which is a bit more general since it will work with *any* C program and does not depend on the particular compiler or operating system you happen to be using.

Suppose we want to be able to read data from the file **input.txt**. The first thing we need to do is declare an identifier called a "file pointer". This can be done with the statement

```
FILE * in;              // read as "file pointer in"
```

[4] The term is historical and comes from the old days when data had to be 'batched' before being submitted for processing.

The word **FILE** must be spelt as shown, with all uppercase letters. The spaces before and after * may be omitted. So you could write **FILE* in**, **FILE *in** or even **FILE*in**. We have used the identifier **in**; any other will do, such as **inf**, **infile**, **inputFile**, **payData**.

The second thing we must do is associate the file pointer **in** with the file **input.txt** and tell C we will be reading data from the file. This is done using the *function* **fopen**, as follows:

```
in = fopen("input.txt", "r");
```

This tells C to "open the file **input.txt** for reading": **"r"** indicates reading. We will use **"w"** if we want the file to be opened for "writing", that is, to receive output. If we wish, we could accomplish both things with one statement, thus:

```
FILE * in = fopen("input.txt", "r");
```

Once this is done, the "data pointer" (see page 50) will be positioned at the beginning of the file. We can now write statements which will read data from the file. We will see how shortly.

It is up to us to ensure that the file exists and contains the appropriate data. If not, we will get an error message such as "File not found". If we need to, we can specify the *path* to the file.

Suppose the file is located at: **C:\testdata\input.txt**.

We can tell C we will be reading data from the file with:

```
FILE * in = fopen("C:\\testdata\\input.txt", "r");
```

Recall that the escape sequence \\ is used to represent \ within a string. If the file is on a diskette, we can use:

```
FILE * in = fopen("A:\\input.txt", "r");
```

5.7.1 fscanf

We use the statement (more precisely, the function) **fscanf** to read data from the file. It is used in exactly the same way as **scanf** except that the first argument is the file pointer **in**. For example, if **num** is **int**, the statement

```
fscanf(in, "%d", &num);
```

will read an integer from the file **input.txt** (the one associated with **in**) and store it in **num**. Note that the argument is the *file pointer* and *not* the name of the file.

When we have finished reading data from the file, we should *close* it. This is done with **fclose**, as follows:

```
fclose(in);
```

There is one argument, the file pointer (not the name of the file). This statement breaks the association of the file pointer **in** with the file **input.txt**. If we need to, we could now link the identifier **in** with another file (**paydata.txt**, say) using:

```
in = fopen("paydata.txt", "r");
```

Note that we do not repeat the **FILE *** part of the declaration, since **in** has already been declared as **FILE ***. Subsequent **fscanf(in, ...)** statements will read data from the file **paydata.txt**.

Finding the average of some numbers in a file

To illustrate the use of **fscanf**, let us re-write Program P5.3 to read several numbers from a file and find their average. On page 93, we discussed how to find the average. We just need to make the changes to read the numbers from a file. Suppose the file is called **input.txt** and contains several positive integers with 0 indicating the end, for example,

```
24 13 55 32 19 0
```

Program P5.6 shows how to define the file as the place from which the data will be read and how to find the average.

Program P5.6

```
//read numbers from a file and find their average; 0 ends the data
#include <stdio.h>
main() {
  FILE * in = fopen("input.txt", "r");
  int num, sum = 0, n = 0;
  fscanf(in, "%d", &num);
  while (num != 0) {
    n = n + 1;
    sum = sum + num;
    fscanf(in, "%d", &num);
  }
  if (n == 0) printf("\nNo numbers entered\n");
  else {
    printf("\n%d numbers were entered\n", n);
    printf("The sum is %d\n", sum);
    printf("The average is %3.2f\n", (double) sum/n);
  }
  fclose(in);
}
```

Comments on Program P5.6

- **FILE *** and **fopen** have been added so that the **fscanf** statement would fetch data from the file **input.txt**.
- Since the data is being read directly from the file, the question of prompting for data does not arise. We have removed the **printf** statements which prompted for data.
- The program makes sure that **n** is not 0 before attempting to find the average.
- When run, the program reads the data from the file and prints the results without any user intervention.
- If the data file contains

```
24 13 55 32 19 0
```

  the output will be

```
5 numbers were supplied
The sum is 143
The average is 28.60
```

- The numbers in the file could be supplied in "free format"—any amount could be put on a line. For example, the sample data could have been typed on one line as above or as follows:

```
24   13
55 32
       19 0
```

or

```
24   13
55
   32 19
 0
```

or

```
24
13
55
32
19
0
```

- As an exercise, add statements to the program so that it also prints the largest and smallest numbers in the file.

A word of advice: when you try to run this program, it may not run properly because it cannot find the file **input.txt**. This may be because the compiler is looking for the file in the wrong place. Some compilers expect to find the file in the same folder/directory as the program file. Others expect to find it in the same folder/directory as the compiler. Try placing **input.txt** in each of these folders, in turn, and run the program. If this does not work then you will need to specify the complete path to the file in the **fopen** statement. For example, if the file is in the folder **data** which is in the folder **CS10E** which is on the **C:** drive, you will need to use the statement:

```
FILE * in = fopen("C:\\CS10E\\data\\input.txt", "r");
```

5.8 Sending output to a file

So far, our programs have read data from the standard input (the keyboard) and sent output to the standard output (the screen). We have just seen how to read data from a file. We now show you how you can send output to a file.

This is important because when we send output to the screen, it is lost when we exit the program or when we switch off the computer. If we need to save our output, we must write it to a file. Then the output is available as long as we wish to keep the file.

The process is similar to reading from a file. We must declare a "file pointer" (we will use **out**) and associate it with the actual file (**output.txt**, say) using **fopen**. This can be done with

```
FILE * out = fopen("output.txt", "w");
```

This tells C to "open the file **output.txt** for writing"; **"w"** indicates writing. When this statement is executed, the file **output.txt** is created if it does not already exist. If it exists, its contents are destroyed. In other words, whatever you write to the file will *replace* its original contents. Be careful that you do not open for writing a file whose contents you wish to keep.

5.8.1 fprintf

We use the statement (more precisely, the function) **fprintf** to send output to the file. It is used in exactly the same way as **printf** except that the first argument is the file pointer **out**. For example, if **sum** is **int** with value 143, the statement

```
fprintf(out, "The sum is %d\n", sum);
```

will write

```
The sum is 143
```

to the file **output.txt**.

Note that the argument is the *file pointer* and *not* the name of the file.

When we have finished writing output to the file, we must *close* it. This is especially important for output files since, the way some compilers operate[5], this is the only way to ensure that all output is sent to the file. We close the file with **fclose**, as follows:

```
fclose(out);
```

[5] For instance, they send output to a temporary buffer in memory and only when the buffer is full is it sent to the file. If you do not close the file, some output may be left in the buffer and never sent to the file.

There is one argument, the file pointer (not the name of the file). This statement breaks the association of the file pointer **out** with the file **output.txt**. If we need to, we could now link the identifier **out** with another file (**payroll.txt**, say) using:

```
out = fopen("payroll.txt", "w");
```

Note that we do not repeat the **FILE *** part of the declaration, since **out** has already been declared as **FILE ***. Subsequent **fprintf(out, ...)** statements will send output to the file **payroll.txt**.

For an example, we re-write Program P5.6 as Program P5.7 by adding the **fopen** and **fprintf** statements. The only difference is that P5.6 sends its output to the screen while P5.7 sends its output to the file **output.txt**.

Program P5.7

```
//read numbers from a file and find their average; 0 ends the data
#include <stdio.h>
main() {
  FILE * in = fopen("input.txt", "r");
  FILE * out = fopen("output.txt", "w");
  int num, sum = 0, n = 0;
  fscanf(in, "%d", &num);
  while (num != 0) {
    n = n + 1;
    sum = sum + num;
    fscanf(in, "%d", &num);
  }
  if (n == 0) fprintf(out, "No numbers entered\n");
  else {
    fprintf(out, "%d numbers were entered\n", n);
    fprintf(out, "The sum is %d\n", sum);
    fprintf(out, "The average is %3.2f\n", (double) sum/n);
  }
  fclose(in);
  fclose(out);
}
```

As explained on page 101, you can, if you wish, specify the complete path to your file in the **fopen** statement. For instance, if you want to send the output to a diskette, you can use

```
FILE * out = fopen("a:\\output.txt", "w");
```

When you run Program P5.7, it will appear as if nothing has happened. However, if you check your file system you will find the file **output.txt**. Open it to view your results.

5.9 Example – payroll

We expand our 'calculating pay' example from page 72 to illustrate many of the ideas discussed so far in this chapter. Specifically, we will write a program to process pay data for several employees.

The data for each employee consists of a first name, a last name, the number of hours worked and the rate of pay. The data will be stored in a file **paydata.txt** and output will be sent to the file **payroll.txt**.

In order to show you another way to read a string, we will assume that the data is stored in the file as follows:

```
Maggie May 50 12.00
Akira Kanda 40 15.00
Richard Singh 48 20.00
Jamie Khan 30 18.00
END
```

We use the "first name" **END** as the end-of-data marker.

Regular pay, overtime pay and net pay will be calculated as described on page 72. The employee name, hours worked, rate of pay, regular pay, overtime pay and net pay are printed under a suitable heading. In addition, we will write the program to do the following:

- count how many employees are processed
- calculate the total wage bill (total net pay for all employees)
- determine which employee earned the highest pay and how much. We will ignore the possibility of a tie.

For the sample data, the output should look like this:

```
Name            Hours   Rate  Regular  Overtime     Net

Maggie May       50.0  12.00   480.00    180.00  660.00
Akira Kanda      40.0  15.00   600.00      0.00  600.00
Richard Singh    48.0  20.00   800.00    240.00 1040.00
Jamie Khan       30.0  18.00   540.00      0.00  540.00

Number of employees: 4
Total wage bill: $2840.00
Richard Singh earned the most pay of $1040.00
```

An outline of the algorithm for reading the data is:

```
read firstName
while firstName is not "END" do
  read lastName, hours, rate
  do the calculations
  print results for this employee
  read firstName
endwhile
```

We will use the specification **%s** in **fscanf** for reading the names. Suppose we have declared **firstName** as

```
char firstName[20];
```

We can read a string into **firstName** with the statement

```
fscanf(in, "%s", firstName);
```

The specification **%s** must be matched with a character array, like **firstName**. As mentioned on page 51, when an *array name* is an argument to **scanf** (or **fscanf**), we must not write **&** before it.

%s is used for reading a string of characters *not containing* any whitespace characters. Beginning with the *next* non-whitespace character, characters are stored in **firstName** until the *next* whitespace character is encountered. It is up to us to make sure that the array is big enough to hold the string.

Because a whitespace character ends the reading of a string, **%s** *cannot be used to read a string containing blanks*. For this reason, we will use separate variables for first name and last name. We will use **firstName** and **lastName**.

For example, suppose the next piece of data contains (◇ denotes a space):

```
◇◇◇Robin◇◇◇◇Hood◇◇
```

fscanf(in, "%s", firstName) will skip over spaces until it reaches the first non-whitespace character **R**. Starting with **R**, it stores characters in **firstName** until it reaches the next space, the one after **n**. Reading stops and **Robin** is stored in **firstName**. The data pointer is positioned at the space after **n**. If we now execute

```
fscanf(in, "%s", lastName);
```

fscanf will skip over spaces until it reaches **H**. Starting with **H**, it stores characters in **lastName** until it reaches the space after **d**. Reading stops and **Hood** is stored in **lastName**. If **d** were the last character on the line, the end-of-line character (which is whitespace) would have stopped the reading.

Because of the way **%s** works, we will need to read the first and last names separately. However, in order to get the output to line up neatly as shown on the previous page, it would be more convenient to have the entire name stored in one

variable (**name**, say). Suppose **Robin** is stored in **firstName** and **Hood** is stored in **lastName**. We will copy **firstName** to **name** with

```
strcpy(name, firstName);
```

We will then add a space with

```
strcat(name, " ");
```

strcat is a predefined string function which allows us to join (concatenate) two strings. It stands for "string concatenation". If **s1** and **s2** are strings, **strcat(s1, s2)** will add **s2** to the end of **s1**. It assumes that **s1** is big enough to hold the joined strings.

We will then add **lastName** with

```
strcat(name, lastName);
```

Using our example, at the end of all this, **name** will contain **Robin Hood**.

In our program, we will use the specification **%-15s** to print **name**. This will print **name** left-justified in a field width of 15. In other words, all names will be printed using 15 print columns. This is necessary for the output to line up neatly. To cater for longer names, you can increase the field width.

As discussed on page 38, we must write the directive

```
#include <string.h>
```

at the head of our program if we want to use the string functions supplied by C.

Our program will need to check if the value in **firstName** is the string **"END"**. Ideally, we would like to say something like

```
while (firstName != "END") {  //cannot write this in C
```

but we cannot do so since C does not allow us to compare *strings* using the relational operators. What we *can* do is use the predefined string function **strcmp** (**str**ing **c**o**mp**are).

If **s1** and **s2** are strings, the expression **strcmp(s1, s2)** is

- 0 if **s1** is identical to **s2**
- < 0 if **s1** is less than **s2** (in alphabetical order)
- > 0 if **s1** is greater than **s2** (in alphabetical order)

For example, **strcmp("hello", "hi")** is **<** 0; **strcmp("hi", "hello")** is **>** 0;
strcmp("allo", "allo") is 0.

Using **strcmp**, we can write the **while** condition as

```
while (strcmp(firstName, "END") != 0)
```

If **strcmp(firstName, "END")** is not 0, it means that **firstName** does not contain the word **END** so we have not reached the end of the data; the **while** loop is entered to process that employee.

When faced with a program which requires so many things to be done, it is best to start by working on part of the problem, getting it right and then tackling the other parts. For this problem, we can start by getting the program to read and process the data without counting, finding the total or finding the highest-paid employee.

Program P5.8 is based on P4.7 (page 78).

Program P5.8

```
#include <stdio.h>
#include <string.h>
#define MaxRegularHours 40
#define OvertimeFactor 1.5
main() {
  FILE * in = fopen("paydata.txt", "r");
  FILE * out = fopen("payroll.txt", "w");
  char firstName[20], lastName[20], name[40];
  double hours, rate, regPay, ovtPay, netPay;

  fprintf(out,"Name          Hours  Rate  Regular  Overtime    Net\n\n");
  fscanf(in, "%s", firstName);
  while (strcmp(firstName, "END") != 0) {
    fscanf(in, "%s %lf %lf", lastName, &hours, &rate);
    if (hours <= MaxRegularHours) {
      regPay = hours * rate;
      ovtPay = 0;
    }
    else {
      regPay = MaxRegularHours * rate;
      ovtPay = (hours - MaxRegularHours) * rate * OvertimeFactor;
    }
    netPay = regPay + ovtPay;

    //make one name out of firstName and lastName
    strcpy(name,firstName); strcat(name," "); strcat(name,lastName);

    fprintf(out, "%-15s %5.1f %6.2f", name, hours, rate);
    fprintf(out, "%9.2f %9.2f %7.2f\n", regPay, ovtPay, netPay);
    fscanf(in, "%s", firstName);
  }
  fclose(in);
  fclose(out);
}
```

Comments on Program P5.8:

- We use the "file pointers" **in** and **out** for reading data from **paydata.txt** and sending output to **payroll.txt**.
- Since data is being read from a file, prompts are not required.
- We use **fscanf** for reading data and **fprintf** for writing output.
- We use **fclose** to close the files.
- We print a heading with the statement

  ```
  fprintf(out,"Name          Hours   Rate  Regular  Overtime    Net\n\n");
  ```

  To get the output to line up nicely, you will need to fiddle with the spaces between the words and the field widths in the statements which print the results. For example, there are 12 spaces between **e** and **H**, 3 spaces between **s** and **R**, 2 between **e** and **R**, 2 between **r** and **O** and 5 between **e** and **N**.

  You should experiment with the field widths in the **fprintf** statements (which write one line of output) to see what effect it has on your output.
- We use a **while** loop to process several employees. When the "first name" **END** is read, the program knows it has reached the end of the data. It closes the files and stops.

Now that we've got the basic processing right, we can add the statements to perform the other tasks. Program P5.9 (next page) is the complete program which counts the employees, calculates the total wage bill and determines the employee who earned the highest salary.

Counting the employees and finding the total wage bill are fairly straightforward. We use the variables **numEmp** and **wageBill** which are initialized to 0 *before* the loop. They are incremented *inside* the loop and their final values are printed *after* the loop. If you have difficulty following the code, you need to re-read Sections 5.1 and 5.2. We use **numEmp++** to add 1 to **numEmp** and **wageBill += netPay** to add **netPay** to **wageBill**.

The variable **mostPay** holds the most pay earned by any employee. It is initialized to 0. Each time we calculate **netPay** for the current employee, we compare it with **mostPay**. If it is bigger, we set **mostPay** to the new amount *and* save the name of the employee (**name**) in **bestPaid**.

Program P5.9

```
#include <stdio.h>
#include <string.h>
#define MaxRegularHours 40
#define OvertimeFactor 1.5
main() {
  FILE * in = fopen("paydata.txt", "r");
  FILE * out = fopen("payroll.txt", "w");
  char firstName[20], lastName[20], name[40], bestPaid[40];
  double hours, rate, regPay, ovtPay, netPay;
  double wageBill = 0, mostPay = 0;
  int numEmp = 0;

  fprintf(out,"Name          Hours  Rate Regular Overtime  Net\n\n");
  fscanf(in, "%s", firstName);
  while (strcmp(firstName, "END") != 0) {
    numEmp++;
    fscanf(in, "%s %lf %lf", lastName, &hours, &rate);
    if (hours <= MaxRegularHours) {
      regPay = hours * rate;
      ovtPay = 0;
    }
    else {
      regPay = MaxRegularHours * rate;
      ovtPay = (hours - MaxRegularHours) * rate * OvertimeFactor;
    }
    netPay = regPay + ovtPay;
    //make one name out of firstName and lastName
    strcpy(name,firstName); strcat(name," "); strcat(name,lastName);

    fprintf(out, "%-15s %5.1f %6.2f", name, hours, rate);
    fprintf(out, "%9.2f %9.2f %7.2f\n", regPay, ovtPay, netPay);

    if (netPay > mostPay) {
      mostPay = netPay;
      strcpy(bestPaid, name);
    }
    wageBill += netPay;
    fscanf(in, "%s", firstName);
  }
  fprintf(out, "\nNumber of employees: %d\n", numEmp);
  fprintf(out, "Total wage bill: $%3.2f\n", wageBill);
  fprintf(out,"%s earned the most pay of $%3.2f\n",bestPaid, mostPay);
  fclose(in);
  fclose(out);
}
```

5.10 The for construct

In Chapters 3, 4 and 5 we showed you three kinds of logic which can be used for writing programs—sequence, selection and repetition. Believe it or not, with these three, you have all the logic control structures you need to express the logic of any program. It has been proven that these three structures are all you need to formulate the logic to solve any problem that can be solved on a computer.

It follows that all you need are **if** and **while** statements to write the logic of any program. However, many programming languages provide additional statements because they allow you to express some kinds of logic *more conveniently* than using **if** and **while**. The **for** statement is a good example.

Whereas **while** lets you repeat statements as long as some condition is true, **for** lets you repeat statements *a specified number of times* (25 times, say). Consider the following *pseudocode* example of the **for** construct (more commonly called the *for loop*):

```
for j = 1 to 5 do
  print "I must not sleep in class"
endfor
```

This says to execute the **print** statement 5 times, with **j** assuming the values 1, 2, 3, 4 and 5, one value for each of the 5 times. The effect is to print:

```
I must not sleep in class
I must not sleep in class
I must not sleep in class
I must not sleep in class
I must not sleep in class
```

The construct consists of:

- the word **for**
- the *loop variable* (**j**, in the example)
- **=**
- the *initial value* (1, in the example)
- the word to
- the *final value* (5, in the example)
- the word **do**
- one or more statements to be executed each time through the loop; these statements make up the *body* of the loop
- the word **endfor**, indicating the end of the construct

We emphasize that **endfor** is not a C word and does not appear in any C program. It is just a convenient word used by programmers when writing pseudocode to indicate the end of a **for** loop.

In order to highlight the structure of the loop and make it more readable, we line up **for** and **endfor**, and indent the statements in the body.

The part of the construct between **for** and **do** is called the *control part* of the loop. This is what determines how many times the body is executed. In the example, the control part is **j = 1 to 5**. This works as follows:

- j is set to 1 and the body (**print**) is executed
- j is set to 2 and the body (**print**) is executed
- j is set to 3 and the body (**print**) is executed
- j is set to 4 and the body (**print**) is executed
- j is set to 5 and the body (**print**) is executed

The net effect is that, in this case, the body is executed 5 times.

In general, if the control part is **j = first to last**, it is executed as follows:

- if **first > last**, the body is not executed at all; execution continues with the statement, if any, after **endfor**; otherwise
- **j** is set to **first** and the body is executed
- 1 is added to **j**; if the value of **j** is less than or equal to **last**, the body is executed again
- 1 is added to **j**; if the value of **j** is less than or equal to **last**, the body is executed again
- and so on

When the value of **j** reaches **last**, the body is executed for the last time and control goes to the statement, if any, after **endfor**.

The net effect is that the body is executed for each value of **j** between **first** and **last**, inclusive.

The for statement in C

The pseudocode construct

```
for j = 1 to 5 do
  print 'I must not sleep in class'
endfor
```

is implemented in C as

```
for (j = 1; j <= 5; j++)
  printf("I must not sleep in class\n");
```

assuming that **j** is declared as **int**.

In C, the body must be a single statement or a block. In the example, it is the single **printf** statement. If it were a block, it would be written in the form

```
for (j = 1; j <= 5; j++) {
  <statement1>
  <statement2>
  etc.
}
```

Program P5.10 illustrates how the **for** statement is used to print

```
I must not sleep in class
```

5 times. As you could probably figure out, if you want to print 100 lines, say, all you have to do is change 5 to 100 in the **for** statement.

Program P5.10

```
#include <stdio.h>
main() {
  int j;
  for (j = 1; j <= 5; j++)
    printf("I must not sleep in class\n");
}
```

The general form of the **for** statement in C is

```
for (<expr1>; <expr2>; <expr3>)
  <statement>
```

The word **for**, the brackets and the semicolons are required by C. You must supply <**expr1**>, <**expr2**>, <**expr3**> and <**statement**>.

In detail, the **for** statement consists of

- the word **for**
- a left bracket, **(**
- <**expr1**> , called the initialization step; this is the first step performed when the **for** is executed.
- a semicolon, **;**
- <**expr2**>, the *condition* which controls whether or not <**statement**> is executed.
- a semicolon, **;**
- <**expr3**>, called the re-initialization step

- a right bracket,)
- **<statement>**, called the *body* of the loop. This can be a simple statement or a block.

When a **for** statement is encountered, it is executed as follows:

(1) <**expr1**> is evaluated.
(2) <**expr2**> is evaluated. If it is **false**, execution continues with the statement, if any, after **<statement>**. If it is **true**, **<statement>** is executed, followed by <**expr3**>, and this step (2) is repeated.

This can be expressed more concisely as follows:

```
<expr1>;
while (<expr2>) {
  <statement>;
  <expr3>;
}
```

In the following

```
for (j = 1; j <= 5; j++)
  printf("I must not sleep in class\n");
```

- **j = 1** is **<expr1>**
- **j <= 5** is **<expr2>**
- **j++** is **<expr3>**
- **<statement>** is **printf(...);**

This code is executed as follows:

(1) **j** is set to 1
(2) the test **j <= 5** is performed. It is **true**, so the body of the loop is executed (one line is printed). The re-initialization step **j++** is then performed, so **j** is now 2.
(3) the test **j <= 5** is again performed. It is **true**, so the body of the loop is executed (a second line is printed); **j++** is performed, so **j** is now 3.
(4) the test **j <= 5** is again performed. It is **true**, so the body of the loop is executed (a third line is printed); **j++** is performed, so **j** is now 4.
(5) the test **j <= 5** is again performed. It is **true**, so the body of the loop is executed (a fourth line is printed); **j++** is performed, so **j** is now 5.
(6) the test **j <= 5** is again performed. It is **true**, so the body of the loop is executed (a fifth line is printed); **j++** is performed, so **j** is now 6.
(7) the test **j <= 5** is again performed. It is now **false**, so execution of the **for** loop ends and the program continues with the statement, if any, after **printf(...)**.

On exit from the **for** loop, the value of **j** (6, in this case) is available and may be used by the programmer if required.

C allows you to *declare* and *initialize* the loop variable in the **for** statement itself[6]. So we could have written

```
for (int j = 1; j <= 5; j++)
```

If we do this, **j** is "known" and available *after* the loop, until the end of the function.

If we need a loop to count backwards (from 5 down to 1, say), we can write

```
for (int j = 5; j >= 1; j--)
```

The loop body is executed with **j** taking on the values 5, 4, 3, 2 and 1. After the loop, the value of **j** is 0.

We can also count upwards in steps other than 1. For example, the statement

```
for (int j = 10; j <= 20; j += 3)
```

will execute the body with **j** taking on the values 10, 13, 16 and 19. After the loop, the value of **j** is 22.

In general, we can use whatever expressions we need to get the effect that we want.

In Program P5.10, **j** takes on the values 1, 2, 3, 4 and 5 inside the loop. We have not used **j** in the body but it *is* available, if needed. We show a simple use in Program P5.11 in which we number the lines by printing the value of **j**.

Program P5.11

```
#include <stdio.h>
main() {
  for (int j = 1; j <= 5; j++)
    printf("%d. I must not sleep in class\n", j);
}
```

When run, this program will print

```
1. I must not sleep in class
2. I must not sleep in class
3. I must not sleep in class
4. I must not sleep in class
5. I must not sleep in class
```

The initial and final values in the **for** statement do not have to be constants; they can be variables or expressions. For example, consider

```
for (j = 1; j <= n; j++) ...
```

[6] Some older compilers may not allow this. If yours doesn't, just declare **j** before the loop.

How many times would the body of this loop be executed? We cannot answer unless we know the value of **n** when this statement is encountered. If **n** has the value 7, then the body would be executed 7 times.

This means that *before* the computer gets to the **for** statement, **n** must have been assigned some value and it is *this* value which determines how many times the loop is executed. If a value has not been assigned to **n**, the **for** statement would not make sense and the program will crash (or, at best, give some nonsensical output).

To illustrate, we can modify Program P5.11 to ask the user how many lines she wants to print. The number entered is then used to control how many times the loop is executed and, hence, how many lines are printed.

The changes are shown in Program P5.12.

Program P5.12

```
#include <stdio.h>
main() {
  int n;
  printf("How many lines to print? ");
  scanf("%d", &n);
  for (int j = 1; j <= n; j++)
    printf("%d. I must not sleep in class\n", j);
}
```

A sample run is shown below. We will show shortly how to neaten the output.

```
How many lines to print? 12

1. I must not sleep in class
2. I must not sleep in class
3. I must not sleep in class
4. I must not sleep in class
5. I must not sleep in class
6. I must not sleep in class
7. I must not sleep in class
8. I must not sleep in class
9. I must not sleep in class
10. I must not sleep in class
11. I must not sleep in class
12. I must not sleep in class
```

Note that we do not (and cannot) know beforehand what number the user will type. However, that is not a problem. We simply store the number in a variable (**n** is used) and use **n** as the "final value" in the **for** statement. Thus, the number the user types will determine how many times the body is executed.

Now the user can change the number of lines printed simply by entering the desired value in response to the prompt. No change is needed in the program. Program P5.12 is much more *flexible* than P5.11.

A bit of aesthetics[7]

In the above run, while the output is correct, the *numbers* do not line up very nicely with the result that the **I**'s do not line up properly. We can get things to line up by using a field width when printing **j**. For this example, 2 will do. However, if the number could run into the hundreds, we must use at least 3 and for thousands at least 4, and so on.

In Program P5.12, if we change the **printf** statement to

```
printf("%2d. I must not sleep in class\n", j);
```

the following output would be much nicer to look at:

```
How many lines to print? 12

 1. I must not sleep in class
 2. I must not sleep in class
 3. I must not sleep in class
 4. I must not sleep in class
 5. I must not sleep in class
 6. I must not sleep in class
 7. I must not sleep in class
 8. I must not sleep in class
 9. I must not sleep in class
10. I must not sleep in class
11. I must not sleep in class
12. I must not sleep in class
```

5.11 Producing multiplication tables

The **for** statement is quite handy for producing multiplication tables. To illustrate, let us write a program to produce a "2 times" table from 1 to 12. The following should be printed by the program:

```
 1 x 2 =  2
 2 x 2 =  4
 3 x 2 =  6
 4 x 2 =  8
 5 x 2 = 10
 6 x 2 = 12
 7 x 2 = 14
 8 x 2 = 16
 9 x 2 = 18
10 x 2 = 20
11 x 2 = 22
12 x 2 = 24
```

A look at the output reveals that each line consists of 3 parts:

[7] aesthetic - showing good taste or appreciation of beauty

1. a number on the left which increases by 1 for each new line;
2. a fixed part " x 2 = " (note the spaces) which is the same for each line;
3. a number on the right, which is derived by multiplying the number on the left by 2.

We can produce the numbers on the left by using

```
for (m = 1; m <= 12; m++)
```

and printing **m** each time through the loop. And we can produce the number on the right by multiplying **m** by 2.

Program P5.13 shows how to write it. When run, it will produce the table above.

Program P5.13

```
#include <stdio.h>
main() {
  for (int m = 1; m <= 12; m++)
    printf("%2d x 2 = %2d\n", m, m * 2);
}
```

Note the use of the field width 2 for printing **m** and **m * 2**. This is to ensure that the numbers line up as shown in the output. Without the field width, the table would not look neat—try it and see.

What if we want to print a "7 times" table? What changes would be needed? We would just need to change the **printf** statement to

```
printf("%2d x 7 = %2d\n", m, m * 7);
```

Similarly, if we want a "9 times" table, we would have to change the 7's to 9's. And we would have to keep changing the program for each table that we want.

A better approach is to let the user tell the computer which table he wants. The program will then use this information to produce the table requested. Now when the program is run, it will prompt:

```
Enter type of table:
```

If the user wants a "7 times" table, he will enter 7. The program will then go ahead and produce a "7 times" table. Program P5.14 (next page) shows how.

Since we do not know beforehand what type of table would be requested, we cannot use **7**, say, in the *format string*, since the user may want a "9 times" table. We must print the variable **factor** which holds the type of table.

Program P5.14

```
#include <stdio.h>
main() {
  int factor;
  printf("Type of table? ");
  scanf("%d", &factor);
  for (int m = 1; m <= 12; m++)
    printf("%2d x %d = %2d\n", m, factor, m * factor);
}
```

The following is a sample run:

```
Type of table? 7

 1 x 7 =  7
 2 x 7 = 14
 3 x 7 = 21
 4 x 7 = 28
 5 x 7 = 35
 6 x 7 = 42
 7 x 7 = 49
 8 x 7 = 56
 9 x 7 = 63
10 x 7 = 70
11 x 7 = 77
12 x 7 = 84
```

We now have a program which can produce *any* multiplication table from 1 to 12. But there is nothing sacred[8] about the range 1 to 12. How can we *generalize* the program to produce *any* table in *any* range? We must let the user tell the program what type of table and what range he wants. And in the program, we will need to replace the numbers 1 and 12 by variables, (**start** and **finish**, say).

All these changes are reflected in Program P5.15 (next page). The following sample run shows how to produce a "6 times" table from 10 to 16.

```
Type of table? 6
From? 10
To? 16

10 x 6 = 60
11 x 6 = 66
12 x 6 = 72
13 x 6 = 78
14 x 6 = 84
15 x 6 = 90
16 x 6 = 96
```

[8] special, maybe, since that's what we all learnt in school

Program P5.15

```
#include <stdio.h>
main() {
  int factor, start, finish;
  printf("Type of table? ");
  scanf("%d", &factor);
  printf("From? ");
  scanf("%d", &start);
  printf("To? ");
  scanf("%d", &finish);
  printf("\n");
  for (int m = start; m <= finish; m++)
    printf("%2d x %d = %2d\n", m, factor, m * factor);
}
```

To cater for bigger numbers, we would need to increase the field width of 2 in the **printf** statement if we want the numbers to line up neatly.

Comment on Program P5.15

The program assumes that **start** is less than or equal to **finish**. What if this is not so? For example, suppose the user enters 20 for **start** and 15 for **finish**. The **for** statement becomes

```
for (int m = 20; m <= 15; m++)
```

m is set to 20; since this value is immediately bigger than the final value 15, the body is not executed at all and the program ends with nothing printed.

To cater for this possibility, we can let the program *validate* the values of **start** and **finish** to ensure that the 'From' value is less than or equal to the 'To' value. One way of doing this is:

```
if (start > finish)
  printf("Invalid data: From value is bigger than To value\n");
else {
  printf("\n");
  for (int m = start; m <= finish; m++)
    printf("%2d x %d = %2d\n", m, factor, m * factor);
}
```

Validating data entered is yet another example of *defensive programming*. Also, it is better to print a message informing the user of the error rather than have the program do nothing. This makes the program more *user-friendly*.

5.12 Temperature conversion table

Some countries use the Celsius scale for measuring temperature while others use the Fahrenheit scale. Suppose we want to print a table of temperature conversions from Celsius to Fahrenheit. The table runs from 0°C to 100°C in steps of 10, thus:

```
Celsius   Fahrenheit

    0          32
   10          50
   20          68
   30          86
   40         104
   50         122
   60         140
   70         158
   80         176
   90         194
  100         212
```

For a Celsius temperature, C, the Fahrenheit equivalent is 32 + 9C/5.

If we use **c** to hold the Celsius temperature, we can write a **for** statement to let **c** take on the values 0, 10, 20, ..., up to 100, with

```
for (c = 0; c <= 100; c += 10)
```

Each time the loop is executed, **c** is incremented by 10. Using this, we write Program P5.16 to produce the table.

Program P5.16

```
#include <stdio.h>
main() {
  double c, f;
  printf("Celsius  Fahrenheit\n\n");
  for (c = 0; c <= 100; c += 10) {
    f = 32 + 9 * c / 5;
    printf("%5.0f %9.0f\n", c, f);
  }
}
```

An interesting part of the program are the **printf** statements. In order to get the temperatures centred under the heading, we need to do some counting. Consider the heading

```
Celsius   Fahrenheit
```

with the **C** in column 1 and 2 spaces between **s** and **F**.

Assume we want the Celsius temperatures lined up under **i** and the Fahrenheit temperatures lined up under **n** (see output above).

By counting, we find that **i** is in column 5 and **n** is in column 15.

From this, we can figure out that the value of **c** must be printed in a field width of 5 (the first 5 columns) and the value of **f** must be printed in the next 10 columns. We use a field width of 9 for **f** since there is already one space between **f** and **%**.

We print **c** and **f** without a decimal point using 0 as the number of decimal places in the format specification. If any temperature is not a whole number, the 0 specification will print it *rounded* to the nearest whole number, as in the table below.

As an exercise, re-write Program P5.16 so that it requests threes values for **start**, **finish** and **incr** and produces a conversion table with Celsius temperatures going from **start** to **finish** in steps of **incr**. Follow the ideas of the previous section for producing any multiplication table. For example, if **start** is 20, **finish** is 40 and **incr** is 2, the program should produce (with Fahrenheit temperatures rounded to the nearest whole number):

```
Celsius  Fahrenheit

   20         68
   22         72
   24         75
   26         79
   28         82
   30         86
   32         90
   34         93
   36         97
   38        100
   40        104
```

As another exercise, write a program which produces a table from Fahrenheit to Celsius. For a Fahrenheit temperature, F, the Celsius equivalent is 5(F – 32)/9.

5.13 The expressive power of for

In C, the **for** statement can be used for a lot more than just counting the number of times a loop is executed. This is possible because **<expr1>**, **<expr2>** and **<expr3>** can be *any* expressions; they are not even required to be related in any way. So, for instance, **<expr1>** can be **j = 1**, **<expr2>** can test if **a** is equal to **b** and **<expr3>** can be **k++** or any other expression the programmer desires. The following is perfectly valid:

```
for (j = 1; a == b; k++) <statement>
```

It is also possible to omit any of **<expr1>**, **<expr2>** or **<expr3>**. However, the semicolons *must* be included. Thus, to omit **<expr3>**, one can write

```
for (<expr1>; <expr2>; ) <statement>
```

In this case,

(1) **<expr1>** is evaluated; then

(2) **<expr2>** is evaluated. If it is **false**, execution continues after **<statement>**. If it is **true**, **<statement>** is executed and this step (2) is repeated.

This is equivalent to

```
<expr1>;
while (<expr2>) <statement>
```

If, in addition, we omit **<expr1>**, we will have

```
for ( ; expr2 ; ) <statement>   // note the semicolons
```

Now, **<expr2>** is evaluated. If it is **false**, execution continues after **<statement>**. If it is **true**, **<statement>** is executed, followed by another evaluation of **<expr2>**, and so on. The net effect is that **<statement>** is executed as long as **<expr2>** is true—the same effect achieved by

```
while (<expr2>) <statement>
```

Most times, **<expr1>** will initialize some variable, **<expr2>** will test it and **<expr3>** will change it. But more is possible. For instance, the following is valid:

```
for (lo = 1, hi = n; lo <= hi; lo++, hi--) <statement>
```

Here, **<expr1>** consists of *two* assignment statements separated by a *comma*; **<expr3>** consists of *two* expressions separated by a comma. This is very useful when two variables are related and we want to highlight the relationship. In this case, the relationship is captured in one place, the **for** statement. We can easily see how the variables are initialized and how they are changed.

This feature comes in very handy when dealing with arrays. We will see examples on pages 191 and 201. For now, we leave you with a simple example of printing all pairs of integers which add up to a given integer, **n**.

The code is:

```
for (lo = 1, hi = n - 1; lo <= hi; lo++, hi--)
  printf("%2d %2d\n", lo, hi);
```

If **n** is 10, this code will print

```
1   9
2   8
3   7
4   6
5   5
```

The variables **lo** and **hi** are initialized to the first pair. After a pair is printed, **lo** is *incremented* by 1 and **hi** is *decremented* by 1 to get the next pair. When **lo** passes **hi**, all pairs have been printed.

Exercises 5

1. What is an end-of-data marker? Give the other names for it.
2. On page 58, problem 7, write the program to read several sets of prices and discounts from a file. Choose an appropriate end-of-data marker. Also, print the number of items and the total amount the customer must pay.
3. On page 58, problem 9, write the program to process data for several customers from a file. Assume that the fixed charge and the rate per unit are the same for all customers and are given on the first line. This is followed by the data for the customers. Each set of data consists of two lines: a name on the first line and the meter readings on the second line. The 'name' **xxxx** ends the data. Print the information for the customers under a suitable heading. Also,

- count how many customers were processed
- print the total due to the electricity company
- find the customer whose bill was the highest

4. On page 59, problem 12, write the program to process several sets of data from a file. Each set of data consists of two lines: a name on the first line and gross salary, deductions allowed and rate of tax on the second line. The 'name' **xxxx** ends the data. Also,

- count how many persons were processed
- print totals for gross salary, tax deducted and net pay
- find the person who earned the highest net pay

5. On page 59, problem 16, write the program to convert several lengths. Choose an appropriate end-of-data marker.
6. On page 82, problem 1, write the program to read several sets of hours worked and cost of parts and, for each, print the charge for the job. Choose an appropriate end-of-data marker. (You cannot choose 0 since either hours or parts could be 0). Also, print the total charge for all jobs.
7. On pages 82-83, for problems 2, 3 and 9, write the programs to process several pairs of weights, lengths and times.
8. A contest was held for the promotion of SuperMarbles. Each contestant was required to guess the number of marbles in a jar. Write a program to determine the Grand Prize winner (ignoring the possibility of a tie) based on the following:

   The first line of data contains a single integer (**answer**, say) representing the actual number of marbles in the jar. Each subsequent line contains a contestant's ID number (an integer) and an integer representing that contestant's guess. The data is terminated by a line containing 0 only.

   The Grand Prize winner is that contestant who guesses closest to **answer** *without exceeding it*. There is no winner if all guesses are too big.

   Assume all data are valid. Print the number of contestants and the ID number of the winner, if any.

9. The manager of a hotel wants to calculate the cost of carpeting the rooms in the hotel. All the rooms are rectangular in shape. He has a file, **rooms.txt**, which contains data for the rooms. Each line of data consists of the room number, the length and breadth of the room (in metres), and the cost per square metre of the carpet for that room. For example, the data line:

```
325  3.0  4.5  40.00
```

means that room 325 is 3.0 metres by 4.5 metres, and the cost of the carpet for that room is $40.00 per square metre. The last line of the file contains 0 only, indicating the end of the data.

Write a program to do the following, sending output to the file **rooms.out**:

- print a suitable heading and under it, for each room, print the room number, the area of the room and the cost of the carpet for the room;
- print the number of rooms processed;
- print the total cost of carpeting all the rooms;
- print the number of the room which will cost the most to carpet (ignore ties).

10. The price of an item is **p** dollars. Due to inflation, the price of the item is expected to increase by **r%** each year. For example, the price might be $79.50 and inflation might be 7.5%. Write a program which reads values for **p** and **r**, and, starting with year 1, prints a table consisting of year and year-end price. The table ends when the year-end price is at least twice the original price.
11. A fixed percentage of water is taken from a well each day. Request values for **W** and **P** where

- **W** is the amount (in litres) of water in the well at the start of the first day
- **P** is the percentage of the water in the well taken out each day

Write a program to print the number of the day, the amount taken for that day and the amount remaining at the end of the day. The output should be terminated when 30 days have been printed or the amount remaining is less than 100 litres, whichever comes first. For example, if **W** = 1000 and **P** = 10, the output should start as follows:

```
Day      Amount        Amount
         Taken      Remaining

  1        100           900
  2         90           810
  3         81           729
```

12. You are given a file containing an unknown amount of numbers. Each number is one of the numbers 1 to 9. A number can appear zero or more times and can appear anywhere in the file. The number 0 indicates the end of the data. Some sample data are:

```
5 3 7 7 7 4 3 3 2 2 2 6 7 4 7 7 2 2 9 6 6 6 6 6 8 5 5 3 7 9 9 9 0
```

Write a program to read the data *once* and print the number which appears the most in consecutive positions and the number of times it appears. Ignore the possibility of a tie. For the above data, output should be 6 5.

13. Write a program to print the following 99 times:

When you have nothing to say, it is a time to be silent

14. Write a program to print 8 copies of your favourite song.
15. Write a program to print a table of squares from 1 to 10. Each line of the table consists of a number and the square of that number.
16. Write a program to request a value for **n** and print a table of squares from 1 to **n**.
17. Write a program to request values for **first** and **last**, and print a table of squares from **first** to **last**.
18. Write a program to print 100 mailing labels for

    The Computer Store
    57 First Avenue
    San Fernando

19. Write a program to print a conversion table from miles to kilometres. The table ranges from 5 to 100 miles in steps of 5. (1 mile = 1.61 km).
20. Write a program which requests a user to enter an amount of money. The program prints the interest payable per year for rates of interest from 5% to 12% in steps of 0.5%.
21. Write a program to request a value for **n**; the user is then asked to enter **n** numbers, one at a time. The program calculates and prints the sum of the numbers. The following is a sample run:

```
How many numbers? 3
Enter a number? 12
Enter a number? 25
Enter a number? 18

The sum of the 3 numbers is 55
```

22. Write a program to request an integer **n** from 1 to 9 and print a line of output consisting of ascending digits from 1 to **n** followed by descending digits from **n** - 1 to 1. For example, if **n** = 5, print the line

    ```
    123454321
    ```

23. Solve problem 9, above, assuming that the first line of data contains the number of rooms (*n*, say) to carpet. This is followed by *n* lines of data, one line for each room.
24. Solve problem 11, above, but this time print the table for exactly 30 days. In other words, do not stop if the amount of water falls below 100 litres.

6 Working with characters

In this chapter, we will explain:

- some important features of character sets
- how to work with character constants and values
- how to declare character variables in C
- how you can use characters in arithmetic expressions
- how to read, manipulate and print characters
- how to test for end-of-line using **\n**
- how to test for end-of-file using **EOF**
- how to compare characters
- how to read characters from a file
- how to convert a number from character form to integer form

6.1 Character sets

Most of us are familiar with a computer or typewriter keyboard (called the *standard English keyboard*). On it, we can type the letters of the alphabet (both uppercase and lowercase), the digits and other 'special' characters like **+**, **=**, **<**, **>**, **&** and **%**—these are the so-called *printable* characters.

On a computer, each character is assigned a unique integer value, called its *code*. This code may be different from one computer to another depending on the *character set* being used. For example, the code for `A` might be `33` on one computer but `65` on another.

Inside the computer, this integer code is stored as a sequence of bits; for example, the 6-bit code for `33` is `100001` and the 7-bit code for `65` is `1000001`.

Nowadays, most computers use the ASCII (American Standard Code for Information Interchange) character set for representing characters. This is a 7-bit character standard which includes the letters, digits and special characters found on a standard keyboard. It also includes *control* characters such as backspace, tab, line feed, form feed and carriage return.

The ASCII codes run from 0 to 127 (the range of numbers which can be stored using 7 bits). The ASCII character set is shown in Appendix B. Interesting features to note are:

- the digits **0** to **9** occupy codes **48** to **57**
- the uppercase letters **A** to **Z** occupy codes **65** to **90**

- the lowercase letters **a** to **z** occupy codes **97** to **122**

Note, however, that even though the ASCII set is *defined* using a 7-bit code, it is *stored* on most computers in 8-bit bytes—a 0 is added at the front of the 7-bit code. For example, the 7-bit ASCII code for A is 1000001; on a computer, it is stored as 01000001, occupying one byte.

In this book, as far as is possible, we will write our programs making no assumptions about the underlying character set. Where it is unavoidable, we will assume that the ASCII character set is used. For instance, we may need to assume that the uppercase letters are assigned consecutive codes; similarly for lowercase letters. This may not necessarily be true for another character set. Even so, we will not rely on the specific values of the codes, only that they are consecutive.

6.2 Character constants and values

A character constant is a single character enclosed in single quotes such as **'A'**, **'+'** and **'5'**. Some characters cannot be represented like this because we cannot type them or because they play a special role in C (e.g. ', \). For these, we use an escape sequence (page 16) enclosed in single quotes. For example,

'\n'	newline character, code 10
'\f'	new page (formfeed) character, code 12
'\t'	tab character, code 9
'\''	single quote (quote, backslash, quote, quote), code 39
'\\'	backslash, code 92

The character constant **'\0'** is special in C; it is the character whose code is 0, normally referred to as the *null character*. One of its special uses is to indicate the end of a string in memory (see page 196).

The *character value* of a character constant is the character represented, without the single quotes. Thus, the character value of **'T'** is **T** and the character value of '\\' is \.

A character constant has an *integer value* associated with it—the numeric code of the character represented. Thus, the integer value of **'T'** is 84 since the ASCII code for **T** is 84. The integer value of '\\' is 92 since the ASCII code for \ is 92. And the integer value of **'\n'** is 10 since the ASCII code for the newline character is 10.

We could print the *character* value using the specification **%c** in **printf** and we could print the *integer* value using **%d**. For example, the statement

```
printf("Character: %c, Integer: %d\n", 'T', 'T');
```

will print

```
Character: T, Integer: 84
```

6.3 The type char

In C, we use the keyword **char** to declare a variable in which we wish to store a character. For example:

```
char ch;
```

declares **ch** as a *character variable*. We could, for instance, assign a character constant to **ch**, as in:

```
ch = 'R';   //assign the letter R to ch
ch = '\n';  //assign the newline character, code 10, to ch
```

We could print the character value of a character variable using **%c** in **printf**. And we could print the integer value of a character variable using **%d**. For instance,

```
ch = 'T';
printf("Mr. %c\n", ch);
printf("Mr. %d\n", ch);
```

will print

```
Mr. T
Mr. 84
```

6.4 Characters in arithmetic expressions

C allows us to use variables and constants of type **char** directly in arithmetic expressions. When we do, it uses the *integer value* of the character. For example, the statement

```
int n = 'A' + 3;
```

assigns 68 to **n** since the code for **'A'** is 65.

Similarly, we can assign an integer value to a **char** variable. For example,

```
char ch = 68;
```

In this case, "the character whose code is 68" is assigned to **ch**; this character is **'D'**.

For a more useful example, consider the following:

```
int d = '5' - '0';
```

5 is assigned to **d** since the code for **'5'** is 53 and the code for **'0'** is 48.

Take note that the code for a digit in character form is **not** the same as the value of the digit; for instance, the *code* for the character `'5'` is 53 but the value of the digit 5 is 5. Sometimes we know that a character variable contains a digit and we want to get the (integer) value of the digit.

The above statements show how we can get the value of the digit—we simply subtract the code for **'0'** from the code for the digit. It does not matter what the actual codes for the digits are; it matters only that the codes for 0 to 9 are consecutive. (Exercise: check this for yourself assuming a different set of code values for the digits).

In general, if **ch** contains a digit character (**'0'** to **'9'**), we can obtain the integer value of the digit with the statement

```
d = ch - '0';
```

Suppose **ch** contains an uppercase letter and we want to convert it to its equivalent lowercase letter. For example, assume **ch** contains **'H'** and we want to change it to **'h'**. First we observe that the ASCII codes for **'A'** to **'Z'** range from 65 to 90 and the codes for **'a'** to **'z'** range from 97 to 122. We further observe that the *difference* between the codes for the two cases of a letter is always 32; for example,

```
'r' - 'R' = 114 – 82 = 32
```

Hence we can convert a letter from uppercase to lowercase by adding 32 to the uppercase code. This can be done with

```
ch = ch + 32;
```

If **ch** contains **'H'** (code 72), the above statement adds 32 to 72 giving 104; the "character whose code is 104" is assigned to **ch**, that is, **'h'**. We have changed the value of **ch** from **'H'** to **'h'**. Conversely, to convert a letter from lowercase to uppercase, we *subtract* 32 from the lowercase code.

By the way, we do not really need to know the codes for the letters. All we need is the *difference* between the uppercase and lowercase codes. We can let C tell us what the difference is by using **'a' – 'A'**, like this:

```
ch = ch + 'a' - 'A';
```

This works no matter what the actual codes for the letters are. It assumes, of course, that **ch** contains an uppercase letter and the difference between the uppercase and lowercase codes is the same for all letters.

6.5 Reading and printing characters

Many programs revolve around the idea of reading and writing one character at a time and developing the skill of writing such programs is a very important aspect of programming. We can use **scanf** to read a *single* character from the standard input (the keyboard) into a **char** variable (**ch**, say) with:

```
scanf("%c", &ch);
```

The *next* character in the data is stored in **ch**. It is very important to note a big difference between reading a number and reading a character. When reading a number, **scanf** will skip over any amount of whitespace until it finds the number. When reading a character, the *very next character* (whatever it is, even a space) is stored in the variable.

While we can use **scanf**, reading a character is important enough that C provides a special function[1] **getchar** for reading characters from the standard input. For the most part, we can think that **getchar** returns the next character in the data. However, strictly speaking, it returns the *numeric code* of the next character. For this reason, it is usually assigned to an **int** variable, as in:

```
int c = getchar();  // the brackets are required
```

However, it can also be assigned to a **char** variable, as in:

```
char ch = getchar();  // the brackets are required
```

To be precise, **getchar** returns the next byte in the data—to all intents and purposes, this is the next character. If we call **getchar** when there is no more data, it returns the value `-1`.

To be more precise, it returns the value designated by the symbolic constant **EOF** (all uppercase) defined in **stdio.h**. This value is usually, though not always, `-1`. The actual value is system-dependent but **EOF** will always denote the value returned on the system on which the program is run. We can, of course, always find out *what* value is returned by printing **EOF**, thus:

```
printf("Value of EOF is %d \n", EOF);
```

To give an example, consider the statement:

```
char ch = getchar();
```

and suppose the data typed by the user is:

```
Hello
```

When **ch = getchar()** is executed, the first character **H** is read and stored in **ch**. We can then use **ch** in whatever way we like. Suppose we just want to print the first character read. We could use:

```
printf("%c \n", ch);
```

This would print:

```
H
```

on a line by itself. We could, of course, label our output with:

```
printf("The first character is %c \n", ch);
```

which would print:

```
The first character is H
```

[1]Strictly speaking, **getchar** is what's called a *macro*, but the distinction is not important for our purposes

Finally, we don't even need **ch**. If all we want to do is print the first character in the data, we could do so with:

```
printf("The first character is %c \n", getchar());
```

If we want to print the *numeric code* of the first character, we could do so by using the specification **%d** instead of **%c**. These ideas are incorporated in Program P6.1.

Program P6.1

```
//read the first character in the data, print it,
//its code and the value of EOF
#include <stdio.h>
main() {
  printf("Type some data and press 'Enter' \n");
  char ch = getchar();
  printf("\nThe first character is %c \n", ch);
  printf("Its code is %d \n", ch);
  printf("Value of EOF is %d \n", EOF);
}
```

The following is a sample run:

```
Type some data and press 'Enter'
Hello

The first character is H
Its code is 72
Value of EOF is -1
```

A word of caution: we might be tempted to write

```
printf("The first character is %c \n", getchar());
printf("Its code is %d \n", getchar());  // wrong
```

But if we did, and assuming that **Hello** is typed as input, these statements will print:

```
The first character is H
Its code is 101
```

Why? In the first **printf**, **getchar** returns **H** which is printed. In the second **printf**, **getchar** returns the *next* character which is **e**; it is **e**'s code (101) that is printed.

In Program P6.1, we *could* use an **int** variable (**n**, say) instead of **ch** and the program would work in an identical manner. If an **int** variable is printed using **%c**, the last (rightmost) 8 bits of the variable are interpreted as a character and this character is printed. For example, the code for **H** is 72 which is 01001000 in

binary, using 8 bits. Assuming **n** is a 16-bit **int**, when **H** is read, the value assigned to **n** will be

```
00000000 01001000
```

If **n** is now printed with **%c**, the last 8 bits will be interpreted as a character which, of course, is **H**.

Similarly, if an **int** value **n** is assigned to a **char** variable (**ch**, say), the last 8 bits of **n** will be assigned to **ch**.

As mentioned, **getchar** returns the integer value of the character read. What does it return when the user presses "Enter" or "Return" on the keyboard? It returns the newline character **\n**, whose code is 10. This can be seen using Program P6.1. When the program is waiting for you to type data, if you press the "Enter" or "Return" key only , the first lines of output would be:

```
The first character is

Its code is 10
```

Why the blank line? Since **ch** contains **\n**, the statement

```
printf("\nThe first character is %c \n", ch);
```

is effectively the same as (**%c** replaced by the value of **ch**)

```
printf("\nThe first character is \n \n");
```

The **\n** after **is** ends the first line and the last **\n** ends the second line, effectively printing a blank line. Note, however, that the code for **\n** is printed correctly.

In Program P6.1, we read just the first character. If we want to read and print the first 3 characters, we could do this with Program P6.2.

Program P6.2

```
//read and print the first 3 characters in the data
#include <stdio.h>
main() {
  printf("Type some data and press 'Enter' \n");
  for (int j = 1; j <= 3; j++) {
    char ch = getchar();
    printf("Character %d is %c \n", j, ch);
  }
}
```

The following is a sample run of the program:

```
Type some data and press 'Enter'
Hi, how are you?
Character 1 is H
Character 2 is i
Character 3 is ,
```

If we want to read and print the first 20 characters, all we have to do is change 3 to 20 in the **for** statement.

Suppose the first part of the data line contains an arbitrary number of blanks. How do we find and print the first non-blank character? Since we do not know how many blanks to read, we cannot say something like "read 7 blanks, then the next character".

More likely, we need to say something like "as long as the character read is a blank, keep reading". We have the notion of doing something (reading a character) as long as some 'condition' is true; the condition here is whether the character is a blank. This can be expressed more concisely as follows:

```
read a character
while the character read is a blank
    read the next character
```

Program P6.3 shows how to read the data and print the first non-blank character. (This code will be written more concisely later in this section).

Program P6.3

```
//read and print the first non-blank character in the data
#include <stdio.h>
main() {
  printf("Type some data and press 'Enter' \n");
  char ch = getchar();  // get the first character
  while (ch == ' ')       // as long as ch is a blank
    ch = getchar();       //  get another character
  printf("The first non-blank is %c \n", ch);
}
```

The following is a sample run of the program (◇ denotes a blank):

```
Type some data and press 'Enter'
◇◇◇Hello
The first non-blank is H
```

The program will locate the first non-blank character regardless of how many blanks precede it.

As a reminder of how the **while** statement works, consider the following portion of code from Program P6.3 with different comments:

```
char ch = getchar();  //executed once; gives ch a value
                      // to be tested in the while condition
while (ch == ' ')
  ch = getchar();     //executed as long as ch is ' '
```

and suppose the data entered is (◇ denotes a space):

```
◇◇◇Hello
```

The code will execute as follows:

1. the first character is read and stored in **ch**; it is a blank
2. the **while** condition is tested; it is **true**
3. the **while** body **ch = getchar();** is executed and the second character is read and stored in **ch**; it is a blank
4. the **while** condition is tested; it is **true**
5. the **while** body **ch = getchar();** is executed and the third character is read and stored in **ch**; it is a blank
6. the **while** condition is tested; it is **true**
7. the **while** body **ch = getchar();** is executed and the fourth character is read and stored in **ch**; it is **H**
8. the **while** condition is tested; it is **false**
9. control goes to the **printf** which prints

```
The first non-blank is H
```

What if **H** was the first character in the data? The code will execute as follows:

1. the first character is read and stored in **ch**; it is **H**
2. the **while** condition is tested; it is **false**
3. control goes to the **printf** which prints

```
The first non-blank is H
```

It still works! If the **while** condition is **false** the first time it is tested, the body is not executed at all.

As another example, suppose we want to print all characters up to, but not including, the first blank. To do this, we could use Program P6.4 (next page).

The following is a sample run of the program:

```
Type some data and press 'Enter'
Way to go
W
a
y
```

Program P6.4

```
//print all characters before the first blank in the data
#include <stdio.h>
main() {
  printf("Type some data and press 'Enter' \n");
  char ch = getchar();  // get the first character
  while (ch != ' ') {       // as long as ch is NOT a blank
    printf("%c \n", ch);   // print it
    ch = getchar();       //  and get another character
  }
}
```

The body of the **while** consists of two statements. These are enclosed by **{** and **}** to satisfy C's rule that the **while** body must be a single statement or a block. Here, the body is executed as long as the character read is *not* a blank—we write the condition using **!=** (not equal to).

If the character is not a blank, it is printed and the next character read. If *that* is not a blank, it is printed and the next character read. If *that* is not a blank, it is printed and the next character read. And so on, until a blank character *is* read, making the **while** condition **false**, causing an *exit* from the loop.

We would be amiss if we didn't enlighten you about some of the expressive power in C. For instance, in Program P6.3, we could have read the character **and** tested it in the **while** condition. We could have rewritten the following three lines:

```
ch = getchar();          // get the first character
while (ch == ' ')        // as long as ch is a blank
  ch = getchar();        //  get another character
```

as one line

```
while ((ch = getchar()) == ' ');          // get a character and test it
```

ch = getchar() is an *assignment expression* whose value is the character assigned to **ch**, that is, the character read. This value is then tested to see if it is a blank. The brackets around **ch = getchar()** are required since **==** has higher precedence than **=**. Without them, the condition would be interpreted as **ch = (getchar() == ' ')**. This would assign the value of a condition (which, in C, is 0 for **false** or 1 for **true**) to the variable **ch**; this is not what we want.

Now that we have moved the statement in the body into the condition, the body is empty; this is permitted in C. The condition would now be executed repeatedly until it becomes **false**.

To give another example, in Program 6.4, the code

```
char ch = getchar();     // get the first character
while (ch != ' ') {      // as long as ch is NOT a blank
  printf("%c \n", ch);   // print it
  ch = getchar();        //  and get another character
}
```

could be re-coded as (assuming **ch** is declared before the loop)

```
while ((ch = getchar()) != ' ') // get a character
  printf("%c \n", ch);          // print it if non-blank; repeat
```

Now that the body consists of just one statement, the braces are no longer required. Five lines have been reduced to two.

6.6 Counting characters

Program P6.3 prints the first non-blank character. Suppose we want to *count* how many blanks there were before the first non-blank. We could use an integer variable **numBlanks** to hold the count. Program P6.5 is the modified program for counting the leading blanks.

Program P6.5

```
//find and print the first non-blank character in the data;
// count the number of blanks before the first non-blank
  #include <stdio.h>
  main() {
    char ch;
    int numBlanks = 0;
    printf("Type some data and press 'Enter' \n");
    while ((ch = getchar()) == ' ')      // repeat as long as ch is blank
      numBlanks++;                       // add 1 to numBlanks
    printf("The number of leading blanks is %d \n", numBlanks);
    printf("The first non-blank is %c \n", ch);
  }
```

The following is a sample run of the program (◇ denotes a space):

```
Type some data and press 'Enter'
◇◇◇◇Hello
The number of leading blanks is 4
The first non-blank is H
```

Comments on Program P6.5:

- **numBlanks** is initialized to 0 *before* the **while** loop.

- **numBlanks** is incremented by 1 *inside* the loop so that **numBlanks** is incremented each time the loop body is executed. Since the loop body is executed when **ch** contains a blank, the value of **numBlanks** is always the number of blanks read so far.
- When we exit the **while** loop, the value in **numBlanks** will be the number of blanks read. This value is then printed.
- Observe that if the first character in the data were non-blank, the **while** condition would be immediately false and control will go directly to the first **printf** statement with **numBlanks** having the value 0. The program will print, correctly:

```
The number of leading blanks is 0
```

Counting characters in a line

Suppose we want to count the number of characters in a line of input. Now we must read characters until the end of the line. How does our program test for end-of-line? Recall that when the "Enter" or "Return" key is pressed by the user, the newline character, **\n**, is returned by **getchar**. The following **while** condition reads a character and tests for **\n**.

```
while ((ch = getchar()) != '\n')
```

Program P6.6 reads a line of input and counts the number of characters in it, not counting the "end-of-line" character.

Program P6.6

```
//count the number of characters in the input line
#include <stdio.h>
main() {
  char ch;
  int numChars = 0;
  printf("Type some data and press 'Enter' \n");
  while ((ch = getchar()) != '\n')       // repeat as long as ch is not \n
    numChars++;                  // add 1 to numChars
  printf("The number of characters is %d \n", numChars);
}
```

The main difference between this and Program P6.5 is that this one reads characters until the end of the line rather than until the first non-blank. A sample run is:

```
Type some data and press 'Enter'
One moment in time
The number of characters is 18
```

6.7 Counting blanks in a line of data

Suppose we want to count **all** the **blanks** in a line of data. We must still read characters until the end of the line is encountered. But now, for each character read, we must check whether it is a blank. If it is, the count is incremented. We would need two counters—one to count the number of characters in the line and the other to count the number of blanks. The logic could be expressed as:

```
set number of characters and number of blanks to 0
while we are not at the end-of-line
  read a character
  add 1 to number of characters
  if character is a blank then add 1 to number of blanks
endwhile
```

This logic is implemented as shown in Program P6.7.

Program P6.7

```
//count the number of characters and blanks in the input line
#include <stdio.h>
main() {
  char ch;
  int numChars = 0;
  int numBlanks = 0;
  printf("Type some data and press 'Enter' \n");
  while ((ch = getchar()) != '\n') {     // repeat as long as ch is not \n
    numChars++;          // add 1 to numChars
    if (ch == ' ') numBlanks++;  // add 1 if ch is blank
  }
  printf("The number of characters is %d \n", numChars);
  printf("The number of blanks is %d \n", numBlanks);
}
```

A sample run is:

```
Type some data and press 'Enter'
One moment in time
The number of characters is 18
The number of blanks is 3
```

The **if** statement tests the condition **ch == ' '**; if it is **true** (that is, **ch** contains a blank), **numBlanks** is incremented by 1. If it is **false**, **numBlanks** is *not* incremented; control would normally go to the next statement within the loop but there is none (the **if** is the last statement). Therefore, control goes back to the top of the **while** loop, where another character is read and tested for **\n**.

6.8 Comparing characters

Characters can be compared using the relational operators **==**, **!=**, **<**, **<=**, **>** and **>=**. We've compared the **char** variable **ch** with a blank using **ch == ' '** and **ch != ' '**.

Let us now write a program to read a line of data and print the 'largest' character, that is, the character with the highest code. For instance, if the line consisted of English words, the letter which comes latest in the alphabet would be printed. (Recall, though, that lowercase letters have higher codes than uppercase letters so that, for instance, **'g'** is greater than **'T'**).

'Finding the largest character' involves the following steps:

- Choose a variable to hold the largest value; we choose **bigChar**.
- Initialize **bigChar** to a very small value. The value chosen should be such that no matter what character is read, *its* value would be greater than this initial value. For characters, we normally use **'\0'**—the null character, the 'character' with a code of 0.
- As each character (**ch**, say) is read, it is compared with **bigChar**; if **ch** is greater than **bigChar**, then we have a 'larger' character and **bigChar** is set to this new character.
- When all the characters have been read and checked, **bigChar** will contain the largest one.

These ideas are expressed in Program P6.8.

Program P6.8

```
//read a line of data and find the 'largest' character
#include <stdio.h>
main() {
  char ch, bigChar = '\0';
  printf("Type some data and press 'Enter' \n");
  while ((ch = getchar()) != '\n')
    if (ch > bigChar) bigChar = ch; // is this character bigger?
  printf("\nThe largest character is %c \n", bigChar);
}
```

The following is a sample run; **u** is printed since its code is the highest of all the characters typed.

```
Type some data and press 'Enter'
Where The Mind Is Without Fear

The largest character is u
```

6.9 Reading characters from a file

In our examples so far, we have read characters typed at the keyboard. If we want to read characters from a file, **input.txt**, say, we must declare a file pointer (**in**, say) and associate it with the file using

```
FILE * in = fopen("input.txt", "r");
```

If you need to refresh your memory, see page 100. Once this is done, we could read the next character from the file into a **char** variable (**ch**, say) with

```
fscanf(in, "%c", &ch);
```

However, C provides the more convenient function **getc** (**get** a **c**haracter) for reading a character from a file. It is used as follows:

```
ch = getc(in);
```

getc takes one argument, the file pointer (not the name of the file). It reads and returns the next character in the file. If there are no more characters to read, **getc** returns **EOF**. Thus, **getc** works exactly like **getchar** except that **getchar** reads from the keyboard while **getc** reads from a file.

To illustrate, let us write a program which reads one line of data from a file, **input.txt**, and prints it on the screen. This is shown as Program P6.9.

Program P6.9

```
#include <stdio.h>
main() {
  char ch;
  FILE *in = fopen("input.txt", "r");
  while ((ch = getc(in)) != '\n')
    putchar(ch);
  putchar('\n');
  fclose(in);
}
```

This program uses the standard function[2] **putchar** to write a single character to the standard output. It takes a character value as its only argument and writes the character in the next position in the output. However, if the character is a *control* character, the *effect* of the character is produced. For example, **putchar('\n')** will end the current output line, the same effect as if "Enter" or "Return" is pressed.

The program reads one character at a time from the file and prints it on the screen using **putchar**. It does this until **\n** is read, indicating that the entire line has been read. On exit from the **while** loop, it uses **putchar('\n')** to terminate the line on the screen.

[2] Like **getchar**, **putchar** is a *macro* but the distinction is not important for our purposes

Be careful, though. This program assumes that the line of data is terminated by an end-of-line character, **\n** (generated when you press "Enter" or "Return"). However, if the line is not terminated by **\n**, the program will 'hang'—it will be caught in a loop from which it cannot get out (we say it will be caught in an *infinite loop*). Why?

Because the **while** condition **((ch = getc(in)) != '\n')** will never become false (this happens when **ch** *is* **'\n'**) since there is no **\n** to be read. But, as discussed on page 132, when we reach the end-of-file, the value returned by **getchar**, and now also by **getc**, is the symbolic constant **EOF** defined in **stdio.h**. Knowing this, we could easily fix our problem by testing for **\n** *and* **EOF** in the **while** condition, thus:

```
while ((ch = getc(in)) != '\n' && ch != EOF)
```

Even if **\n** is not present, **getc(in)** will return **EOF** when the end of the file is reached, and the condition **ch != EOF** would be false, causing an exit from the loop.

Writing characters to a file

Suppose we want to write characters to a file, **output.txt**, say. As always, we must declare a file pointer (**out**, say) and associate it with the file using

```
FILE * out = fopen("output.txt", "w");
```

If **ch** is a **char** variable, we can write the value of **ch** to the file with

```
fprintf(out, "%c", ch);
```

C also provides the function **putc** (**put** a **c**haracter) to do the same job. To write the value of **ch** to the file associated with **out**, we must write:

```
putc(ch, out);
```

Note that the file pointer is the *second* argument to **putc**.

Example – echo the input, number the lines

Let us expand the example on the previous page to read data from a file and write back the same data (*echo* the data) to the screen with the lines numbered starting from 1.

The program would read the data from the file and write it to the screen, thus:

```
1. First line of data
2. Second line of data
      etc.
```

This problem is a bit more difficult than those we have met so far. When faced with such a problem, it is best to tackle it a bit at a time, solving easier versions of the problem and working your way up to solving the complete problem.

For this problem, we can first write a program which simply echoes the input *without* numbering the lines. When we get this right, we can tackle the job of numbering the lines.

An outline of the algorithm for this first version is:

```
read a character, ch
while ch is not the end-of-file character
  print ch
  read a character, ch
endwhile
```

This will maintain the line structure of the data file since, for instance, when \n is read from the file, it is immediately printed to the screen, forcing the current line to end.

Program P6.10 implements the above algorithm for reading the data from a file and printing an exact copy on the screen.

Program P6.10

```
#include <stdio.h>
main() {
  char ch;
  FILE *in = fopen("input.txt", "r");
  while ((ch = getc(in)) != EOF)
    putchar(ch);
  fclose(in);
}
```

Now that we can echo the input, we need only figure out how to print the line numbers. A simplistic approach is based on the following outline:

```
set lineNo to 1
print lineNo
read a character, ch
while ch is not the end-of-file character
  print ch
  read a character, ch
  if ch is \n
    add 1 to lineNo
    print lineNo
  endif
endwhile
```

We have simply added the statements which deal with the line numbers to the algorithm above. We can easily add the code that deal with the line numbers to

Program P6.10 to get Program P6.11. Note that when we print the line number, we do not terminate the line with \n since the data must be written on the same line as the line number.

Program P6.11

```
//This program prints the data from a file numbering the lines
#include <stdio.h>
main() {
  char ch;
  FILE *in = fopen("input.txt", "r");
  int lineNo = 1;
  printf("%d. ", lineNo);
  while ((ch = getc(in)) != EOF) {
    putchar(ch);
    if (ch == '\n') {
      lineNo++;
      printf("%d. ", lineNo);
    }
  }
  fclose(in);
}
```

Assuming that the input file contains

```
There was a little girl
  Who had a little curl
Right in the middle of her forehead
```

Program P6.11 will print:

```
1. There was a little girl
2.   Who had a little curl
3. Right in the middle of her forehead
4.
```

Almost, but not quite, correct! The little glitch is that we print an extra line number at the end. To see why, look at the **if** statement. When \n of the third data line is read, 1 would be added to **lineNo**, making it 4, which is printed by the next statement. This printing of an extra line number also holds if the input file is empty, since line number 1 would be printed in this case, but there is no such line.

To get around this problem, we must delay printing the line number until we are sure that there is at least one character on the line. We will use an **int** variable **writeLineNo**, initially set to 1. If we have a character to print and **writeLineNo** is 1, the line number is printed and **writeLineNo** is set to 0. When **writeLineNo** is 0, all that happens is that the character just read is printed.

When \n is printed to end a line of output, **writeLineNo** is set to 1. If it turns out that there *is* a character to print on the next line, the line number will be printed first since **writeLineNo** is 1. If there are no more characters to print, nothing further is printed; in particular, the line number is not printed.

Program P6.12 contains all the details. When run, it will number the lines without printing an extra line number.

Program P6.12

```
//This program prints the data from a file numbering the lines
#include <stdio.h>
main() {
  char ch;
  FILE *in = fopen("input.txt", "r");
  int lineNo = 0, writeLineNo = 1;
  while ((ch = getc(in)) != EOF) {
    if (writeLineNo) {
      printf("%d. ", ++lineNo);
      writeLineNo = 0;
    }
    putchar(ch);
    if (ch == '\n') writeLineNo = 1;
  }
  fclose(in);
}
```

We wrote the **if** condition as **if (writeLineNo)**. If **writeLineNo** is 1 the condition evaluates to 1 and is, therefore, **true**; if it is 0, the condition is **false**. We could also have written the condition as **if (writeLineNo == 1)**.

In the statement

```
printf("%d. ", ++lineNo);
```

the expression **++lineNo** means that **lineNo** is incremented **first** before being printed. By comparison, if we had used **lineNo++**, then **lineNo** would be printed first and **then** incremented.

Exercise: Modify Program P6.12 to send the output to a file, **linecopy.txt**.

Exercise: Write a program to copy the contents of a file, **input.txt**, to a file, **copy.txt**. Hint: you just need to make minor changes to Program P6.10.

6.10 Converting digit characters to an integer

Let us consider how we can convert a sequence of digits into an integer. When we type the number 385, we are actually typing three individual characters – '3' then '8' then '5'. Inside the computer, the integer 385 is completely different from the three characters '3' '8' '5'. So when we **type** 385 and try to read it into an **int** variable, the computer has to convert this sequence of three characters into the *integer* 385.

To illustrate, the 8-bit ASCII codes for the characters '3', '8' and '5' are 00110011, 00111000 and 00110101, respectively. When typed to the screen or a file, the digits 385 are represented by

```
00110011  00111000  00110101
```

Assuming an integer is stored using 16 bits, the *integer* 385 is represented by its binary equivalent

```
0000000110000001
```

Observe that the character representation is quite different from the integer representation. When we ask **scanf** (or **fscanf**) to read an integer that we type, it must convert the character representation to the integer representation. We now show how this is done.

The basic step requires us to convert a digit character into its equivalent integer value; for example, we must convert the character '5' (represented by 00110101) into the integer 5 (represented by 0000000000000101).

Assuming that the codes for the digits 0 to 9 are consecutive (as they are in ASCII and other character sets), this can be done as follows:

```
integer value of digit = code for digit character – code for character '0'
```

For example, in ASCII, the code for '5' is 53 and the code for '0' is 48. Subtracting 48 from 53 gives us the integer value (5) of the character '5'. Once we can convert individual digits, we can construct the value of the number as we read it from left to right, using the following algorithm:

```
set num to 0
get a character, ch
while ch is a digit character
  convert ch to the digit value, d = ch - '0'
  set num to num*10 + d
  get a character, ch
endwhile
num now contains the integer value
```

The sequence of characters 385 is converted as follows:

```
num = 0
get '3'; convert to 3
num = num*10 + 3 = 0*10 + 3; num is now 3
```

```
get '8'; convert to 8
num = num*10 + 8 = 3*10 + 8; num is now 38
get '5'; convert to 5
num = num*10 + 5 = 38*10 + 5; num is now 385
```

There are no more digits and the final value of **num** is 385.

Let us use this idea to write a program which reads data character by character until it finds an integer. It constructs and then prints the integer.

The program will have to read characters until it finds a digit, the first of the integer. Having found the first digit, it must construct the integer by reading characters as long as it keeps getting a digit. For example, if the data was

```
Number of items: 385, all in good condition
```

the program will read characters until it finds the first digit, 3. It will construct the integer using the 3 and then reading 8 and 5. When it reads the comma, it knows the integer has ended.

This outline can be expressed in pseudocode by

```
read a character, ch
while ch is not a digit do
  read a character, ch
endwhile
//at this point, ch contains a digit
while ch is a digit do
  use ch to build the integer
  read a character, ch
endwhile
print the integer
```

How do we test if the character in **ch** is a digit? We must test if

```
ch >= '0' && ch <= '9'
```

If this is true, we know that the character is between '0' and '9', inclusive. Conversely, to test if **ch** is *not* a digit, we can test if

```
ch < '0' || ch > '9'
```

Putting all these ideas together gives us Program P6.13 (next page).

A sample run is shown below:

```
Type data including a number and press "Enter"
hide the number &(%%)7085&*(&^ here
Number is 7085
```

This program will find the number, no matter where it is hidden in the line.

Program P6.13

```
#include <stdio.h>
main() {
  char ch = getchar();
  // as long as the character is not a digit, keep reading
  while (ch < '0' || ch > '9') ch = getchar() ;
  // at this point, ch contains the first digit of the number
  int num = 0;
  while (ch >= '0' && ch <= '9') { // as long as we get a digit
       num = num * 10 + ch - '0';  // update num
       ch = getchar();
  }
  printf("Number is %d\n", num);
}
```

Exercises 6

1. Give the range of ASCII codes for (a) the digits (b) the uppercase letters (c) the lowercase letters.
2. How is the single quote represented as a character constant?
3. What is the character value of a character constant?
4. What is the numeric value of a character constant?
5. How is the expression **5 + 'T'** evaluated? What is its value?
6. What value is assigned to **n** by **n = 7 + 't'**?
7. What character is stored in **ch** by **ch = 4 + 'n'**?
8. If **ch** = **' 8 '** , what value is assigned to **d** by **d = ch - '0'**?
9. If **ch** contains any uppercase letter, explain how to change **ch** to the equivalent lowercase letter.
10. If **ch** contains any lowercase letter, explain how to change **ch** to the equivalent uppercase letter.
11. Write a program to request a line of data and print the first digit on the line.
12. Write a program to request a line of data and print the first letter on the line.
13. Write a program to request a line of data and print the number of digits and letters on the line.
14. Write a program to read a passage from a file and print how many times each vowel appears.
15. Modify Program P6.13 so that it will find negative integers as well.
16. Write a program which reads a file containing a C program and outputs the program to another file with all the // comments removed.

17. Write a program to read the data, character by character, and store the next number (with or without a decimal point) in a **double** variable (**dv**, say). For example, given the data

```
Mary works for $43.75 per hour
```

your program should store `43.75` in **dv**.

18. In the programming language Pascal, comments can be enclosed by **{** and **}** or by **(*** and ***)**. Write a program which reads a data file **input.pas** containing Pascal code and writes the code to a file **output.pas**, replacing each **{** with **(*** and each **}** with ***)**. For example, the statements

```
read(ch);             {get the first character}
while ch = ' ' do     {as long as ch is a blank}
  read(ch);           {get another character}
writeln('The first non-blank is ', ch);
```

should be converted to

```
read(ch);             (*get the first character*)
while ch = ' ' do     (*as long as ch is a blank*)
  read(ch);           (*get another character*)
writeln('The first non-blank is ', ch);
```

19. As in 18, but remove the comments altogether.

20. Someone has typed a letter in a file **letter.txt**, but does not always start the word after a period with a capital letter. Write a program to copy the file to another file **format.txt** so that all words after a period now begin with a capital letter. For example, the text

```
Things are fine. we can see you now. let us know when is a good time.
bye for now.
```

must be re-written as

```
Things are fine. We can see you now. Let us know when is a good time.
Bye for now.
```

7 Functions

In this chapter, we will explain:

- why functions are important in programming
- how to write functions
- what happens when a function is called
- where functions are placed in a program
- some important concepts relating to functions using several examples

So far, all our programs have consisted of a single function called **main**. However, we have made use of predefined C functions such as **printf**, **scanf**, **strcpy** and **fopen**. When we run a program, it starts executing with the first statement in **main** and ends when it reaches the last statement.

As we have seen, it is possible to write reasonably useful programs with only **main**. However, there are many limitations to this approach. The problem to be solved may be too complex to be solved with one function. We may need to break it up into subproblems and try to solve each of these individually. It would be impractical to solve all the subproblems in one function. It might be better to write a separate function to solve each subproblem.

Also, we may want to reuse the solution to common problems. It would be difficult to reuse a solution if it is part of the solution to a bigger problem. For example, if we need the highest common factor (HCF) of two numbers in several places, it would be best to write a routine which works out the HCF of two given numbers; we call this routine whenever we need to find the HCF of two numbers.

A well-written function performs some well-defined task; for example, skip a specified number of lines in the output or arrange some numbers in ascending order. However, quite often, a function also *returns a value*; for example, calculate the salary of a person and return the answer or play one turn of a game and return the score for that turn. The value returned is normally used at the point from which the function was called.

On page 108, we used the string function **strcmp** which returns a value which tells us the result of comparing two strings. And we have used **getchar** and **getc** to return the next character in the input.

We are now ready to learn how to write our own functions (called *user-defined* functions) and we will see several examples in the rest of this book.

7.1 skipLines

We have seen that we can use **\n** in a **printf** statement to print a blank line. For example, the statement

```
printf("%d\n\n%d\n", a, b);
```

will print **a** on one line, skip one line and print **b** on the next line. We can usually skip any number of lines by writing the appropriate number of **\n**'s in the **printf** statement.

Sometimes we may want to skip 3 lines, sometimes 2 lines, sometimes 5 lines, and so on. It would be nice if there was a statement we could use to skip any number of lines we want. For instance, to skip 3 lines, we should be able to write:

```
skipLines(3);
```

and to skip 5 lines, we write:

```
skipLines(5);
```

What we want is a *function* called **skipLines** which takes an *integer argument* (**n**, say) and skips **n** lines. In C, we write this function as follows:

```
void skipLines(int n) {
  for (int j = 1; j <= n; j++)
    printf("\n");
}
```

Observe that the structure of the function is similar to the structure of **main**. It consists of a *header* (the first line, except **{**) followed by the *body* enclosed in braces. The word **void** indicates that the function does not return a value and **(int n)** defines **n** as an integer *parameter*. When the function is called, we must supply it with an integer value to match the parameter **n**.

This is the *definition* of the function **skipLines**. We *use* the function by *calling* it when we write a statement such as:

```
skipLines(3);
```

in **main**[28]. We say that we *call* (or *invoke*) the function with the *argument*[29] **3**. The "call" is executed as follows:

- The value of the argument is determined. In this case, it is just the constant 3 but, in general, it could be an expression.

[28] A function can normally be called from any other function but, to focus our discussion, we will assume it is called from **main**.

[29] In this book, we use the term 'parameter' when referring to the *definition* of the function and the term 'argument' when the function is *called*. Others use the terms interchangeably

- The value is copied to a temporary memory location. This location is passed to the function where it is labelled with the name of the parameter, **n**. In effect, the parameter variable **n** is set to the value of the argument. We can picture this as:

- The body of the function is executed. In this case, since **n** is 3, the **for** loop becomes **for (int j = 1; j <= 3; j++)** and it prints \n three times.
- When the function is finished, the location containing the argument is discarded and control returns to **main** to the statement following **skipLines(3)**.

Note that we can get **skipLines** to print a different number of blank lines by supplying a different argument when we call it.

When the *value* of an argument is passed to a function, we say the argument is passed "by value". In C, arguments are passed "by value".

7.2 A program with a function

We write Program P7.1 to show how **skipLines** fits into a complete program.

Program P7.1

```
#include <stdio.h>
main() {
  void skipLines(int);
  printf("Sing a song of sixpence\n");
  skipLines(2);
  printf("A pocket full of rye\n");
}

void skipLines(int n) {
  for (int j = 1; j <= n; j++)
    printf("\n");
}
```

When we wish to use a variable in **main**, we must declare the variable in **main**. Similarly, if we want to use **skipLines** in **main**, we must tell C about it using what is called a *function prototype*. A function prototype is a *declaration* pretty much like the function header. In the program, we use the prototype:

```
void skipLines(int);
```

The prototype describes the function by stating the *return type* of the function (**void**, in this case), the name of the function (**skipLines**) and the type(s) of any

argument(s) (**int**, in this example). If you wish, you can write a variable after the type, as in:

```
void skipLines(int a);
```

This variable will be used by the compiler only if it needs to generate an error message. In this book, we will write our prototypes using the type only.

Note that the function *prototype* is followed by a *semicolon* whereas the function *header* is followed by a *left brace*.

As another example, the prototype

```
int max(int, int);
```

says that **max** is a function which takes two integer arguments and returns an integer value.

A common mistake made by beginners is to forget to write the function prototype. However, that is not a big problem. If you forget, the compiler will remind you of it. It is like forgetting to declare a variable—the compiler will tell you about it. You just fix it and move on.

In terms of layout, the functions, including **main**, which make up a C program can appear in any order. However, it is customary to place **main** first where the overall logic of the program can be easily seen.

We emphasize that this program is for illustrative purposes only since the output could be produced more easily with:

```
printf("Sing a song of sixpence\n\n\n");
printf("A pocket full of rye\n");
```

The function header

In our example, we used the function header

```
void skipLines(int n)
```

In general, the function header consists of:

- a *type* (such as **void**, **int**, **double**, **char**), which specifies the type of value returned by the function. If no value is returned, we use the word **void**. The function **skipLines** does not return a value so we use **void**.
- the name we make up for the function, **skipLines** in the example.
- one or more parameters, called the *parameter list*, enclosed in brackets[30]; one parameter **n** of type **int** is used in the example.

The function header is followed by the left brace of the body.

[30] It is allowed to write a function without any parameters; in this case, the brackets alone are present, for example, **void printHeading()**.

Parameters are specified in the same way variables are declared. In fact, they really *are* declarations. The following are all valid examples of headers of **void** functions:

```
void sample1(int m, int n)  // 2 parameters

void sample2(double a, int n, char c) // 3 parameters

void sample3(double a, double b, int j, int k) // 4 parameters
```

Each parameter must be declared individually and two consecutive declarations are separated by a comma. For example, it is invalid to write

```
void sample1(int m, n)  // not valid; must write (int m, int n)
```

We will see examples of functions which return a value from page 156.

How a function gets its data

A function is like a mini program. In the programs we have written, we have stated what data must be supplied to the program, what processing must take place and what the output (results) should be. We must do the same when we write a function.

When we write a function header, we use the parameter list to specify what data must be supplied to the function when it is called. The list specifies *how many* data items, the *type* of the each item and the *order* in which they must be supplied.

For example, we wrote **skipLines** with an integer parameter **n**; this says that an integer value must be supplied to **skipLines** when it is called. When **skipLines** *is* called, the argument supplied becomes the specific value of **n** and the function is executed assuming that **n** has this value. In the call **skipLines(3)**, the argument 3 is the data that **skipLines** needs to perform its job.

It is worth emphasizing that **main** gets its data by using **scanf**, among other functions, to read and store the data in variables. On the other hand, a function gets its data when it is called. The variables in the parameter list are set to the values of the corresponding arguments used in the call. For example, when we write the header

```
void sample(int n, char c,  double b)
```

we are saying that, when we call **sample**, we must do so with 3 arguments: the first must be an **int** value, the second a **char** value and the third a **double** value.

Assuming that **num** is **int**, **ch** is **char** and **x** is **double**, the following are all valid calls to **sample**:

```
sample(25, 'T', 7.5);
sample(num, 'A', x);
sample(num, ch, 7);  //an int argument can match a double parameter
sample(num + 1, ch, x / 2.0);
```

If, when a function is called, the type of an argument is not the same as the corresponding parameter, C tries to convert the argument to the required type. For example, in the call

```
sample(num, 72, 'E');
```

the value 72 is converted to **char** and the parameter **c** is set to **'H'** (since the code for **H** is 72); the numeric value of **'E'** (which is 69) is converted to the **double** value 69.0 and the parameter **b** is set to 69.0.

If it is not possible to convert the argument to the required type, you will get a "type mismatch" error, as in the call

```
sample(num, ch, "hi"); // error - cannot convert string to double
```

You will also get an error if you do not supply the required number of arguments, as in

```
sample(num, x); // error - must have 3 arguments
```

7.3 max

Finding the larger of two values is something we need to do sometimes. If **a** and **b** are two numbers, we can set the variable **max** to the larger of the two with:

```
if (a > b) max = a;
else max = b;
```

If the numbers are equal, **max** will be set to **b** (the **else** part will be executed). We can, of course, write this statement every time we want to get the larger of two values. But this will become clumsy and awkward. It will be more convenient and readable if we can simply write something like

```
big = max(a, b);
```

or even

```
printf("The bigger is %d\n", max(a, b));
```

We can, if we write the *function* **max** as follows:

```
int max(int a, int b) {
  if (a > b) return a;
  return b;
}
```

The first line (except **{**)is the *function header*. It consists of

- the word **int**, indicating that the function returns an integer value
- the name we make up for the function, **max** in the example

- one or more parameters, called the *parameter list*, enclosed in brackets; two parameters **a** and **b** of type **int** are used in the example

The *body* of the function is the part from **{** to **}**. Here, we use the **if** statement to determine the larger of **a** and **b**. If **a** is bigger, the function "returns" **a**; if not, it returns **b**.

In C, a function "returns a value" by using the **return** statement. It consists of the word **return** followed by the value to be returned. The value is returned to the place at which the function was called.

To show how **max** fits into an overall program and how it can be used, we write Program P7.2 which reads pairs of integers and, for each pair, prints the larger of the two. The program ends when the user types 0 0.

Program P7.2

```
#include <stdio.h>
main() {
  int n1, n2;
  int max(int, int);
  printf("Enter two whole numbers: ");
  scanf("%d %d", &n1, &n2);
  while (n1 != 0 || n2 != 0) {
    printf("The bigger is %d\n", max(n1, n2));
    printf("Enter two whole numbers: ");
    scanf("%d %d", &n1, &n2);
  }
}

int max(int a, int b) {
  if (a > b) return a;
  return b;
}
```

The following is a sample run:

```
Enter two whole numbers: 24 33
The bigger is 33
Enter two whole numbers: 10 -13
The bigger is 10
Enter two whole numbers: -5 -8
The bigger is -5
Enter two whole numbers: 0 7
The bigger is 7
Enter two whole numbers: 0 0
```

In order to call **max** from **main**, we must "declare" **max** in **main** using the function prototype

```
int max(int, int);
```

This says that **max** takes two integer arguments and returns an integer value.

The variables **n1** and **n2**, declared in **main**, are considered as belonging to **main**.

When the program is run, suppose **n1** is 24 and **n2** is 33. When the function is called with **max(n1, n2)** from within **printf**, the following occurs:

- The *values* of the arguments **n1** and **n2** are determined. These are 24 and 33, respectively.
- Each value is copied to a temporary memory location. These locations are passed to the function **max** where 24 is labelled with **a**, the first parameter, and 33 is labelled with **b**, the second parameter. We can picture this as:

- The **if** statement is executed; since **a** (24) is not greater than **b** (33), control goes to the statement **return b;** and 33 is returned as the value of the function. This value is returned to the place from which **max** was called (the **printf** statement).
- Just before the function returns, the locations containing the arguments are thrown away. The value returned by **max** (33, in our example) replaces the call to **max**. Thus, **max(n1, n2)** is replaced by 33 and **printf** prints

```
The bigger is 33
```

When a function returns a value, it makes sense for this value to be used in a situation where a value is required. Above, we printed the value. We could also assign the value to a variable, as in

```
big = max(n1, n2);
```

or use it as part of an expression, as in

```
ans = 2 * max(n1, n2);
```

What does *not* make sense is to use it in a statement by itself, thus:

```
max(n1, n2);        //a useless statement
```

Here, the value is not being used in any way, so the statement makes no sense at all. It is the same as if we had written a number on a line by itself, like this

```
33;                 //a useless statement
```

Think carefully when you call a function which returns a value. Be very clear in your mind what you intend to use the value for.

As written, **max** returns the larger of two integers. What if we want to find the larger of two **double** numbers? Could we use **max**? Unfortunately, no. If we called **max** with **double** values as arguments, we may get strange results when a **double** number is assigned to an **int** parameter.

On the other hand, if we wrote **max** with **double** parameters and **double** return type, it would work for both **double** and **int** arguments, since we can assign an **int** value to a **double** parameter without losing any information.

Note, however, that if we call **max** with two character arguments, it would work by returning the larger of the two codes. For example, **max('A', 'C')** will return 67, the code for **C**.

Exercise: Write functions to return the smaller of two integers and two floating-point numbers.

7.4 Print the day

Let us write a program which requests a number from 1 to 7 and prints the name of the day of the week. For example, if the user enters 5, the program prints **Thursday**. Program P7.3 does the job using a series of **if...else** statements.

Program P7.3

```
#include <stdio.h>
main() {
  int d;
  printf("Enter a day from 1 to 7: ");
  scanf("%d", &d);
  if (d == 1) printf("Sunday\n");
  else if (d == 2) printf("Monday\n");
  else if (d == 3) printf("Tuesday\n");
  else if (d == 4) printf("Wednesday\n");
  else if (d == 5) printf("Thursday\n");
  else if (d == 6) printf("Friday\n");
  else if (d == 7) printf("Saturday\n");
  else printf("Invalid day\n");
}
```

Now suppose that printing the name of a day of the week was a small part of a much larger program. We wouldn't want to clutter up **main** with this code nor would we want to re-write this code every time we needed to print the name of a day. It would be much nicer if we could write **printDay(n)** and get the appropriate name printed. We would be able to do this if we write a function **printDay** to do the job.

The first thing to ask is what information does **printDay** need to do its job. The

answer is that it needs the number of the day. This immediately suggests that **printDay** must be written with the number of the day as a parameter. Apart from this, the body of the function will contain essentially the same code as Program P7.3. Also, **printDay** does not return a value so its "return type" is **void**.

```
void printDay(int d) {
  if (d == 1) printf("Sunday\n");
  else if (d == 2) printf("Monday\n");
  else if (d == 3) printf("Tuesday\n");
  else if (d == 4) printf("Wednesday\n");
  else if (d == 5) printf("Thursday\n");
  else if (d == 6) printf("Friday\n");
  else if (d == 7) printf("Saturday\n");
  else printf("Invalid day\n");
}
```

When we write the function, we can use *any* variable name we want for the parameter. We never have to worry about *how* the function will be called. Many beginners mistakenly believe that if the function is called with **printDay(n)**, the parameter in the header must be **n**. But that cannot be true since it could be called with **printDay(4)** or **printDay(n)** or **printDay(j)** or even **printDay(n + 1)**. The choice is up to the calling function.

All we need to know is that *whatever* the *value* of the argument, *that* value will be assigned to **d** (or whatever variable we happen to use as the parameter) and the function will be executed assuming the parameter (**d**, in our case) has that value.

We now re-write Program P7.3 as P7.4 (next page) to illustrate how the function fits into an overall program and how it can be used.

Now that we have delegated the printing to a function, notice how **main** is much less cluttered. However, we do have to write the function prototype for **printDay** in **main** so that **printDay** can be called from **main**. This is done with

```
void printDay(int);
```

As with all C programs, execution begins with the first statement in **main**. This prompts the user for a number and the program goes on to print the name of the day by calling the function **printDay**.

A sample run is:

```
Enter a day from 1 to 7: 4
Wednesday
```

In **main**, suppose **n** has the value 4. The call **printDay(n)** is executed as follows:

- The *value* of the argument **n** is determined. It is 4.

Program P7.4

```
#include <stdio.h>
main() {
   int n;
   void printDay(int);
   printf("Enter a day from 1 to 7: ");
   scanf("%d", &n);
   printDay(n);
}

void printDay(int d) {
   if (d == 1) printf("Sunday\n");
   else if (d == 2) printf("Monday\n");
   else if (d == 3) printf("Tuesday\n");
   else if (d == 4) printf("Wednesday\n");
   else if (d == 5) printf("Thursday\n");
   else if (d == 6) printf("Friday\n");
   else if (d == 7) printf("Saturday\n");
   else printf("Invalid day\n");
}
```

- The value 4 is copied to a temporary memory location. This location is passed to the function **printDay** where it is labelled with the name of the parameter, **d**. In effect, **d** is set to the value of the argument.
- The body of the function is executed. In this case, since **d** is 4, the statement **printf("Wednesday\n")** will be executed.
- After printing **Wednesday**, the function is finished. The location containing the argument is discarded and control returns to **main** to the statement following the call **printDay(n)**. In this case, there are no more statements so the program ends.

7.5 Highest Common Factor

In Chapter 5, we wrote Program P5.2 (page 91) which read two numbers and found their highest common factor (HCF). You should refresh your memory by taking a look at the program.

It would be nice if, whenever we want to find the HCF of two numbers (**m** and **n**, say), we could make a function call **hcf(m, n)** to get the answer. For instance, the call **hcf(42, 24)** would return the answer 6. To be able to do this, we write the function as shown on the next page.

The logic for finding the HCF is the same as used in P5.2. The difference here is that values for **m** and **n** will be passed to the function when it is called. In P5.2, we prompted the user to enter values for **m** and **n** and fetched them using **scanf**.

```
//returns the hcf of m and n
int hcf(int m, int n) {
  int r;
  while (n != 0) {
    r = m % n;
    m = n;
    n = r;
  }
  return m;
}
```

Suppose the function is called with **hcf(42, 24)**. The following occurs:

- Each of the arguments is copied to a temporary memory location. These locations are passed to the function **hcf** where 42 is labelled with **m**, the first parameter, and 24 is labelled with **n**, the second parameter.
  We can picture this as:

- The **while** loop is executed, working out the HCF. On exit from the loop, the HCF is stored in **m**, which will contain 6 at this time. This is the value returned by the function to the place from where it was called.
- Just before the function returns, the locations containing the arguments are thrown away; control then returns to the place from where the call was made.

Program P7.5 (next page) tests the function by reading pairs of numbers and printing the HCF of each pair. The call to **hcf** is made in the **printf** statement. The program stops if either number is less than or equal to 0. A sample run is:

```
Enter two positive numbers: 42 24
The HCF is 6
Enter two positive numbers: 32 512
The HCF is 32
Enter two positive numbers: 100 31
The HCF is 1
Enter two positive numbers: 84 36
The HCF is 12
Enter two positive numbers: 0 0
```

We emphasize again that even though the function is written with parameters called **m** and **n**, it can be called with any two integer values—constants, variables or expressions. In particular, it does not *have* to be called with variables named **m** and **n**. In our program, we called it with **a** and **b**.

Program P7.5

```
#include <stdio.h>
main() {
  int a, b;
  int hcf(int, int);
  printf("Enter two positive numbers: ");
  scanf("%d %d", &a, &b);
  while (a > 0 && b > 0) {
    printf("The HCF is %d\n", hcf(a, b));
    printf("Enter two positive numbers: ");
    scanf("%d %d", &a, &b);
  }
}

//returns the hcf of m and n
int hcf(int m, int n) {
  int r;
  while (n != 0) {
    r = m % n;
    m = n;
    n = r;
  }
  return m;
}
```

We remind you that in order to use **hcf** in **main**, we must "declare" it using the function prototype

```
int hcf(int, int);
```

If we wish, the two **int** declarations in **main** can be written in one statement, thus:

```
int a, b, hcf(int, int);
```

Using HCF to find LCM

A common task in arithmetic is to find the lowest common multiple (LCM) of two numbers. For example, the LCM of 8 and 6 is 24 since 24 is the smallest number which can divide both 8 and 6 exactly.

If we know the HCF of the two numbers, we can find the LCM by multiplying the numbers and dividing by their HCF. Given that the HCF of 8 and 6 is 2, we can find their LCM by working out $\frac{8 \times 6}{2} = 24$. In general,

LCM(m, n) = (m × n) / HCF(m, n)

Knowing this, we can easily write a function **lcm** which, given two arguments **m** and **n**, returns the LCM of **m** and **n**.

```
//returns the lcm of m and n
int lcm(int m, int n) {
  int hcf(int, int);
  return (m * n) / hcf(m, n);
}
```

Since **lcm** uses **hcf**, we must declare **hcf** by writing its prototype. We leave it as an exercise for you to write a program to test **lcm**. Remember to include the function **hcf** in your program. You may place **hcf** before or after **lcm**.

7.6 factorial

So far, we have written several functions which illustrate various concepts you need to know in writing and using functions. We now write another one and discuss it in detail, reinforcing some of the concepts we have met thus far and introducing new ones.

Before we write the function, let us first write a program which reads an integer *n* and prints *n*! (*n* factorial) where

$$0! = 1$$
$$n! = n(n - 1)(n - 2)...1 \quad \text{for } n > 0$$

For example, 5! = 5.4.3.2.1 = 120.

The program will be based on the following algorithm:

```
set nfac to 1
read a number, n
for j = 2 to n do
  nfac = nfac * j
endfor
print nfac
```

Dry run the algorithm with a value of 3 for **n** and convince yourself that it will print 6, the value of 3!. Check also that it produces the correct answer when **n** is 0 or 1 (hint: the **for** loop is not executed when **n** is 0 or 1).

The algorithm does not validate the value of **n**. For instance, **n** should not be negative since factorial is not defined for negative numbers. As a matter of interest, what would the algorithm print if **n** is negative? (Hint: the **for** loop is not executed). To keep matters simple, our Program P7.6 does not validate **n**.

Program P7.6

```
#include <stdio.h>
main() {
  int nfac = 1, n;
  printf("Enter a positive whole number: ");
  scanf("%d", &n);
  for (int j = 2; j <= n; j++)
    nfac = nfac * j;
  printf("%d! = %d\n", n, nfac);
}
```

A sample run of this program is:

```
Enter a positive whole number: 4
4! = 24
```

We now consider the problem of writing a function (which we will call **factorial**) which, given an integer *n*, calculates and returns the value of *n*!. Since *n*! is an integer, the "return type" of the function is **int**.

We first write the function header. It is

```
int factorial(int n)
```

It is interesting to note that the function header is all the information we need in order to use the function correctly. Ignoring for the moment what the rest of **factorial** might look like, we can use it as follows:

```
printf("5! = %d\n", factorial(5));
```

or

```
scanf("%d", &num);
printf("%d! = %d\n", num,factorial(num));
```

In the latter case, if num is 4, **printf** prints:

```
4! = 24
```

The call **factorial(num)** returns the value 24 directly to the **printf** statement.

Following the logic of Program P7.6, we write the function **factorial** as follows:

```
int factorial(int n) {
  int nfac = 1;
  for (int j = 2; j <= n; j++)
    nfac = nfac * j;
  return nfac;
}
```

It is worthwhile comparing Program P7.6 and the function:

- The program prompts for and reads a value for **n**; the function gets a value for **n** when the function is called, as in **factorial(4)**. It is *wrong* to attempt to read a value for **n** in this function.
- In addition to **n**, both the program and the function need the variables **nfac** and **j** to express their logic.
- The *logic* for calculating the factorial is the same for both program and function.
- The program prints the answer (in **nfac**); the function *returns* the answer (in **nfac**) to the calling function. The answer is returned to the point at which **factorial** was called.

Other comments on **factorial**

- Variables declared within a function are said to be *local to the function*. Thus, **nfac** and **j** are *local* variables; **nfac** is used to hold the factorial and **j** is used as the **for** loop variable which takes on the values from 2 to **n**. When **factorial** is called, storage is allocated to **nfac** and **j**. These variables are used to work out the factorial. Just before the function returns, **nfac** and **j** are discarded.
- You should verify that the function works properly if **n** is 0 or 1 (that is, it returns 1).

We now take a detailed look at what happens when **factorial** is called (from **main**, say). Consider the statements (**m** and **fac** are **int**):

```
m = 3;
fac = factorial(m);
```

The second statement is executed as follows:

- The *value* of the argument **m** is determined; it is 3.
- This value is *copied* to a temporary memory location and *this* location is passed to the function. The function labels it with the name of the parameter, **n**. The net effect is as if execution of the function began with the statement

  ```
  n = 3;
  ```

  In programming terminology, we say that the argument **m** is passed "by value". The *value* of the argument is copied to a temporary location and it is this temporary location that is passed to the function. The function has **no access** whatsoever to the **original** argument. In this example, **factorial** has no access to **m** and, hence, cannot affect it in any way.
- After **n** is assigned the value 3, execution of **factorial** proceeds as described above. Just before the function returns, the storage location occupied by **n** is discarded. In effect, the parameter **n** is treated like a local variable except that it is initialized to the value of the argument supplied.

- The value returned by the function is the last value stored in **nfac**. In this example, the last value assigned to **nfac** is 6. Therefore, the value 6 is returned to the place from which the call **factorial(3)** was made.
- The value 6 returned by **factorial** is assigned to **fac**.
- Execution continues with the next statement, if any.

Using factorial

We illustrate how **factorial** can be used by writing a complete Program P7.7 which prints n! for n = 0, 1, 2, 3, 4, 5, 6 and 7.

Program P7.7

```
#include <stdio.h>
main() {
  int factorial(int);
  printf(" n    n!\n\n");
  for (int n = 0; n <= 7; n++)
    printf("%2d %5d\n", n, factorial(n));
}

int factorial(int n) {
  int nfac = 1;
  for (int j = 2; j <= n; j++)
    nfac = nfac * j;
  return nfac;
}
```

When run, this program prints the following:

```
 n      n!

 0       1
 1       1
 2       2
 3       6
 4      24
 5     120
 6     720
 7    5040
```

As you can see, the value of factorial increases very quickly. Even 8! = 40320, which is too big to fit in a 16-bit integer (largest value which can be stored is 32767). As an exercise, write the loop from 0 to 8 and see what happens.

Let us take a closer look at **main**. The first statement is the function prototype for **factorial**. This is needed since **factorial** will be called from **main**.

When **main** is executed,

- **printf** prints a heading
- The **for** loop is executed with **n** assuming the values 0, 1, 2, 3, 4, 5, 6, 7. For each value of **n**, **factorial** is called with **n** as its argument. The factorial is calculated and returned to the place in **printf** from where it was called.

We have deliberately used a variable called **n** in **main** to illustrate that this **n** does not (and cannot) conflict with the parameter **n** of **factorial**. Suppose **n** in **main** is stored in memory location 865 and has the value 3. The call **factorial(n)** stores the *value* of **n**, i.e. 3, in a temporary location (472, say) and this temporary location is passed to **factorial** where it is known as **n**. This is illustrated by:

We now have *two* locations called **n**. While in **factorial**, **n** refers to location 472; when in **main**, **n** refers to location 865; **factorial** has no access whatsoever to location 865.

It does not happen here, but if **factorial** were to change the value of **n**, it is the value in location 472 that would be changed; the value in location 865 would not be affected. When **factorial** finishes, location 472 is discarded—*that* **n** no longer exists.

From another point of view, **factorial** is oblivious to the actual argument that was used to call it since it sees only the argument's value, not how it was derived.

We used **n** in **main** as a loop variable to illustrate the point above. However, we could have used any variable. In particular, we could have used **j** and there would be no conflict with the local variable **j** of the function **factorial**. While in **factorial**, **j** refers to the local variable; when in main, **j** refers to the **j** declared in **main**.

An example – combinations

Suppose there are 7 people on a committee. How many subcommittees of 3 people can be formed? The answer is denoted by ${}^{7}C_{3}$ where

$$ {}^{7}C_{3} = \frac{7!}{4!\,3!} = 35 $$

We say there are 35 *combinations* of 7 objects taken 3 at a time. In general, ${}^{n}C_{r}$ denotes the number of combinations of *n* objects taken *r* at a time and is given by the formula:

$$ {}^{n}C_{r} = \frac{n!}{(n-r)!\,r!} $$

Using **factorial**, we can write a function, **combinations**, which, given **n** and **r**, returns the number of combinations of **n** objects taken **r** at a time. Here it is:

```
int combinations(int n, int r) {
   int factorial(int);
   return factorial(n) / (factorial(n-r) * factorial(r));
}
```

The body consists of the function prototype for **factorial** and one **return** statement with 3 calls to **factorial**.

We note, in passing, that this is perhaps the easiest, but not the most efficient, way to evaluate ${}^{n}C_{r}$. For instance, if we were calculating ${}^{7}C_{3}$ by hand, we would use:

$$ \frac{7.6.5}{3.2.1} \text{ rather than } \frac{7.6.5.4.3.2.1}{4.3.2.1.3.2.1} $$

that the function uses. As an exercise, write an efficient function for evaluating combinations.

To show the functions **factorial** and **combinations** in a complete program and to show how they may be used, we write a program to read values for **n** and **r** and print the number of combinations we can get from *n* objects taken *r* at a time.

Program P7.8 (next page) shows how it's done.

The program reads values for **n** and **r** and prints the number of combinations. This is done until a value of **0** is entered for **n**. The following is a sample run:

```
Enter values for n and r: 7 3
There are 35 combinations of 7 objects taken 3 at a time

Enter values for n and r: 5 2
There are 10 combinations of 5 objects taken 2 at a time

Enter values for n and r: 6 6
There is 1 combination of 6 objects taken 6 at a time

Enter values for n and r: 3 5
There are 0 combinations of 3 objects taken 5 at a time

Enter values for n and r: 0 0
```

Observe the use of **if...else** to get the program to "speak" correct English. In the statement, also note how a long string is broken into two pieces and each piece is put on one line. Recall that, in C, the opening and closing quotes of a string constant must be on the same line. When the program is compiled, the pieces will be joined together and stored in memory as one string.

Program P7.8

```
#include <stdio.h>
main() {
  int n, r, nCr, factorial(int), combinations(int, int);
  printf("Enter values for n and r: ");
  scanf("%d %d", &n, &r);
  while (n != 0) {
    nCr = combinations(n, r);
    if (nCr == 1)
      printf("There is 1 combination of %d objects taken "
                          "%d at a time\n", n, r);
    else
      printf("There are %d combinations of %d objects taken "
                          "%d at a time\n", nCr, n, r);
    printf("Enter values for n and r: ");
    scanf("%d %d", &n, &r);
  }
}

int factorial(int n) {
  int nfac = 1;
  for (int j = 2; j <= n; j++)
    nfac = nfac * j;
  return nfac;
}

int combinations(int n, int r) {
  int factorial(int);
  return factorial(n) / (factorial(n-r) * factorial(r));
}
```

7.7 An example – job charge

In Program 4.6 (page 76), we read the number of hours worked and the cost of parts and calculated the cost for a job. Let us write a function which, given the hours worked and cost of parts, returns the cost for the job. When we say that a function is *given* some data, that immediately implies that such data should be defined as parameters of the function. The function is shown on the next page.

The logic of the function is the same as that of the program. Here, the parameter list indicates what data would be given to the function when it is called. Also, we must specify the return type of the function; it is **double** since the job cost is a **double** value.

```
#define ChargePerHour 100
#define MinJobCost 150
double calcJobCost(double hours, double parts) {
  double jobCharge;
  jobCharge = hours * ChargePerHour + parts;
  if (jobCharge < MinJobCost) return MinJobCost;
  return jobCharge;
}
```

When the function is called, as in

```
jobCost = calcJobCost(1.5, 87.50);
```

the parameter **hours** is set to `1.5` and **parts** is set to `87.50`; the body of the function is then executed using *these* values for **hours** and **parts**.

As an exercise, write a complete program to read several values for hours worked and cost of parts and, for each pair, print the cost of the job.

7.8 An example – calculating pay

In Program P4.7 (page 78), we read values for **hours** and **rate**, and calculated net pay. All the code was written in **main**. We now write a function which, *given* values for **hours** and **rate**, returns the value of net pay calculated as described on page 72. The function is shown below.

```
#define MaxRegularHours 40
#define OvertimeFactor 1.5
double calcNetPay(double hours, double rate) {
  if (hours <= MaxRegularHours) return hours * rate;
  return MaxRegularHours * rate +
          (hours - MaxRegularHours) * rate * OvertimeFactor;
}
```

If the condition is true, the first **return** is executed; if it is false, the second **return** is executed. Note that there is no need for **else**. If the first **return** is taken, we exit the function and the second **return** cannot be executed.

If we want to find out the net pay of someone who worked for 50 hours at $12.00 per hour, all we have to do is call **calcNetPay(50, 12.00)**.

As an exercise, write a complete program to read several values for a name, hours worked and rate of pay and, for each person, print the net pay received. Hint: study Program P5.8 on page 109.

7.9 An example – finding the sum of exact divisors

Let us write a function to return the sum of the exact divisors of a given integer. We assume the divisors include 1 but not the given number. For example, the exact divisors of 50 are 1, 2, 5, 10 and 25. Their sum is 43. The function is shown below:

```
//returns the sum of the exact divisors of n
int sumDivisors(int n) {
  int sumDiv = 1;
  for (int j = 2; j <= n / 2; j++)
    if (n % j == 0) sumDiv += j;
  return sumDiv;
}
```

- **sumDiv** is used to hold the sum of the exact divisors; it is set to 1 since 1 is always an exact divisor.
- Other possible divisors are 2, 3, 4 and so on up to n/2. The **for** loop checks each of these in turn.
- If **j** is an exact divisor of **n** then the remainder when **n** is divided by **j** is 0, that is, **n % j** is 0. If this is so, **j** is added to **sumDiv**.
- The last statement returns the value of **sumDiv** to the place from which **sumDivisors** is called.

In the next example, we will see how **sumDivisors** may be used.

Classifying numbers as deficient, perfect or abundant

Positive integers can be classified based on the sum of their exact divisors. If *n* is an integer and *s* is the sum of its exact divisors (including 1 but not including *n*) then:

- if **s < n**, **n** is *deficient*; e.g. 15 (divisors 1, 3, 5; sum 9)
- if **s = n**, **n** is *perfect*; e.g. 28 (divisors 1, 2, 4, 7, 14; sum 28)
- if **s > n**, **n** is *abundant*; e.g. 12 (divisors 1, 2, 3, 4, 6; sum 16)

Let us write Program P7.9 (next page) to read several numbers and, for each, print whether it is deficient, perfect or abundant.

Note that we call **sumDivisors** once (for each number) and store the result in **sum**. We use **sum** when we need the "sum of divisors" rather than re-calculating it each time.

As an exercise, write a program to find all the perfect numbers less than 10,000.

Program P7.9

```
#include <stdio.h>
main() {
  int num, sumDivisors(int);
  printf("Enter a number: ");
  scanf("%d", &num);
  while (num != 0) {
    int sum = sumDivisors(num);
    if (sum < num) printf("Deficient\n\n");
    else if (sum == num) printf("Perfect\n\n");
    else printf("Abundant\n\n");
    printf("Enter a number: ");
    scanf("%d", &num);
  }
}

//returns the sum of the exact divisors of n
int sumDivisors(int n) {
  int sumDiv = 1;
  for (int j = 2; j <= n / 2; j++)
    if (n % j == 0) sumDiv += j;
  return sumDiv;
}
```

The following is a sample run of Program P7.9:

```
Enter a number: 15
Deficient

Enter a number: 12
Abundant

Enter a number: 28
Perfect

Enter a number: 0
```

7.10 Some character functions

In this Section, we write several functions relating to characters.

Perhaps the simplest is a function which takes a character as argument; it returns 1 if the character is a digit and 0, if it is not. (Recall that, in C, a zero value is interpreted as **false** and a non-zero value is interpreted as **true**.) This description suggests that we must write a function which takes a **char** argument and returns an **int** value. We will call it **isDigit**. Here it is:

```
int isDigit(char ch) {
  return ch >= '0' && ch <= '9';
}
```

The Boolean expression **(ch >= '0' && ch <= '9')** is **true** if **ch** lies between **'0'** and **'9'**, inclusive; that is, if **ch** contains a digit. Hence, if **ch** contains a digit, the function returns 1 (for **true**); if **ch** does not contain a digit, it returns 0 (for **false**).

We *could* have written the body of the function as

```
if (ch >= '0' && ch <= '9') return 1;
return 0;
```

but the single **return** statement used above is the preferred way.

Similarly, we can write the function **isUpperCase** which returns 1 if its argument is an uppercase letter and 0 if it's not, thus:

```
int isUpperCase(char ch) {
  return ch >= 'A' && ch <= 'Z';
}
```

and the function **isLowerCase** which returns 1 if its argument is a lowercase letter and 0 if it's not, thus:

```
int isLowerCase(char ch) {
  return ch >= 'a' && ch <= 'z';
}
```

If we wish to know if the character is a letter (either uppercase or lowercase), we can write **isLetter** which uses **isUpperCase** and **isLowerCase**, thus:

```
int isLetter(char ch) {
  int isUpperCase(char), isLowerCase(char);
  return isUpperCase(ch) || isLowerCase(ch);
}
```

We need to include the function prototypes for **isUpperCase** and **isLowerCase**.

Example – position of a letter in the alphabet

Let us write a function which, given a character, returns 0 if it is not a letter of the English alphabet; otherwise, it returns the position—an integer value—of the letter in the alphabet. The function should work if the character is either an uppercase or a lowercase letter. For example, given **'Y'** or **'y'**, the function should return 25.

The function takes a **char** argument and returns an **int** value. Using the functions **isUpperCase** and **isLowerCase**, we write the function (which we call **position**) as follows:

```
int position(char ch) {
  int isUpperCase(char), isLowerCase(char);
  if (isUpperCase(ch)) return ch - 'A' + 1;
  if (isLowerCase(ch)) return ch - 'a' + 1;
  return 0;
}
```

We use **isUpperCase** and **isLowerCase** to establish what kind of character we have. If it is neither, control goes to the last statement and we return 0.

If we have an uppercase letter, we find the *distance* between the letter and **A** by subtracting the code for **A** from the code for the letter. For example, the distance between **A** and **A** is 0 and the distance between **A** and **F** is 5. Adding 1 gives the position of the letter in the alphabet. Here, adding 1 gives us 1 for **A** and 6 for **F**.

If we have a lowercase letter, we find the *distance* between the letter and **a** by subtracting the code for **a** from the code for the letter. For example, the distance between **a** and **b** is 1 and the distance between **a** and **z** is 25. Adding 1 gives the position of the letter in the alphabet. Here, adding 1 gives us 2 for **b** and 26 for **z**.

To illustrate how the function may be used, we write Program P7.10 (next page) which reads a line of input; for each character on the line, it prints 0 if it is not a letter and its position in the alphabet if it is a letter.

A sample run is:

```
Type some letters and non-letters and press "Enter"
FaT($hY&n
F  6
a  1
T  20
(  0
$  0
h  8
Y  25
&  0
n  14
```

Program P7.10

```
#include <stdio.h>
main() {
  char c;
  int position(char);
  printf("Type some letters and non-letters and press 'Enter' ");
  while ((c = getchar()) != '\n')
    printf("%c  %d\n", c, position(c));
}

int isUpperCase(char ch) {
  return ch >= 'A' && ch <= 'Z';
}

int isLowerCase(char ch) {
  return ch >= 'a' && ch <= 'z';
}

int position(char ch) {
  int isUpperCase(char), isLowerCase(char);
  if (isUpperCase(ch)) return ch - 'A' + 1;
  if (isLowerCase(ch)) return ch - 'a' + 1;
  return 0;
}
```

We have written the functions **isDigit**, **isUpperCase**, **isLowerCase** and **isLetter** to illustrate basic concepts about character functions. However, C provides a number of predefined functions (actually, *macros*, but the distinction is not important for us) for working with characters. Among these are **isdigit** (test for a digit), **isupper** (test for an uppercase letter), **islower** (test for a lowercase letter) and **isalpha** (test for a letter). To use these functions, you need to place the directive

```
#include <ctype.h>
```

at the head of your program. As an exercise, rewrite P7.10 using **isupper** and **islower**. Without **isUpperCase**, **isLowerCase** and their prototypes, your program would be much shorter.

7.11 Example – fetch the next integer

On page 149, we wrote Program P6.13 which read the data character by character, constructed and stored the next integer found in a variable, and finally printed the integer.

Let us now write a *function*, **getInt**, which reads the data character by character and *returns* the next integer found. The function does not take any arguments but

the brackets must still be written after the name. The code is essentially the same as in P6.13, except that we use the predefined function **isdigit**. Here is **getInt**:

```
int getInt() {
  char ch = getchar();
  // as long as the character is not a digit, keep reading
  while (!isdigit(ch)) ch = getchar() ;
  // at this point, ch contains the first digit of the number
  int num = 0;
  while (isdigit(ch)) { // as long as we get a digit
       num = num * 10 + ch - '0';  // update num
       ch = getchar();
  }
  return num;
}
```

Note that

```
while (ch < '0' || ch > '9')
```

of P6.13 is replaced by

```
while (!isdigit(ch))
```

and

```
while (ch >= '0' && ch <= '9')
```

is replaced by

```
while (isdigit(ch))
```

We believe this makes the program a little more readable.

The function needs the variables **ch** and **num** to do its job; **ch** holds the next character in the data and **num** holds the number constructed so far. We declare them within the function, making them local variables. This way, they will not conflict with any variables with the same names declared anywhere else in the program. This makes the function *self-contained*—it does not depend on variables declared elsewhere.

The function can be used as in

```
id = getInt();
```

This fetches the next positive integer from the input, regardless of how many and what kind of characters come before it, and stores it in **id**. Recall that **scanf("%d", &id)** works only if the next integer is preceded by zero or more *whitespace* characters. Our **getInt** is more general.

We test it by rewriting Program P4.2 (page 68) which requests two lengths given in metres and centimetres and finds the sum. We observed then that the data must be entered with digits only. If, for instance, we had typed `3m 75cm` we would have

gotten an error since `3m` is not a valid integer constant. With **getInt**, we *will* be able to enter the data in the form `3m 75cm`.

The new program is shown as Program P7.11.

Program P7.11

```
//find the sum of two lengths given in metres and cm
#include <stdio.h>
#include <ctype.h>
main() {
  int m1, cm1, m2, cm2, mSum, cmSum, getInt();
  printf("Enter first length: ");
  m1 = getInt();
  cm1 = getInt();
  printf("Enter second length: ");
  m2 = getInt();
  cm2 = getInt();

  mSum = m1 + m2;  //add the metres
  cmSum = cm1 + cm2;  //add the centimetres
  if (cmSum >= 100) {
    cmSum = cmSum - 100;
    mSum = mSum + 1;
  }
  printf("\nSum is %dm %dcm\n", mSum, cmSum);
}

int getInt() {
  char ch = getchar();
  // as long as the character is not a digit, keep reading
  while (!isdigit(ch)) ch = getchar() ;
  // at this point, ch contains the first digit of the number
  int num = 0;
  while (isdigit(ch)) { // as long as we get a digit
       num = num * 10 + ch - '0';  // update num
       ch = getchar();
  }
  return num;
}
```

A sample run is

```
Enter first length: 3m 75cm
Enter second length: 5m 50cm

Sum is 9m 25cm
```

You are encouraged to:

- modify **getInt** so that it works for negative integers;
- write a function **getDouble** which returns the next floating-point number in the input. It should work even if the next number does not contain a decimal point.

Exercises 7

1. Explain why functions are important in writing a program.
2. Given the function header

   ```
   void test(int n)
   ```

   explain carefully what happens when the call **test(5)** is made.
3. Given the function header

   ```
   double fun(int n)
   ```

   explain carefully what happens when the following statement is executed:

   ```
   printf("The answer is %f\n", fun(9));
   ```
4. Given the function header

   ```
   void test(int m, int n, double x)
   ```

   say whether each of the following calls is valid or invalid. If invalid, state why.

   ```
   test(1, 2, 3);
   test(-1, 0.0, 3.5);
   test(7, 2);
   test(14, '7', 3.14);
   ```
5. Write a function **sqr** which, given an integer **n**, returns n^2.
6. Write a function **isEven** which, given an integer **n**, returns **1** if **n** is even and **0** if **n** is odd.
7. Write a function **isOdd** which, given an integer **n**, returns **1** if **n** is odd and **0** if **n** is even.
8. Write a function **isPerfectSquare** which, given an integer **n**, returns **1** if **n** is a perfect square (e.g. 25, 81) and **0** if it is not. Use only elementary arithmetic operations. Hint: try numbers starting at 1. Compare the number times itself with **n**.
9. Write a function **isVowel** which, given a character **c**, returns **1** if **c** is a vowel and **0** if it is not.
10. Write a function which, given an integer **n**, returns the sum $1 + 2 + \ldots + n$.
11. Write a function which, given an integer **n**, returns the sum $1^2 + 2^2 + \ldots + n^2$.
12. Using Program P4.9 (page 81) as a guide, write a function which, given three integer values representing the sides of a triangle, returns:
    - 0 if the values cannot be the sides of any triangle. This is so if any value is negative or zero, or if the length of any side is greater than or equal to the sum of the other two;
    - 1 if the triangle is scalene (all sides different);
    - 2 if the triangle is isosceles (two sides equal).
    - 3 if the triangle is equilateral (three sides equal);

13. Write a function which, given three integer values representing the sides of a triangle, returns **1** if the triangle is right-angled and **0** if it is not. The sides are given in any order.
14. Write a function **power** which, given a **double** value **x** and an integer **n**, returns x^n.
15. Using the algorithm of problem 10 on page 83, write a function which, given a year between 1900 and 2099, returns an integer value indicating the day on which Easter Sunday falls in that year. If **d** is the day of the month, return **d** if the month is March and **-d** if the month is April. For example, if the year is 1999, return **-4** since Easter Sunday fell on April 4 in 1999. Assume that the given year is valid.

    Write a program which reads two years, **y1** and **y2**, and, using the function above, prints the day on which Easter Sunday falls for each year between **y1** and **y2**.
16. Write a function which, given integer values for **month** and **year**, returns the number of days in the month. See problem 8 on page 83.
17. Write a function **numLength** which, given an integer **n**, returns the number of digits in the integer. For example, given **309**, the function returns **3**.
18. Write a function **max3** which, given 3 integers, returns the biggest.
19. Write a function **isPrime** which, given an integer **n**, returns **1** if **n** is a prime number and **0** if it is not. A prime number is an integer > 1 which is divisible only by 1 and itself.

    Using **isPrime**, write a program to prompt for an even number **n** greater than **4** and print all pairs of prime numbers which add up to **n**. Print an appropriate message if **n** is not valid. For example, if **n** is **22**, your program should print

```
 3  19
 5  17
11  11
```

20. You are required to generate a sequence of integers from a given positive integer *n*, as follows. If *n* is even, divide it by 2. If *n* is odd, multiply it by 3 and add 1. Repeat this process with the new value of *n*, stopping when *n* = 1. For example, if *n* is 13, the following sequence will be generated:

```
13  40  20  10  5  16  8  4  2  1
```

    Write a function which, given *n*, returns the *length* of the sequence generated, including *n* and 1. For *n* = 13, your function should return **10**.

    Using the function, write a program to read two integers *m* and *n* (*m* < *n*), and print the maximum sequence length for the numbers between *m* and *n*, inclusive. Also print the number which gives the maximum length. For example, if *m* = 1 and *n* = 10, your program should print

```
9 generates the longest sequence of length 20
```

21. We can code the 52 playing cards using the numbers 1 to 52. We can assign 1 to the Ace of Spades, 2 to the Two of Spades and so on, up to 13 to the King of Spades. We can then assign 14 to the Ace of Hearts, 15 to the Two of Hearts and so on, up to 26 to the King of Hearts. Similarly, we can assign the numbers 27-39 to Diamonds and 40-52 to Clubs.

    Write a function which, given integers **rank** and **suit**, returns the code for that card. Assume **rank** is a number from **1** to **13** with **1** meaning **Ace** and **13** meaning **King**; **suit** is **1**, **2**, **3** or **4** representing Spades, Hearts, Diamonds and Clubs, respectively.

8 Working with arrays

In this chapter, we will explain:

- what is an array and how to declare one
- how to store values in an array
- how to read a known number of values into an array using a **for** loop
- how to process elements of an array using a **for** loop
- how to read an unknown number of values into an array using a **while** loop
- how to extract a required element from an array with a subscript
- how to find the sum of numbers stored in an array
- how to find the average of numbers stored in an array
- how to use an array to keep several counts
- how to work with a **string** as an array of characters
- how to reverse the elements in an array
- how to write a function to tell if a phrase is a palindrome
- how to pass an array as an argument to a function
- how to find the largest and smallest values in an array
- how to search an array using sequential search
- how to sort an array using selection sort

The variables we have been using so far (such as **ch**, **n**, **sum**) are normally called *simple* variables. At any given time, a simple variable can be used to store *one* item of data, for instance, one number or one character. Of course, the value stored in the variable can be changed, if we wish. However, there are many situations in which we wish to store a group of related items and to be able to refer to them by a common name. The *array variable* allows us to do this.

For example, suppose we wish to store a list of 60 scores made by students in a test. We can do this by inventing 60 different **int** variables and storing one score in one variable. But it would be quite tedious, cumbersome, unwieldy and time-consuming to write code to manipulate these 60 variables. (Think of how you would assign values to these 60 variables). And what if we needed to deal with 200 scores?

A better way is to use an *array* to store the 60 scores. We can think of this array as having 60 'locations'—we use one location to store one *element*, in this case, one score. To refer to a particular score, we use a *subscript*. For example, if **score**

is the name of the array, then **score[5]** refers to the score in position 5—here 5 is used as a subscript. It is written inside the *square* brackets, **[** and **]**.

In general, an array can be used to store a list of values of the *same type*; for instance, we speak of an array of integers, an array of characters, an array of strings or an array of floating-point numbers. As you will see, using an array allows us to work with a list in a simple, systematic way, regardless of its size. We can process all or some items using a simple loop. We can also do things like search for an item in the list or sort the list in ascending or descending order.

8.1 Declaring an array

Before an array is used, it must be *declared*. For example, the statement

```
int score[60];
```

declares that **score** is an 'integer array' or an 'array of **int**s' with subscripts ranging from 0 to 59. An array declaration consists of

- the type (**int**, in this example)
- the name of the array (**score**, in this example)
- a left square bracket, **[**
- the *size* of the array (60, in this example)
- a right square bracket, **]**

In C, array subscripts start at 0 and go up to **n-1**, if **n** is the size of the array.

We can think of the declaration as creating 60 **int** variables which can be referred to collectively by the *array variable* **score**. To refer to a specific one of these scores, we use a *subscript* written in square brackets after the array name. In this example,

score[0] refers to the 1st score;
score[1] refers to the 2nd score;
score[2] refers to the 3rd score;
.
.
score[58] refers to the 59th score;
score[59] refers to the 60th score;

As you can see, array subscripting is a bit awkward in C; it would be much nicer (and logical) if **score[j]** were to refer to the **j**th score. We will see how to get around this shortly.

It is an error to try to refer to an element that is outside the range of subscripts allowed. If you do, you will get an "array subscript" error. For example, you cannot refer to **score[-1]**, **score[60]** and **score[99]** since they do not exist.

A subscript can be written using a constant (like **25**), a variable (like **n**) or an expression (like **j + 1**). The *value* of the subscript determines which element is being referred to.

In our example, *each element* of the array is an **int** and can be used in any way that an ordinary **int** variable can. In particular, a value can be stored in it, its value can be printed and it can be compared with another **int**.

We could picture **score** as in Figure 8.1.

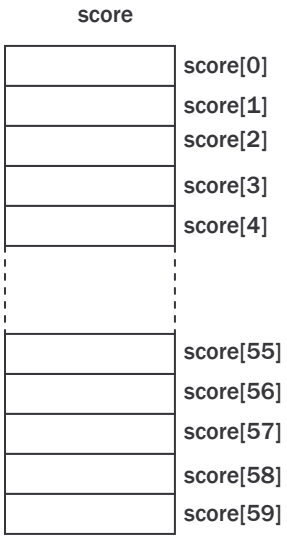


Figure 8.1: The declaration **int score[60]**

Like a simple variable, when an array is declared, the values of its elements remain *undefined* until we execute statements which store values in them, as discussed in Section 8.2, next.

To give another example, suppose we need to store the item numbers (integers) and prices (floating-point numbers) of 100 items. We can use one array (**item**, say) to hold the item numbers and another array (**price**, say) to hold the prices. These can be declared with:

```
int item[100];
double price[100];
```

The elements of **item** range from **item[0]** to **item[99]** and the elements of **price** range from **price[0]** to **price[99]**. When we store values in these arrays (see next), we will ensure that

price[0] holds the price of **item[0]**;
price[1] holds the price of **item[1]**;

and, in general,

price[j] holds the price of **item[j]**.

8.2 Storing values in an array

Consider the array **score**. If we wish, we could set selected elements to specific values, as follows:

```
score[3] = 56;
score[7] = 81;
```

But what if we wish to set the 60 locations to 60 scores? Would we have to write 60 statements such as:

```
score[0] = 45;
score[1] = 63;
score[2] = 39;
      .
      .
score[59] = 78;
```

This is certainly one way of doing the job, but it is very tedious, time-consuming and inflexible. A neater way is to let the subscript be a *variable* rather than a *constant*. For example, **score[j]** can be used to refer to the score in location **j**; which score is meant depends on the value of **j**. If the value of **j** is 47, then **score[j]** refers to **score[47]**, the score in location 47.

Note that **score[j]** can be used to refer to another score simply by changing the value of **j**, but, at any one time, **score[j]** refers to one specific score, determined by the current value of **j**.

Suppose the 60 scores are stored in a file **scores.txt**. The following code will read the 60 scores and store them in the array **score**:

```
FILE * in = fopen("scores.txt", "r");
for (int j = 0; j < 60; j++)
  fscanf(in, "%d", &score[j]);
```

Suppose the file **scores.txt** begins with the following data:

```
45  63  39 ...
```

The **for** loop is executed with the value of **j** ranging from 0 to 59:

- when **j** is 0, the first score, **45**, is read and stored in **score[0]**;
- when **j** is 1, the second score, **63**, is read and stored in **score[1]**;
- when **j** is 2, the third score, **39**, is read and stored in **score[2]**;

and so on, up to

- when **j** is 59, the 60th score is read and stored in **score[59]**.

Note that this method is much more concise than writing 60 assignment statements. We are using one statement

```
fscanf(in, "%d", &score[j]);
```

to store the scores in 60 different locations. This is achieved by varying the value of the subscript, **j**. This method is also more flexible. If we had to deal with 200 scores, say, we only need to change 60 to 200 in the declaration of **score** and in the **for** statement (and supply the 200 scores in the data file). The previous method would require us to write 200 assignment statements.

If we wish to print the scores as they are read, we could write the **for** loop as:

```
for (int j = 0; j < 60; j++) {
  fscanf(in, "%d", &score[j]);
  printf("%d\n", score[j]);
}
```

On the other hand, if we wish to print the scores *after* they are read and stored in the array, we could write *another* **for** loop:

```
for (j = 0; j < 60; j++)
  printf("%d\n", score[j]);
```

We have used the same loop variable **j** that was used to read the scores. But it is not required that we do so. Any other loop variable would have the same effect. For instance, we could have written:

```
for (int x = 0; x < 60; x++)
  printf("%d\n", score[x]);
```

What is important is the *value* of the subscript, *not the variable* that is used as the subscript.

We often need to set all elements of a numeric array to 0. This may be necessary, for instance, if we are going to use them to hold totals, or as counters. For example, to set the 60 elements of **score** to 0, we could write:

```
for (int j = 0; j < 60; j++)
  score[j] = 0;
```

The **for** loop is executed 60 times, with **j** taking on the values 0 to 59:

- the first time through the loop, **j** is 0, so **score[0]** is set to 0;
- the second time through the loop, **j** is 1, so **score[1]** is set to 0;

and so on, until

- the 60th time through the loop, **j** is 59, so **score[59]** is set to 0.

If we want to set the elements to a different value (−1, say), we could write:

```
for (int j = 0; j < 60; j++)
  score[j] = -1;
```

It should be noted that even though we have declared **score** to be of size 60, it is not required that we use all the elements. For example, suppose we want to set just the first 20 elements of **score** to 0, we could do this with:

```
for (int j = 0; j < 20; j++)
  score[j] = 0;
```

This sets elements **score[0]**, **score[1]**, **score[2]**, up to **score[19]** to 0. Elements **score[20]** to **score[59]** remain undefined.

About not using element 0

As we have seen, starting from element 0 can be a bit awkward and unnatural when we have to say things like "the third element is stored in location 2"; the subscript is "out of sync" with the position of the element. It would be much more sensible and logical to say "the first element is stored in location 1" or "the fifth element is stored in location 5".

For situations like these, it is better to ignore element 0 and pretend that the subscripts start from 1. However, you will have to declare the *size* of your array to be one more than you actually need. For instance, if we want to cater for 60 scores, we will have to declare **score** as

```
int score[61];
```

This creates elements **score[0]** to **score[60]**. We can ignore **score[0]** and use only **score[1]** to **score[60]**. Having to declare an extra element is a small price to pay for being able to work with our problem in a more natural and logical manner.

There are times when it is better to work with an array from position 0. But, for those times when it is not, we will *declare* our array size to be one more than required and ignore the element in position 0.

Suppose we want to cater for 60 scores. A good way to do this is as follows:

```
#define MaxScores 60
...
int score[MaxScores + 1];
```

We can now work with elements **score[1]** to **score[MaxScores]**.

8.3 Example – finding average and differences from average

Consider the problem of finding the average of a set of numbers (integers) and the amount by which each number differs from the average. In order to find the average, we need to know all the numbers. We saw in Section 5.2, page 93, how to find the average by reading and storing one number at a time. Each new

number read replaced the previous one. At the end, we could calculate the average but we've lost all the numbers.

Now, if we also want to know how much each number differs from the average, we would need to store the original numbers so that they are available after the average is calculated. We will store them in an array. The program will be based on the following assumptions:

- no more than 100 numbers will be supplied; this information is needed to declare the size of the array;
- the numbers will be terminated by 0; it is assumed that 0 is not one of the numbers.

The following shows how we want the program to work:

```
Enter up to 100 numbers (end with 0)
2 7 5 3 0

Numbers entered: 4
Sum of numbers: 17

The average is 4.25

Numbers and differences from average
   2  -2.25
   7   2.75
   5   0.75
   3  -1.25
```

Program P8.2 (next page) shows how to write the program to work like this.

Points to note about Program P8.2:

- Using **#define**, we set the symbolic constant **MaxNum** to 100; we use it to declare the array and in the prompt for numbers. This makes the program easy to modify if we change our mind and wish to cater for a different amount of numbers.
- We enter the **while** loop when the number read is not 0. Inside the loop, we add it to the sum, store it in the array and count it. Each time we reach the end of the loop, the value of **n** is the amount of numbers stored in the array so far.
- On exit from the **while** loop, we test **n**. If it is still 0, then no numbers were supplied and there's nothing else to do. The program does not make the mistake of trying to divide by **n** if it is 0. If **n** is positive, we confidently divide the sum by it to find the average.
- The **for** loop 'steps through' the array, printing the numbers and their differences from the average. Here, **n** is the number of elements of the array that were actually used, not necessarily the entire array. The elements used are **num[0]** to **num[n-1]**.

Program P8.2

```
//find average and difference from average
#include <stdio.h>
#define MaxNum 100
main() {
  int a, num[MaxNum];
  int n = 0;
  double sum = 0;
  printf("Enter up to %d numbers (end with 0)\n", MaxNum);
  scanf("%d", &a);
  while (a != 0) {
    sum += a;
    num[n++] = a;  //store in location n, then add 1 to n
    scanf("%d", &a);
  }
  if (n == 0) printf("No numbers entered\n");
  else {
    printf("\nNumbers entered: %d\n", n);
    printf("Sum of numbers: %1.0f\n\n", sum);
    double average = sum / n;
    printf("The average is %3.2f\n", average);
    printf("\nNumbers and differences from average\n");
    for (a = 0; a < n; a++)
      printf("%4d %6.2f\n", num[a], num[a] - average);
  }
}
```

- The program works out the sum of the numbers as they are read. If we need to find the sum of the first **n** elements *after* they have been stored in the array, we can do this with:

```
sum = 0;
for(int j = 0; j < n; j++) sum += num[j];
```

Program P8.2 does the basics. But what if the user entered more than 100 numbers? Recall that, as declared, the elements of **num** range from **num[0]** to **num[99]**.

Now suppose that **n** is 100, meaning that 100 numbers have already been stored in the array. If another one is entered, and it is not 0, the program will enter the **while** loop and attempt to execute the statement

```
num[n++] = a;
```

Since **n** is 100, this is now the same as **num[100] = a**. But there is no element **num[100]**—you will get an "array subscript" error. When you start working with arrays, you must be very careful that your program logic does not take you outside the range of subscripts. If it does, your program will crash.

To cater for this possibility, we could write the **while** condition as

```
while (a != 0 && n < MaxNum) { ...
```

If **n** is equal to **MaxNum** (100), it means we have already stored 100 values in the array and there is no room for any more. In this case, the loop condition will be **false**, the loop will not be entered and the program will not try to store another value in the array.

This is another example of *defensive programming*, of trying to make our programs immune to outside forces. Now there is no way for a user action to cause our program to crash by exceeding the bounds of the array.

8.4 Example – letter frequency count

Let us write a program which counts the frequency of each letter in the input. The program will treat an uppercase letter and its lowercase equivalent as the same letter; for example, **E** and **e** increment the same counter.

In Program P7.10 on page 176, we wrote a function, **position**, which, given a character, returns 0 if the character is not a letter; if it is a letter, it returns its position in the alphabet. We will use **position** to solve this problem. However, we will rewrite it using the predefined character functions **isupper** and **islower**.

To solve this problem, we need to keep 26 counters, one for each letter of the alphabet. We need a counter for **a**'s and **A**'s, one for **b**'s and **B**'s, one for **c**'s and **C**'s, and so on. We *could* declare 26 variables called **a**, **b**, **c**, ..., up to z; **a** holds the count for **a**'s and **A**'s, **b** holds the count for **b**'s and **B**'s, and so on. And, in our program, we could write statements of the form (assuming **ch** contains the next character):

```
if (ch == 'a' || ch == 'A') a++;
else if (ch == 'b' || ch == 'B') b++;
else if (ch == 'c' || ch == 'C') c++;
else if ...
```

This gets tiresome very quickly. And we will have similar problems when we have to print the results. Having to work with 26 variables for such a small problem is neither suitable nor convenient. As we will see, an array lets us solve this problem much more easily.

We will need an **int** array with 26 elements to hold the count for each letter of the alphabet. Since it is more natural to use element 1 (rather than element 0) to hold

the count for **a**'s and **A**'s, element 2 (rather than element 1) to hold the count for **b**'s and **B**'s, and so on, we will declare the array **letterCount** as

```
int letterCount[27];
```

We will ignore **letterCount[0]** and use

- **letterCount[1]** to hold the count for **a**'s and **A**'s
- **letterCount[2]** to hold the count for **b**'s and **B**'s
- **letterCount[3]** to hold the count for **c**'s and **C**'s

  etc.
- **letterCount[26]** to hold the count for **z**'s and **Z**'s

When a character **ch** is read, we will call the function **position**, as in

```
n = position(ch);
```

If **n** is greater than 0, we know that **ch** contains a letter and **n** is the position in the alphabet of that letter. For example, if **ch** contains **Y**, then **n** is 25, since **Y** is the 25th letter of the alphabet. If we add 1 to **letterCount[n]**, we are adding 1 to the count for the letter that **ch** contains. Here, if we add 1 to **letterCount[25]**, we are adding 1 to the count for **Y**. This is accomplished by

```
if (n > 0) ++letterCount[n];
```

The complete program is shown as Program P8.3 (next page). It reads data from the file **passage.txt** and sends output to the file **output.txt**. You may wish to remind yourself how this is done by looking at page 142.

Take a look at the f**printf** statement that prints one line of the output:

```
fprintf(out, "%4c %8d\n", 'a' + n - 1, letterCount[n]);
```

This prints a (lowercase) letter followed by its count. Let us see how. The code for **'a'** is 97. When **n** is 1,

```
'a' + n - 1
```

is evaluated as 97+1–1, which is 97; when 97 is printed with **%c**, it is interpreted as a character, so **a** is printed. When **n** is 2,

```
'a' + n - 1
```

is evaluated as 97+2–1, which is 98; when 98 is printed with **%c**, it is interpreted as a character, so **b** is printed. When **n** is 3,

```
'a' + n - 1
```

is evaluated as 97+3–1, which is 99; when 99 is printed with **%c**, it is interpreted as a character, so **c** is printed.. And so on. As **n** takes on the values from 1 to 26,

```
'a' + n - 1
```

will take on the codes for the letters from **'a' to 'z'**.

Program P8.3

```
#include <stdio.h>
#include <ctype.h>
main() {
  char ch;
  int n, letterCount[27], position(char);
  FILE * in = fopen("passage.txt", "r");
  FILE * out = fopen("output.txt", "w");

  for (n = 1; n <= 26; n++) letterCount[n] = 0;  //set counts to 0

  while ((ch = getc(in)) != EOF) {
    n = position(ch);
    if (n > 0) ++letterCount[n];
  }

  //print the results
  fprintf(out, "Letter  Frequency\n\n");
  for (n = 1; n <= 26; n++)
    fprintf(out, "%4c %8d\n", 'a' + n - 1, letterCount[n]);
  fclose(in);
  fclose(out);
}

int position(char ch) {
  if (isupper(ch)) return ch - 'A' + 1;
  if (islower(ch)) return ch - 'a' + 1;
  return 0;
}
```

As a matter of interest, we could have used the special form of the **for** statement described on page 124 to achieve the same result. Here it is:

```
for (ch = 'a', n = 1; n <= 26; ch++, n++)
  fprintf(out, "%4c %8d\n", ch, letterCount[n]);
```

The loop is still executed with **n** going from 1 to 26. But, in sync with **n**, it is also executed with **ch** going from **'a'** to **'z'**. Note the use of **ch++** to move on to the next character.

If **passage.txt** contains

```
The quick brown fox jumps over the lazy dog.
If the quick brown fox jumped over the lazy dog then
Why did the quick brown fox jump over the lazy dog?
```

the program sends the following output to the file **output.txt**:

```
Letter  Frequency

   a         3
   b         3
   c         3
   d         6
   e        11
   f         4
   g         3
   h         8
   i         5
   j         3
   k         3
   l         3
   m         3
   n         4
   o        12
   p         3
   q         3
   r         6
   s         1
   t         7
   u         6
   v         3
   w         4
   x         3
   y         4
   z         3
```

8.5 Making better use of fopen

When we write a statement such as

```
FILE * in = fopen("passage.txt", "r");
```

we are saying "open the file **passage.txt** for reading". It assumes that the file has been created and the appropriate data stored in it. But what if the user forgot to create the file or has put it in the wrong place (the wrong folder, for instance)? We can use **fopen** to check for this. If **fopen** cannot find the file, it returns the predefined value **NULL** (defined in **stdio.h**). We can test for this, as in:

```
FILE * in = fopen("passage.txt", "r");
if (in == NULL) {
  printf("File cannot be found\n");
  exit(1);
}
```

If **in** *is* **NULL**, the program prints a message and stops. If **in** is not **NULL**, the program proceeds as before.

The predefined function **exit** is used to terminate execution of a program and return control to the operating system. It is conventional to use **exit(0)** to indicate normal temination; other arguments are used to indicate some sort of error.

To use **exit**, we must write the directive

```
#include <stdlib.h>
```

at the head of our program, since **exit** is defined in the "standard library", **stdlib.h**. Among other things, this library contains functions for working with random numbers, functions for searching and functions for sorting.

As usual, we can assign a value to **in** and test it for **NULL**, using

```
FILE * in;
if ((in = fopen("passage.txt", "r")) == NULL) {
  printf("File cannot be found\n");
  exit(1);
}
```

Note that we cannot use **FILE * in** in the **if** condition, since a declaration is not permitted there.

Similarly, when we write

```
FILE * out = fopen("output.txt", "w");
```

we are assuming that the file **output.txt** exists or can be created. If it does not exist and cannot be created (the disk may be write-protected, for instance), **fopen** will return **NULL**. We can test for this, as in:

```
FILE * out;
if ((out = fopen("output.txt", "w")) == NULL) {
  printf("File cannot be found or created\n");
  exit(1);
}
```

So far, we have written the name of our file in the **fopen** statement. To use a different file, we would have to change the name in the statement, and we would have to re-compile the program. Our program would be more flexible if we let the user tell us the name of the file when the program is run.

We can declare **dataFile** to hold the name of the file with

```
char dataFile[40];
```

You can change 40 to any size you wish. If **in** has been declared as **FILE ***, we can prompt the user for the file name and test if everything is okay with:

```
printf("Enter name of file: ");
scanf("%s", dataFile);
if ((in = fopen(dataFile, "r")) == NULL) {
  printf("File cannot be found\n");
  exit(1);
}
```

Since we are using **%s** to read the name of the file, the name may not contain a space. If your file name *may* contain a space, you can use **gets** (page 51).

8.6 Passing an array as an argument to a function

In Chapter 7, we saw how arguments are passed to functions. In C, arguments are passed "by value". When an argument is passed "by value", a temporary location is created with the value of the argument, and this temporary location is passed to the function. The function never has access to the original argument.

We also saw on page 51 that when we use **gets(item)** to read a string into the character array **item**, the function is able to put the string into the argument **item**. This implies that the function has access to the actual argument—no copy is involved.

In C, *an array name denotes the address of its first element*. When we use an array name as an argument to a function, the address of the first element is passed to the function which, therefore, has access to the array.

We now take a closer look at some issues involved in writing functions with array arguments.

We will write a function, **sumList**, which returns the sum of the integers in an array passed to the function. For example, if the array contains

3	8	1	5	7
0	1	2	3	4

the function should return 24.

We *could* write the function header like this:

```
int sumList(int num[])
```

The array argument is written just like an array declaration but with no size specified. However, the square brackets must be present to distinguish it from a simple argument. For instance, if we had written **int num**, this would mean that **num** is an ordinary **int** variable.

You *can* specify a size, if you wish, using a constant, a symbolic constant or any integer expression which can be evaluated at the time the program is compiled. However, your program will be more flexible if you do not.

Now, suppose **score** is declared in **main** as

```
int score[10];
```

and we make the call **sumList(score)**. We can simply think that, in the function, **score** is known by the name **num**; any reference to **num** is a reference to the original argument **score**.

The more precise explanation is this: since the name **score** denotes the address of **score[0]**, *this* address is passed to the function where it becomes the address of the first element of **num**, **num[0]**. In fact, *any* address can be passed to the function where it will be taken to be the address of **num[0]**.

The function is free to to assume any size it wishes for **num**. Obviously, this can land us in trouble if we attempt to process array elements which do not exist. For this reason, it is good programming practice to 'tell' the function how many elements to process. We do this using another argument, as in:

```
int sumList(int num[], int n)
```

Now the calling function can tell **sumList** how many elements to process by supplying a value for **n**. Using the declaration of **score**, above, the call **sumList(score, 10)** tells the function to process the first 10 elements of **score** (the whole array). But, and herein lies the advantage of this approach, we could also make a call such as **sumList(score, 5)** to get the function to process the first 5 elements of score.

Using *this* function header, we write **sumList** as follows:

```
int sumList(int num[], int n) {
  int sum = 0;
  for (int j = 0; j < n; j++) sum += num[j];
  return sum;
}
```

The function 'steps through' the array, from **num[0]** to **num[n - 1]**, using a **for** loop. Each time through the loop, it adds one element to **sum**. On exit from the loop, the value of **sum** is returned as the value of the function.

The construct

```
for (j = 0; j < n; j++)
```

is typical for processing the first **n** elements of an array.

To use the function, consider the following code in **main**:

```
int sumList(int [], int), score[10];
for (int j = 0; j < 5; j++) scanf("%d", &score[j]);
printf("Sum of scores is %d\n", sumList(score, 5));
```

As usual, any function that wants to use **sumList** must declare it using a function prototype. Note the use of **int []** to indicate that the first argument is an integer array. If we wish, we could use an identifier in declaring the prototype, as in:

```
int sumList(int s[], int);
```

The actual identifier used is not important. We could replace **s** by any valid identifier.

The **for** loop reads 5 values into the array. Note that since an array *element* is just like an ordinary variable, we must write **&score[j]** in **scanf** to read a value into **score[j]**.

Suppose the values read into **score** are:

score

3	8	1	5	7
0	1	2	3	4

In **printf**, the call **sumList(score, 5)** will get the function to return the sum of the first 5 elements of **score**, that is, 24. You should gather by now that, to find the sum of the first 3 elements, say, we can write **sumList(score, 3)**.

8.7 A string is an array of characters

In Section 2.6 (page 37), we showed you how to store a string in a "character array". Now that we know a bit about arrays, we can explain how strings are actually stored.

In C, a string is stored in an *array of characters*. Each character in the string is stored in one position in the array, starting at position 0. The *null character*, **\0**, is put after the last character. This is done so that programs can tell when the end of a string has been reached. For example, the string

```
"Enter rate:"
```

is stored as follows (◊ denotes a space):

E	n	t	e	r	◊	r	a	t	e	:	\0
0	1	2	3	4	5	6	7	8	9	10	11

(Of course, inside the computer, each character is represented by its numeric code, in binary.)

The *null string*, a string with no characters, is written as **""** (two consecutive double quotes) and stored as

\0
0

The *string* constant **"a"** is stored as:

a	\0
0	1

This should not be confused with the *character* constant **'a'**, which has a numeric value (its integer code value) associated with it and can be used in arithmetic expressions. There is no numeric value associated with **"a"**.

We can compare two *characters* using the relational operators **==**, **!=**, **<**, **<=**, **>** and **>=**, but we *cannot* compare two strings, even single-character strings like **"a"** and **"h"**, this way. To compare two strings, we use a function like **strcmp** (p. 108).

Suppose we intend to store a name in the variable **name** declared as

```
char name[25];
```

If we read a string into **name** using **gets(name)** or **scanf("%s", name)**, C will put **\0** after the last character stored. (This is called *properly terminating* the string with **\0**). We must ensure that there is enough room in the array to store **\0**. So if we declare an array of size 25, we can store a string of at most 24 characters in it since we must reserve one location for **\0**.

For example, suppose **Alice Wonder** is typed in response to **gets(name)**. The array **name** will look like this (only the used positions are shown):

A	l	i	c	e	◊	W	o	n	d	e	r	\0
0	1	2	3	4	5	6	7	8	9	10	11	12

Since **name** *is* an array, we can work with individual characters, if we so desire. For instance, **name[0]** refers to the first character, **name[1]** refers to the second, and so on. In general, we can use **name[j]** to refer to the character in position **j**. And, as we have seen, we can use **name**, by itself, to refer to the string stored in the array.

The *length* of a string is defined as the number of characters in it, not counting **\0**. The predefined string function **strlen** takes an array of characters as its argument and returns the length of the string stored in it. In this example, **strlen(name)** would return 12, the number of characters in **"Alice Wonder"**. As a matter of interest, **strlen** starts counting characters from the beginning of the array until it finds **\0**.

In fact, all the standard string functions (like **strlen**, **strcpy**, **strcat** and **strcmp**) assume that the strings we give them are properly terminated with **\0**. If they are not, unpredictable results will occur. Imagine what will happen, for instance, if we give **strlen** an array of characters but there was no **\0** to indicate the end of the string. It will go on forever looking for **\0**.

When we write statements like

```
char name[25] = "Alice Wonder";
```

or

```
strcpy(name, "Alice Wonder");
```

C *will* store **\0** after the last character so we do not have to worry about it.

However, if we store characters in an array *ourselves*, we must be careful and add **\0** at the end. This is very important if we intend to use any of the standard string functions with the string or if we intend to print it with **%s**. For example, consider the code:

```
char word[10];
int n = 0;
char ch = getchar();
while (!isalpha(ch)) ch = getchar(); //read and ignore non-letters
while (isalpha(ch)) {
  word[n++] = ch;
  ch = getchar();
}
word[n] = '\0';
```

This code reads characters from the input and stores the first word found in the array **word**. Here, a word is defined as any consecutive string of alphabetic characters. The first **while** loop reads over any non-alphabetic characters. It exits when it finds the first alphabetic character. The second **while** loop is executed as long as the character read *is* alphabetic. It uses **n** to step through the positions in the array, starting at position 0. On exit from this loop, **\0** is stored in position **n**, since, at this time, **n** indicates the position *after* which the last letter was stored.

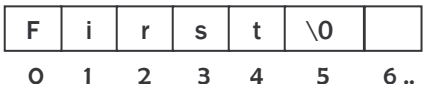
To illustrate, suppose the data was:

```
123$#%&First Knight7890
```

The first **while** loop will read characters until it reaches **F**, since **F** is the first alphabetic character in the data. The second loop will store

F in **word[0]**;
i in **word[1]**;
r in **word[2]**;
s in **word[3]**;
t in **word[4]**;

Since **n** is incremented *after* each character is stored, the value of **n** at this stage is 5. When the space after **t** is read, the **while** loop exits and **\0** is stored in **word[5]**, properly terminating the string. The array **word** will look like this:



We can now use **word** with any of the standard string functions and can print it using **%s**, as in:

```
printf("%s", word);
```

%s will stop printing characters when it reaches **\0**.

The above code is not perfect—we used it mainly for illustrative purposes. Since **word** is of size 10, we can store a maximum of 9 letters (plus **\0**) in it. If the next word is longer than 9 letters (for example, **serendipity**), the code will attempt to access **word[10]**, which does not exist, giving an "array subscript" error.

As an exercise, consider how you would handle words which are longer than what you have catered for. (Check that **n** is valid before storing anything in **word[n]**.)

To illustrate how we can work with individual characters in a string, we write a function, **numSpaces**, to count and return the number of spaces in a string **str**:

```
int numSpaces(char str[]) {
  int j = 0, spaces = 0;
  while (str[j] != '\0') {
    if (str[j] == ' ') spaces++;
    j++;
  }
  return spaces;
}
```

Consider the code:

```
char phrase[] = "How we live and how we die";
printf("Number of spaces is %d\n", numSpaces(phrase));
```

The first statement creates an array of just the right size to hold the characters of the string plus \0. Since the phrase contains 26 characters (letters and spaces), the array **phrase** will be of size 27, with **phrase[0]** containing **H**, **phrase[25]** containing **e** and **phrase[26]** containing \0.

In **printf**, the call **numSpaces(phrase)** will transfer control to the function, where **phrase** will be known as **str**. In the function, the **while** loop will step through the array until it reaches \0. For each character, it will check if it is a space. If it is, 1 is added to **spaces**. On exit from the loop, the value of **spaces** is returned as the value of the function. For the sample phrase, the value returned will be 6.

As a matter of interest, the body of the **while** loop could be written as:

```
if (str[j++] == ' ') spaces++;
```

Here, **j** is incremented *after* we test if **str[j]** contains a space.

Exercises: (a) Write a function to return the number of digits in a string **str**.

(b) Write a function to return how many vowels there are in a string **str**. Hint: it would be useful to write a function **isVowel** which, given a character **ch**, returns **1** if **ch** is a vowel and **0** if it is not.

As another example, we write code to reverse the characters in a string **str**. For example, if **str** contains **lived**, we must change it to **devil**. To illustrate how the code will work, we picture **str** as (\0 is not shown)

l	i	v	e	d
0	1	2	3	4

We will first exchange **str[0]**, **l**, and **str[4]**, **d**, giving

Next, we will exchange **str[1]**, **i**, and **str[3]**, **e**, giving

str[2] is already in place (the middle letter does not move), so there is nothing more to do and the method ends with **str** reversed.

It appears that we will need two variables: one will take on subscript values starting from 0 and increasing, while the other will take on subscript values starting from **length(str) – 1** and decreasing. We will call them **lo** and **hi**. Initially, we will set **lo** to 0 and **hi** to **length(str) – 1**.

The basic idea of the algorithm is as follows:

1. set lo to 0
2. set hi to length(str) - 1
3. exchange the characters in positions lo and hi
4. add 1 to lo
5. subtract 1 from hi
6. repeat from step 3

When do we stop? Well, we can stop when there are no more characters to exchange. This will happen when **lo** becomes greater than or equal to **hi**. Or, put another way, we must keep exchanging characters as long as **lo** is less than **hi**. We can now write the algorithm as follows:

```
set lo to 0
set hi to length(str) - 1
while lo < hi do
  exchange the characters in positions lo and hi
  add 1 to lo
  subtract 1 from hi
endwhile
```

In this form, it is easily converted to C as follows (assume **c** is **char**):

```
lo = 0;
hi = strlen(str) - 1;
while (lo < hi) do begin
  c = str[lo];
  str[lo] = str[hi];
  str[hi] = c;
  lo++;
  hi--;
}
```

However, we can use the expressive power of the **for** statement to write this more concisely and, perhaps, more readable, as:

```
for (lo = 0, hi = strlen(str) - 1; lo < hi; lo++, hi--) {
  c = str[lo];
  str[lo] = str[hi];
  str[hi] = c;
}
```

Swapping two characters in a string is something we may want to do from time to time. It would be convenient to write a function (**swap**, say) to do this task. When we call **swap**, we will give it the string and the subscripts of the characters we want to exchange. For example, if **word** is a **char** array, the call

```
swap(word, i, j);
```

will exchange characters **word[i]** and **word[j]**. Since **word** *is* an array, the original array (not a copy) is passed to **swap**. When the function swaps two characters, it is swapping them in the actual argument, **word**.

The function can be written as:

```
void swap(char str[], int i, int j) {
  char c = str[i];
  str[i] = str[j];
  str[j] = c;
}
```

In the function, the actual argument (**word**, say) is known by the name **str**.

Using **swap**, we can reverse the characters with another function, **reverse**, written as:

```
void reverse(char str[]) {
  void swap(char [], int, int);
  int lo, hi;
  for (lo = 0, hi = strlen(str) - 1; lo < hi; lo++, hi--)
    swap(str, lo, hi);
}
```

Since **reverse** uses **swap**, we must declare the prototype for **swap** in **reverse**. Note, again, that the prototype is similar to the function header, except that we omit the variable names. However, if you wish, you may include the names—any names will do.

Using these functions, we write Program P8.4 (next page) which reads a string, reverses it and prints it.

Program P8.4

```
#include <stdio.h>
#include <string.h>
main() {
   char sample[100];
   void reverse(char s[]);
   printf("Type some data and I will reverse it\n");
   gets(sample);
   reverse(sample);
   printf("%s\n", sample);
}

void reverse(char str[]) {
   void swap(char [], int, int);
   int lo, hi;
   for (lo = 0, hi = strlen(str) - 1; lo < hi; lo++, hi--)
      swap(str, lo, hi);
}

void swap(char str[], int i, int j) {
   char c = str[i];
   str[i] = str[j];
   str[j] = c;
}
```

The following is a sample run:

```
Type some data and I will reverse it
Once upon a time
emit a nopu ecnO
```

Reversing a string may not seem too important in its own right but there are times when we need to reverse the elements of an array. For example, we may have a list of student marks stored in an array and sorted in ascending order, like this:

32	45	59	67	81
0	1	2	3	4

If we want the marks in descending order, all we have to do is reverse the array:

81	67	59	45	32
0	1	2	3	4

8.8 Example – palindrome

Consider the problem of determining if a given string is a *palindrome* (the same when spelt forwards or backwards). Examples of palindromes (ignoring case, punctuation and spaces) are:

civic
Racecar
Madam, I'm Adam.
A man, a plan, a canal, Panama.

If all the letters were of the same case (upper or lower) and the string (**word**, say) contained no spaces or punctuation marks, we *could* solve the problem as follows:

```
assign word to another string, temp
reverse the letters in temp
if temp = word then word is a palindrome
else word is not a palindrome
```

In other words, if the reverse of a word is the same as the word, it is a palindrome. Sounds logical and correct. However, it is not efficient. Let us see why.

Suppose the word was **thermostat**. This method would reverse **thermostat** to get **tatsomreht**. Comparing the two tells us that **thermostat** is not a palindrome. But we can get the answer more quickly as follows:

```
compare the first and last letters, t and t
they are the same, so
compare the second and second to last letters, h and a
these are different so the word is not a palindrome
```

We will write a function called **palindrome** which, given a string **word**, returns **1** if **word** is a palindrome and **0** if it is not. For the moment, we will assume that **word** is all uppercase or lowercase and does not contain spaces or punctuation. The function will be based on the following idea:

```
compare the first and last letters
if they are different, the string is not a palindrome
if they are the same, compare the second and second to last letters
if they are different, the string is not a palindrome
if they are the same, compare the third and third to last letters
```

and so on; we continue until we find a non-matching pair (and it's not a palindrome) or there are no more pairs to compare (and it is a palindrome). We can express this logic in pseudocode as follows:

```
set lo to 0
set hi to length(word) - 1
while lo < hi do //while there are more pairs to compare
  if word[lo] != word[hi] then return 0 // not a palindrome
  //the letters match, move on to the next pair
  lo = lo + 1
  hi = hi - 1
endwhile
return 1 // all pairs match, it is a palindrome
```

The **while** loop compares pairs of letters; if it finds a non-matching pair, it immediately returns 0. If all pairs match, it will exit in the normal way when **lo** is no longer less than **hi**. In this case, it returns 1.

The function **palindrome** is shown in Program P8.5 which tests it by reading several words and printing whether or not each is a palindrome.

Program P8.5

```
#include <stdio.h>
#include <string.h>
main() {
  char aWord[100];
  int palindrome(char str[]);
  printf("Type a word. (To stop, press 'Enter' only): ");
  gets(aWord);
  while (strcmp(aWord, "") != 0) {
    if (palindrome(aWord)) printf("is a palindrome\n");
    else printf("is not a palindrome\n");
    printf("Type a word. (To stop, press 'Enter' only): ");
    gets(aWord);
  }
}

int palindrome(char word[]) {
  int lo = 0;
  int hi = strlen(word) - 1;
  while (lo < hi)
    if (word[lo++] != word[hi--]) return 0;
  return 1;
}
```

In the function, we use the single statement

```
if (word[lo++] != word[hi--]) return 0;
```

to express all the logic of the body of the **while** loop in the above algorithm. Since we use **++** and **--** as suffixes, **lo** and **hi** are changed *after* **word[lo]** is compared with **word[hi]**. We could, of course, have expressed it as:

```
if (word[lo] != word[hi]) return 0;
lo++;
hi--;
```

The program prompts the user to type a word and tells her if it is a palindrome. It then prompts for another word. To stop, the user must press "Enter" only. When she does this, the empty string is stored in **aWord**. The **while** condition checks for this by comparing **aWord** with **""** (two consecutive double quotes denote the empty string). The following is a sample run of Program P8.5:

```
Type a word. (To stop, press "Enter" only): racecar
is a palindrome
Type a word. (To stop, press "Enter" only): race car
is not a palindrome
Type a word. (To stop, press "Enter" only): Racecar
is not a palindrome
Type a word. (To stop, press "Enter" only): DEIFIED
is a palindrome
Type a word. (To stop, press "Enter" only):
```

Note that **race car** is not a palindrome because **'e'** is not the same as **' '** and **Racecar** is not a palindrome because **'R'** is not the same as **'r'**. We will fix this shortly.

A better palindrome function

The function we wrote works for one-word palindromes with all uppercase or all lowercase letters. We now tackle the more difficult problem of checking words or phrases which may contain uppercase letters, lowercase letters, spaces and punctuation marks. To illustrate our approach, consider the phrase:

```
Madam, I'm Adam
```

We will convert all the letters to one case (lower, say) and remove all spaces and non-letters, giving

```
madamimadam
```

We can now use the function we wrote above to test if *this* is a palindrome.

Let us write a function **lettersOnlyLower** which, given a string **phrase**, converts all letters to lowercase and removes all spaces and non-letters. The function stores the converted string in the second argument. Here it is:

```
void lettersOnlyLower(char phrase[], char word[]) {
  int j = 0, n = 0;
  char c;
  while ((c = phrase[j++]) != '\0')
    if (isalpha(c))  word[n++] = tolower(c);
  word[n] = '\0';
}
```

Comments on the function lettersOnlyLower

- **j** is used to index the given phrase, stored in **phrase**;
- **n** is used to index the converted phrase, stored in **word**;
- the **while** loop looks at each character of **phrase**, in turn. If it is a letter, it is converted to lowercase using the predefined function **tolower** and stored in the next position in **word**; to use **tolower**, your program must be preceded by the directive

  ```
  #include <ctype.h>
  ```

- on exit from the **while**, **word** is properly terminated with **\0**.

Putting everything together, we get Program P8.6 (next page) which tests our new function, **letterOnlyLower**. The program prompts the user for a phrase and tells her whether or not it is a palindrome. We also print the converted phrase to show you how the function works.

A sample run is:

```
Type a phrase. (To stop, press "Enter" only): Madam I'm Adam
Converted to: madamimadam
is a palindrome
Type a phrase. (To stop, press "Enter" only): Flo, gin is a sin. I golf.
Converted to: floginisasinigolf
is a palindrome
Type a phrase. (To stop, press "Enter" only): Never odd or even.
Converted to: neveroddoreven
is a palindrome
Type a phrase. (To stop, press "Enter" only): Thermostat
Converted to: thermostat
is not a palindrome
Type a phrase. (To stop, press "Enter" only): Pull up if I pull up.
Converted to: pullupifipullup
is a palindrome
Type a phrase. (To stop, press "Enter" only):
```

Program P8.6

```
#include <stdio.h>
#include <string.h>
#include <ctype.h>
main() {
  char aPhrase[100], aWord[100];
  void lettersOnlyLower(char p[], char w[]);
  int palindrome(char str[]);
  printf("Type a phrase. (To stop, press 'Enter' only): ");
  gets(aPhrase);
  while (strcmp(aPhrase, "") != 0) {
    lettersOnlyLower(aPhrase, aWord);
    printf("Converted to: %s\n", aWord);
    if (palindrome(aWord)) printf("is a palindrome\n");
    else printf("is not a palindrome\n");
    printf("Type a word. (To stop, press 'Enter' only): ");
    gets(aPhrase);
  }
}

void lettersOnlyLower(char phrase[], char word[]) {
  int j = 0, n = 0;
  char c;
  while ((c = phrase[j++]) != '\0')
    if (isalpha(c))  word[n++] = tolower(c);
  word[n] = '\0';
}

int palindrome(char word[]) {
  int lo = 0;
  int hi = strlen(word) - 1;
  while (lo < hi)
    if (word[lo++] != word[hi--]) return 0;
  return 1;
}
```

8.9 Array of strings – name of the day revisited

In Program P7.4 (page 161), we wrote a function **printDay** which printed the name of a day, given the number of the day. We will now write a function **nameOfDay** which will be given two arguments: the first is the number of a day and the second is a character array. The function will store, in the array, the *name* of the day corresponding to the number of the day. For example, the call

```
nameOfDay(6, dayName);
```

will store **Friday** in **dayName**, assuming **dayName** is a character array.

We show how to write **nameOfDay** using an array to store the names of the days. Suppose we have an array **day** as follows (**day[0]** is not used and is not shown):

If **d** contains a value from 1 to 7, then **day[d]** contains the name of the day corresponding to **d**. For instance, if **d** is 3, **day[d]** contains **Tuesday**. But how can we store the names of the days in an array? What kind of array would we need?

We will need an array where each element can hold a string—an array of strings. But a string itself is stored in an array of characters. So we need an array of "array of characters"—we need a two-dimensional array. Consider the declaration

```
char day[8][10];
```

We can think of **day** as having 8 rows and 10 columns. If we store the name of a day in each row, then we can store 8 names. *Each* name is stored in an array of 10 characters. The rows are numbered from 0 to 7 and the columns are numbered from 0 to 9. As hinted in the above diagram, we will not use row 0. We will store the names in rows 1 to 7. If we store the names of the days in this array, it will look like this (we put the null string **""** in **day[0]**):

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	\0									
1	S	u	n	d	a	y	\0			
2	M	o	n	d	a	y	\0			
3	T	u	e	s	d	a	y	\0		
4	W	e	d	n	e	s	d	a	y	\0
5	T	h	u	r	s	d	a	y	\0	
6	F	r	i	d	a	y	\0			
7	S	a	t	u	r	d	a	y	\0	

C allows us to refer to the **j**th row with **day[j]**. If we need to, we can use **day[j][k]** to refer to the character in row **j** and column **k**. For example, **day[3][2]** is **e** and **day[7][4]** is **r**.

We can declare the array **day** and initialize it with the names of the days using:

```
char day[8][10] = {"", "Sunday", "Monday", "Tuesday", "Wednesday",
                   "Thursday", "Friday", "Saturday"};
```

This declaration will create the array shown on the previous page. The strings to be placed in the array are enclosed by **{** and **}** and separated by commas with no comma after the last one. The first string, the null string, is placed in **day[0]**, the second in **day[1]**, the third in **day[2]**, and so on.

The complete function, **nameOfDay**, is shown in Program P8.7 in which **main** is used simply to test the function.

Program P8.7

```
#include <stdio.h>
#include <string.h>
main() {
  void nameOfDay(int, char[]);
  int n;
  char dayName[12];
  printf("Enter a day from 1 to 7: ");
  scanf("%d", &n);
  nameOfDay(n, dayName);
  printf("%s\n", dayName);
}

void nameOfDay(int n, char name[]) {
  char day[8][10] = {"", "Sunday", "Monday", "Tuesday", "Wednesday",
                     "Thursday", "Friday", "Saturday"};
  if (n < 1 || n > 7) strcpy(name, "Invalid day");
  else strcpy(name, day[n]);
}
```

In the function, the statement

```
if (n < 1 || n > 7) strcpy(name, "Invalid day");
else strcpy(name, day[n]);
```

checks the value of **n**; if it is not a value from 1 to 7, the function stores **Invalid day** in **name**. If it *is* a valid day number, it stores the value of **day[n]** in **name**. For example, if **n** is 6, the function stores **day[6]**, that is, **Friday**, in **name**.

In **main**, **dayName** is declared to be of size 12 since it needs to hold the string **"Invalid day"** if the day number is invalid.

8.10 A flexible getString function

So far, we have used the format specification **%s** to read a string containing no whitespace characters and the function **gets** to read a string up to the end-of-line. However, neither of these allows us to read a string delimited by double quotes, for instance. For example, if we had data in the following format:

```
"Denise Richards" "Clerical Assistant"
```

we would not be able to use **%s** or **gets** to read this data easily.

We will write a function, **getString**, which lets us read a string enclosed within 'delimiter' characters. For example, we could specify a string as **$John Smith$** or **"John Smith"**. This is a very flexible way of specifying a string. *Each* string can be specified with its own delimiters which could be different for the next string. It is particularly useful for specifying strings which may include special characters such as the double quotes without having to use an escape sequenc like \".

For instance, in order to to specify the string:

```
"Don't move!" he commanded.
```

in C, we must write:

```
"\"Don't move!\" he commanded."
```

With **getString**, this string could be supplied as

```
$"Don't move!" he commanded.$
```

or

```
%"Don't move!" he commanded.%
```

or using *any* other character as a delimiter, provided it is not one of the characters in the string. We could even use:

```
7"Don't move!" he commanded."7
```

but would normally use special characters like **"**, **$**, **%** or **#** as delimiters.

We will write **getString** with two parameters: a file designated by **in** and a character array **str**. The function will read the next string from **in** and store it in **str**.

The function assumes that the first non-whitespace character met (**delim**, say) is the delimiter. Characters are read and stored until **delim** is met again, indicating the end of the string. The delimiter characters are not stored since they are not part of the string.

Suppose we have the following declarations in **main**, say:

```
FILE * input = fopen("quizdata.txt", "r");
char country[50];
```

and the file **quizdata.txt** contains strings delimited as described above. We would be able to read the next string from the file and store it in **country** with:

```
getString(input, country);
```

It is up to us to ensure that **country** is big enough to hold the next string. If not, the program may crash or nonsense results will occur.

Here is **getString**:

```
void getString(FILE * in, char str[]) {
//stores, in str, the next string within delimiters
// the first non-whitespace character is the delimiter
// the string is read from the file 'in'

  char ch, delim;
  int n = 0;
  str[0] = '\0';
  // read over white space
  while (isspace(ch = getc(in))) ; //empty while body
  if (ch == EOF) return;

  delim = ch;
  while (((ch = getc(in)) != delim) && (ch != EOF))
    str[n++] = ch;
  str[n] = '\0';
} // end getString
```

Comments on getString

- The predefined function **isspace** returns **1** (true) if its **char** argument is a space, tab or newline character and **0** (false), otherwise.
- If **getString** encounters end-of-file before finding a non-whitespace character (the delimiter), the empty string is returned in **str**. Otherwise, it builds the string by reading one character at a time; the string is terminated by the next occurrence of the delimiter or end-of-file, whichever comes first.
- We can read a string from the standard input (the keyboard) by calling **getString** with **stdin** as the first argument.

8.11 A Geography quiz program

Let us write a program which quizzes a user on countries and their capitals. The program will illustrate some useful programming concepts like reading from the keyboard **and** a file and being very flexible in terms of user input. The following is a sample run of the program, indicating how we want the finished program to work. The user is given two tries at a question. If she gets it wrong both times, the program tells her the correct answer.

```
What is the capital of Trinidad? Tobago
Wrong. Try again.
What is the capital of Trinidad? Port of Spain
Correct!

What is the capital of Jamaica? Kingston
Correct!

What is the capital of Grenada? Georgetown
Wrong. Try again.
What is the capital of Grenada? Castries
Wrong. Answer is St. George's
```

We will store the names of the countries and their capitals in a file (**quizdata.txt**, say). For each country, we will store its name, its capital and a special string consisting only of the letters in the capital, all converted to uppercase. This last string will be used to enable users to type their answers with a lot of flexibility. It is not absolutely necessary to store this last string but it will enable us to write a more efficient program. The string **"*"** is used to indicate the end of the data. The following shows some sample data:

```
"Trinidad"  "Port of Spain"  "PORTOFSPAIN"
"Jamaica"  "Kingston"  "KINGSTON"
"Grenada"  "St. George's"  "STGEORGES"
"*"
```

We show 3 strings per line but this is not necessary. The only requirement is that they are supplied in the right *order*. If you wish, you can have 1 string per line or 6 strings per line or different numbers of strings per line. Also, you can use any character to delimit a string, provided it is not a character in the string. And you can use different delimiters for different strings. It is perfectly okay to supply the above data as:

```
"Trinidad"  $Port of Spain$  *PORTOFSPAIN*
%Jamaica%  "Kingston"  &KINGSTON&
$Grenada$  %St. George's%  ^STGEORGES^
#*#
```

We can do this because of the versatility of **getString**. We will use **getString** to read the (delimited) strings from the file and **gets** to get the user's answers typed at the keyboard.

Suppose a country's data are read into the variables **country**, **capital** and **CAPITAL**, respectively. (Remember that **capital** is a different variable from **CAPITAL**). When the user types an answer (**answer**, say), it must be compared with **capital**. If we use a straightforward comparison like

```
if (strcmp(answer, capital) == 0) ...
```

to check if **answer** is the same as **capital**, then answers like **"Portof Spain"**, **"port of spain"**, **" Port ofSpain"** and **"st georges"** would all be considered wrong. If we want these answers to be correct (and we probably should) we must convert all user answers to a common format before comparing.

We take the view that as long as all the letters are there, in the correct order, regardless of case, the answer is considered correct. When the user types an answer, we ignore spaces and punctuation and convert *the letters only* to uppercase. This is then compared with **CAPITAL**. For example, the answers above would be converted to **"PORTOFSPAIN"** and **"STGEORGES"** and would elicit a **"Correct!"** response.

In the palindrome program (page 207), we wrote a function **lettersOnlyLower** which kept the letters only from a string and converted them to lowercase. Here, we want the same function but we convert to uppercase instead. We call the function **lettersOnlyUpper**. The code is identical to **lettersOnlyLower** except that **tolower** is replaced by **toupper**. Our test for correctness now becomes:

```
lettersOnlyUpper(answer, ANSWER);
if (strcmp(ANSWER, CAPITAL) == 0) printf("Correct!\n");
```

All the details are captured in Program P8.8.

As mentioned earlier, it is not absolutely necessary to store **CAPITAL** in the file. We can store **country** and **capital** only, and when these are read, convert **capital** with

```
lettersOnlyUpper(capital, CAPITAL);
```

Program P8.8

```
#include <stdio.h>
#include <string.h>
#include <ctype.h>
#include <stdlib.h>
#define MaxLength 50
main() {
  void getString(FILE *, char[]);
  void askOneQuestion(char[], char[], char[]);
  char EndOfData[] = "*", country[MaxLength+1] ;
  char capital[MaxLength+1], CAPITAL[MaxLength+1];
  FILE * in = fopen("quizdata.txt", "r");
  if (in == NULL){
    printf("Cannot find file\n");
   exit(1);
  }
  getString(in, country);
  while (strcmp(country, EndOfData) != 0) {
    getString(in, capital);
    getString(in, CAPITAL);
    askOneQuestion(country, capital, CAPITAL);
    getString(in, country);
  }
} // end main
```

```
void askOneQuestion(char country[], char capital[], char CAPITAL[]) {
  void lettersOnlyUpper(char [], char[]);
  char answer[MaxLength+1], ANSWER[MaxLength+1];

  printf("\nWhat is the capital of %s?", country);
  gets(answer);
  lettersOnlyUpper(answer, ANSWER);
  if (strcmp(ANSWER, CAPITAL) == 0) printf("Correct!\n");
  else {
    printf("Wrong. Try again\n");
    printf("\nWhat is the capital of %s?", country);
   gets(answer);
   lettersOnlyUpper(answer, ANSWER);
   if (strcmp(ANSWER, CAPITAL) == 0) printf("Correct!\n");
    else printf("Wrong. Answer is %s\n", capital);
  }
} // end askOneQuestion

void lettersOnlyUpper(char word[], char WORD[]) {
// stores the letters in word (converted to uppercase) in WORD
  int j = 0, n = 0;
  char c;
  while ((c = word[j++]) != '\0')
    if (isalpha(c)) WORD[n++] = toupper(c);
  WORD[n] = '\0';
} // end lettersOnlyUpper

// getString can go here
```

You can use the idea of this program to write many similar ones. On the Geography theme, you can ask about mountains and heights, rivers and lengths, countries and population, countries and prime ministers, and so on. For a different application, you can use it to drill a user in English-Spanish (or any other combination of languages) vocabulary. Your questions could take the form:

What is the Spanish word for water?

or, if you prefer,

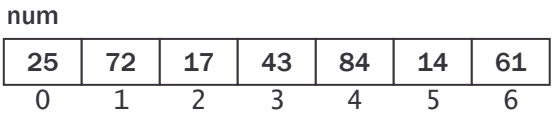
What is the English word for agua?

Better yet, let the user choose whether she is given English or Spanish words.

You can ask about books and authors, songs and performers, movies and stars. As an exercise, think of five other areas in which the idea of this program can be used to quiz a user.

8.12 Finding the largest number in an array

Let us consider the problem of finding the largest of a set of values stored in an array. The *principle* of finding the largest is the same as we discussed in Section 5.5. Suppose the integer array **num** contains the following values:



We can easily see that the largest number is 84 and that it is in location 4. But how does a program determine this? One approach is as follows:

- Assume that the first element (the one in position 0) is the largest; we do this by setting **big** to 0. As we step through the array, we will use **big** to hold the *position* of the largest number encountered so far and **num[big]** to refer to the actual number.
- Next, starting at position 1, we look at the number in each successive position, up to 6, and compare the number with the one in position **big**.
- The first time, we compare **num[1]** with **num[0]**; since **num[1]**, 72, is larger than **num[0]**, 25, we update **big** to 1. This means that the largest number so far is in position 1.
- Next, we compare **num[2]**, 17, with **num[big]** (that is, **num[1]**), 72; since **num[2]** is smaller than **num[1]**, we go on to the next number, leaving **big** at 1.
- Next, we compare **num[3]**, 43, with **num[big]** (that is, **num[1]**), 72; since **num[3]** is smaller than **num[1]**, we go on to the next number, leaving **big** at 1.
- Next, we compare **num[4]**, 84, with **num[big]** (that is, **num[1]**), 72; since **num[4]** is larger than **num[1]**, we update **big** to 4. This means that the largest number so far is in position 4.
- Next, we compare **num[5]**, 14, with **num[big]**(that is, **num[4]**), 84; since **num[5]** is smaller than **num[4]**, we go on to the next number, leaving **big** at 4.
- Next, we compare **num[6]**, 61, with **num[big]**(that is, **num[4]**), 84; since **num[6]** is smaller than **num[4]**, we go on to the next number, leaving **big** at 4.
- Since there is no next number, the process ends with the value of **big** being 4, the *position* of the largest number. The actual number is denoted by **num[big]**; since **big** is 4, this is **num[4]**, which is 84.

We can express the process just described by the following pseudocode:

```
big = 0
for j = 1 to 6
  if num[j] > num[big] then big = j
endfor
print "Largest is ", num[big], " in position ", big
```

We will now write a function, **getLargest**, to find the largest value in an array. To be general, we will specify which *portion* of the array to search for the value. This is important since, most times, we declare an array to be of some maximum size (100, say) but do not always put 100 values in the array.

When we *declare* the array to be of size 100, we are *catering* for 100 values. But, at any time, the array may have less than this amount. We use another variable (**n**, say) to tell us how many values are currently stored in the array. For example, if **n** is 36, it means that values are stored in elements 0 to 35 of the array.

So when we are finding the largest, we must specify which elements of the array to search. We will write the function such that it takes three arguments—the array **num**, and two integers **lo** and **hi**—and returns the *position* of the largest number from **num[lo]** to **num[hi]**, inclusive. It is up to the caller to ensure that **lo** and **hi** are within the range of subscripts declared for the array. For instance, the call

- **getLargest(score, 0, 6)** will return the position of the largest number from **score[0]** to **score[6]**; and the call
- **getLargest(mark, 10, 20)** will return the position of the largest number from **mark[10]** to **mark[20]**.

Here is the function, **getLargest**:

```
int getLargest(int num[], int lo, int hi) {
  int big = lo;
  for (int j = lo + 1; j <= hi; j++)
    if (num[j] > num[big]) big = j;
  return big;
}
```

The function assumes the largest number is in position **lo**, the first one, by setting **big** to **lo**. In turn, it compares the numbers in locations **lo + 1** up to **hi** with the one in location **big**. If a bigger one is found, **big** is updated to *its* location.

8.13 Finding the smallest number in an array

The function, **getLargest**, could be easily modified to find the *smallest* value in an array. Simply change **big** to **small**, say, and replace **>** by **<**, giving:

```
int getSmallest(int num[], int lo, int hi) {
  int small = lo;
  for (int j = lo + 1; j <= hi; j++)
    if (num[j] < num[small]) small = j;
  return small;
}
```

This function returns the location of the smallest element from **num[lo]** to **num[hi]**, inclusive. On page 227, we will show you how to use this function to arrange a set of numbers in ascending order.

We have shown how to find the largest and smallest values in an integer array. The procedure is exactly the same for arrays of other types such as **double**, **char** or **float**. The only change which has to be made is in the declaration of the arrays. Keep in mind that when we compare two characters, the 'larger' one is the one with the higher numeric code.

8.14 Example – a voting problem

We now illustrate how to use some of the ideas just discussed to solve the following problem.

Problem: In an election, there are seven candidates. Each voter is allowed one vote for the candidate of his/her choice. The vote is recorded as a number from 1 to 7. The number of voters is unknown beforehand but the votes are terminated by a vote of 0. Any vote which is not a number from 1 to 7 is an invalid (spoilt) vote. A file, **votes.txt**, contains the names of the candidates. The first name is considered as candidate 1, the second as candidate 2, and so on. The names are followed by the votes. Write a program to read the data and evaluate the results of the election. Print all output to the file, **results.txt**.

Your output should specify the total number of votes, the number of valid votes and the number of spoilt votes. This is followed by the votes obtained by each candidate and the winner(s) of the election.

Given the following data:

```
Victor Taylor
Denise Duncan
Kamal Ramdhan
Michael Ali
Anisa Sawh
Carol Khan
Gary Owen

3 1 2 5 4 3 5 3 5 3 2 8 1 6 7 7 3 5
6 9 3 4 7 1 2 4 5 5 1 4 0
```

your program should send the following output to **results.txt**:

```
Invalid vote: 8
Invalid vote: 9

Number of voters: 30
Number of valid votes: 28
Number of spoilt votes: 2
```

```
Candidate       Score

Victor Taylor     4
Denise Duncan     3
Kamal Ramdhan     6
Michael Ali       4
Anisa Sawh        6
Carol Khan        2
Gary Owen         3

The winner(s):
Kamal Ramdhan
Anisa Sawh
```

We need to store the names of the 7 candidates and the votes obtained by each. We will use an **int** array for the votes. In order to work naturally with candidates 1 to 7, we will write the declaration

```
int vote[8];
```

and use **vote[1]** to **vote[7]** for counting the votes for the candidates; **vote[j]** will hold the count for candidate **j**. We will not use **vote[0]**.

But what kind of array can we use for the names, since a name itself is stored in a **char** array? We will need an "array of arrays"—a two-dimensional array. Consider the declaration

```
char name[8][15];
```

We can think of **name** as having 8 rows and 15 columns. If we store one name in each row, then we can store 8 names. *Each* name is stored in an array of 15 characters. The rows are numbered from 0 to 7 and the columns are numbered from 0 to 14. In our program, we will not use row 0. We will store the names in rows 1 to 7. If we store the sample names in this array, it will look like this:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0															
1	V	i	c	t	o	r		T	a	y	l	o	r	\0	
2	D	e	n	i	s	e		D	u	n	c	a	n	\0	
3	K	a	m	a	l		R	a	m	d	h	a	n	\0	
4	M	i	c	h	a	e	l		A	l	i	\0			
5	A	n	i	s	a		S	a	w	h	\0				
6	C	a	r	o	l		K	h	a	n	\0				
7	G	a	r	y		O	w	e	n	\0					

To cater for longer names, we will use the declaration

```
char name[8][31];
```

to store the names of the candidates. We will store the name of candidate **j** in **name[j]**; **name[0]** will not be used.

To make the program flexible, we will define symbolic constants with:

```
#define MaxCandidates 7
#define MaxNameLength 30
```

and, in **main**, use the declarations

```
char name[MaxCandidates + 1][MaxNameLength + 1];
int vote[MaxCandidates + 1];
```

The **#define** directives will be placed at the top of the program, before **main**. When we do this, the symbolic constants will be available to any function that needs to use them.

In general, variables and identifiers declared *outside* of any function are said to be *external* and are available to any function that comes after it in the same file[31]. So if the declarations are placed at the top of the program, the variables and identifiers would be available to all functions in the program, assuming the entire program is stored in one file (as is the case with our programs).

One of the first things the program must do is read the names and set the vote counts to 0. We will write a function **initialize** to do this. This will also let us show you how to pass a 2-dimensional array to a function.

As explained on page 107, we will read a candidate's name in two parts (first name and last name) and then join them together to create a single name which we will store in **name[j]**. Here is the function:

```
void initialize(char name[][MaxNameLength + 1], int vote[]) {
  char lastName[MaxNameLength];
  for (int j = 1; j <= MaxCandidates; j++) {
    fscanf(in, "%s %s", name[j], lastName);
    strcat(name[j], " ");
    strcat(name[j], lastName);
    vote[j] = 0;
  }
}
```

As we see in the case of the parameter **vote**, we just need the square brackets to signify that **vote** is a one-dimensional array. However, in the case of the two-dimensional array **name**, we *must* specify the size of the *second* dimension and we *must* use a constant or an expression whose value can be determined when the program is compiled. The size of the *first* dimension may remain unspecified as

[31] The rules are a bit more complicated than this, but this will suffice for our purposes.

indicated by empty square brackets. This holds for any two-dimensional array used as a parameter.

Next, we must read and process the votes. Processing vote **v** involves checking that it is valid. If it is, we want to add 1 to the score for candidate **v**. We will read and process the votes with the following:

```
fscanf(in, "%d", &v);
while (v != 0) {
  if (v < 1 || v > MaxCandidates) {
    fprintf(out, "Invalid vote: %d\n", v);
    ++spoiltVotes;
  }
  else {
    ++vote[v];
    ++validVotes;
  }
  fscanf(in, "%d", &v);
}
```

The key statement here is

```
++vote[v];
```

This is a clever way of using the vote **v** as a subscript to add 1 for the right candidate. For example, if **v** is 3, we have a vote for candidate 3, **Kamal Ramdhan**. We wish to add 1 to the vote count for candidate 3. This count is stored in **vote[3]**. When **v** is 3, the statement becomes

```
++vote[3];
```

which adds 1 to **vote[3]**. The beauty is that the *same* statement will add 1 for *any* of the candidates, depending on the value of **v**. This illustrates some of the power of using arrays. It doesn't matter whether there are 7 candidates or 700; the one statement will work for all.

Now that we know how to read and process the votes, it remains only to determine the winner(s) and print the results. We will delegate this task to the function **printResults**.

Using the sample data, the array **vote** will contain the following values after all the votes have been tallied (remember we are not using **vote[0]**).

vote

4	3	6	4	6	2	3
1	2	3	4	5	6	7

To find the winner, we must first find the largest value in the array. To do this, we will call **getLargest** (page 216) with

```
int win = getLargest(vote, 1, MaxCandidates);
```

which will set **win** to the *subscript* of the largest value from **vote[1]** to **vote[7]** (since **MaxCandidates** is 7). In our example, **win** will be set to 3 since the largest value, 6, is in position 3. (6 is also in position 5 but we just need the largest value which we can get from either position).

Now that we know the largest value is in **vote[win]**, we can 'step through' the array, looking for those candidates with that value. This way, we will find all the candidates (1 or more) with the highest vote and declare them as winners.

The details are given in the function **printResults** shown as part of Program P8.9, our solution to the voting problem posed at the beginning of this section.

Program P8.9

```
#include <stdio.h>
#include <string.h>
#define MaxCandidates 7
#define MaxNameLength 30
FILE *in, *out;
main() {
  char name[MaxCandidates + 1][MaxNameLength + 1];
  int vote[MaxCandidates + 1];
  int v, validVotes = 0, spoiltVotes = 0;
  void initialize(char n[][MaxNameLength + 1], int v[]);
  void printResults(char n[][MaxNameLength + 1], int v[], int, int);
  in = fopen("votes.txt", "r");
  out = fopen("results.txt", "w");

  initialize(name, vote);
  fscanf(in, "%d", &v);
  while (v != 0) {
    if (v < 1 || v > MaxCandidates) {
      fprintf(out, "Invalid vote: %d\n", v);
      ++spoiltVotes;
    }
    else {
      ++vote[v];
      ++validVotes;
    }
    fscanf(in, "%d", &v);
  }

  printResults(name, vote, validVotes, spoiltVotes);

  fclose(in);
  fclose(out);
} // end main
```

```
void initialize(char name[][MaxNameLength + 1], int vote[]) {
  char lastName[MaxNameLength];
  for (int j = 1; j <= MaxCandidates; j++) {
    fscanf(in, "%s %s", name[j], lastName);
    strcat(name[j], " ");
    strcat(name[j], lastName);
    vote[j] = 0;
  }
}

int getLargest(int num[], int lo, int hi) {
  int big = lo;
  for (int j = lo + 1; j <= hi; j++)
    if (num[j] > num[big]) big = j;
  return big;
}

void printResults(char name[][MaxNameLength + 1], int vote[],
                  int valid, int spoilt) {
  int j, getLargest(int v[], int, int);
  fprintf(out, "\nNumber of voters: %d\n", valid + spoilt);
  fprintf(out, "Number of valid votes: %d\n", valid);
  fprintf(out, "Number of spoilt votes: %d\n", spoilt);
  fprintf(out, "\nCandidate      Score\n\n");

  for (j = 1; j <= MaxCandidates; j++)
    fprintf(out, "%-15s %3d\n", name[j], vote[j]);

  fprintf(out, "\nThe winner(s)\n");
  int win = getLargest(vote, 1, MaxCandidates);
  int winningVote = vote[win];
  for (j = 1; j <= MaxCandidates; j++)
    if (vote[j] == winningVote) fprintf(out, "%s\n", name[j]);
} //printResults
```

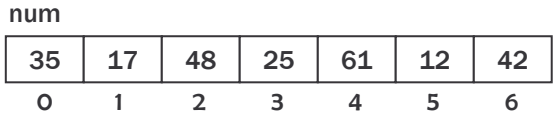
8.15 Searching an array - sequential search

In many cases, an array is used for storing a list of information. Having stored the information, it may be required to find a given item in the list. For example, an array may be used to store a list of the names of 50 people. It may then be required to find the position in the list at which a given name (**Pamela**, say) is stored.

We need to develop a technique for searching the elements of an array for a given one. Since it is possible that the given item is not in the array, our technique must also be able to determine this. The *technique* for searching for an item is the same

regardless of the *type* of elements in the array. We will use an integer array to illustrate the technique called *sequential search*.

Consider the array **num** of 7 integers:



We wish to determine if the number 61 is stored. In search terminology, 61 is called the *search key* or, simply, the *key*. The search proceeds as follows:

- compare 61 with the 1st number, **num[0]**, which is 35; they do not match so we move on to the next number;
- compare 61 with the 2nd number, **num[1]**, which is 17; they do not match so we move on to the next number;
- compare 61 with the 3rd number, **num[2]**, which is 48; they do not match so we move on to the next number;
- compare 61 with the 4th number, **num[3]**, which is 25; they do not match so we move on to the next number;
- compare 61 with the 5th number, **num[4]**, which is 61; they match, so the search stops and we conclude that the key is in position 4.

But what if we were looking for 32? In this case, we will compare 32 with all the numbers in the array and none of them will match. We conclude that 32 is not in the array.

Assuming the array contains **n** numbers, we can express the above logic as follows:

```
for j = 0 to n - 1
  if (key == num[j]) then key found, exit the loop
endfor
if j < n then key found in position j
else key not found
```

This is a situation where we *may* want to exit the loop before we have looked at all elements in the array. On the other hand, we may have to look at all the elements before we can conclude that the key is not there.

If we find the key, we exit the loop and **j** will be less than **n**. If we exit the loop because **j** becomes **n**, then the key is not in the array.

Let us express this technique in a function **search** which, given an **int** array **num**, an integer **key**, and two integers **lo** and **hi**, searches for **key** from **num[lo]** to **num[hi]**. If found, the function returns the position in the array. If not found, it returns -1. For example, the statement

```
n = search(num, 61, 0, 6);
```

will search **num[0]** to **num[6]** for 61. It will find it in position 4 and return 4, which is stored in **n**. The call **search(num, 32, 0, 6)** will return -1 since 32 is not stored in the array. Here is the function, **search**:

```
int search(int num[], int key, int lo, int hi) {
  for (int j = lo; j <= hi; j++)
    if (key == num[j]) return j;
  return -1;
}
```

We first set **j** to **lo** to start the search from that position. The **for** loop 'steps through' the elements of the array until it finds the key or **j** passes **hi**.

To give an example of how a search may be used, consider the voting problem of the last section. After the votes have been tallied, our arrays **name** and **vote** look like this (remember we are not using **name[0]** and **vote[0]**):

	name	vote
1	Victor Taylor	4
2	Denise Duncan	3
3	Kamal Ramdhan	6
4	Michael Ali	4
5	Anisa Sawh	6
6	Carol Khan	2
7	Gary Owen	3

Suppose we want to know how many votes **Carol Khan** received. We would have to search for her name in the **name** array. When we find it (in position 6), we can retrieve her votes from **vote[6]**. In general, if a name is in position **n**, the number of votes received will be in **vote[n]**.

We can modify our **search** function to look for a name in the **name** array. Here it is:

```
//search for key from name[lo] to name[hi]
int search(char name[][MaxNameLength+1], char key[], int lo, int hi) {
  for (int j = lo; j <= hi; j++)
    if (strcmp(key, name[j]) == 0) return j;
  return -1;
}
```

Recall that we compare two strings using **strcmp**. And, in order to use a pre-defined string function, we must use the directive

```
#include <string.h>
```

at the head of our program.

We can use this function as follows:

```
n = search(name, "Carol Khan", 1, 7);
if (n > 0) printf("%s received %d vote(s)\n", name[n], vote[n]);
else printf("Name not found\n");
```

Using our sample data, search will return 6 which will be stored in **n**. Since 6 > 0, the code will print

```
Carol Khan received 2 vote(s)
```

8.16 Sorting an array - selection sort

Consider the voting program again. On page 218, we printed the results in the order in which the names were given. But suppose we want to print the results in alphabetical order by name or in order by votes received, with the winner(s) first. We would have to rearrange the names or the votes in the order we want. We say we would have to *sort* the names in *ascending* order or *sort* the votes in *descending* order.

Sorting is the process by which a set of values are arranged in ascending or descending order. There are many reasons to sort. Sometimes we sort in order to produce more readable output (for example, to produce an alphabetical listing). A teacher may need to sort her students in order by name or by average score. If we have a large set of values and we want to identify duplicates, we can do so by sorting; the repeated values will come together in the sorted list. There are many ways to sort. We will discuss a method known as *selection sort*.

Consider the following array:

num

57	48	79	65	15	33	52
0	1	2	3	4	5	6

Sorting **num** in ascending order using selection sort proceeds as follows:

1st pass

- Find the smallest number in positions 0 to 6; the smallest is 15, found in position 4.
- Interchange the numbers in positions 0 and 4. This gives us:

num

15	48	79	65	57	33	52
0	1	2	3	4	5	6

2nd pass

- Find the smallest number in positions 1 to 6; the smallest is 33, found in position 5.
- Interchange the numbers in positions 1 and 5. This gives us:

num

15	33	79	65	57	48	52
0	1	2	3	4	5	6

3rd pass

- Find the smallest number in positions 2 to 6; the smallest is 48, found in position 5.
- Interchange the numbers in positions 2 and 5. This gives us:

num

15	33	48	65	57	79	52
0	1	2	3	4	5	6

4th pass

- Find the smallest number in positions 3 to 6; the smallest is 52, found in position 6.
- Interchange the numbers in positions 3 and 6. This gives us:

num

15	33	48	52	57	79	65
0	1	2	3	4	5	6

5th pass

- Find the smallest number in positions 4 to 6; the smallest is 57, found in position 4.
- Interchange the numbers in positions 4 and 4. This gives us:

num

15	33	48	52	57	79	65
0	1	2	3	4	5	6

6th pass

- Find the smallest number in positions 5 to 6; the smallest is 65, found in position 6.
- Interchange the numbers in positions 5 and 6. This gives us:

num

15	33	48	52	57	65	79
0	1	2	3	4	5	6

and the array is now completely sorted.

If we let **j** go from 0 to 5, on each pass, we find the smallest number from positions **j** to 6. If the smallest number is in position **s**, we interchange the numbers in positions **j** and **s**. For an array of size **n**, we make **n – 1** passes. In our example, we sorted 7 numbers in 6 passes. The following is an outline of the algorithm:

```
for j = 0 to n - 2
  s = position of smallest number from num[j] to num[n-1]
  swap num[j] and num[s]
endfor
```

On page 216, we wrote a function to return the position of the smallest number in an integer array. Here it is for easy reference:

```
//find position of smallest from num[lo] to num[hi]
int getSmallest(int num[], int lo, int hi) {
  int small = lo;
  for (int j = lo + 1; j <= hi; j++)
    if (num[j] < num[small]) small = j;
  return small;
}
```

And on page 201, we wrote a function **swap** which swapped two elements in a a character array. We now re-write **swap** to swap two elements in an integer array:

```
//swap elements num[i] and num[j]
void swap(int num[], int i, int j) {
  int hold = num[i];
  num[i] = num[j];
  num[j] = hold;
}
```

With **getSmallest** and **swap**, we can code the algorithm, above, as a function **selectionSort** (next page). To emphasize that we can use any names for our parameters, we write the function to sort an integer array called **list**. To make it general, we also tell the function which *portion* of the array to sort by specifying subscripts **lo** and **hi**. Instead of the loop going from 0 to **n – 2** as in the algorithm, it now goes from **lo** to **hi – 1**, just a minor change for greater flexibility.

We write Program P8.10 to test whether **selectionSort** works properly. Only **main** is shown in the box on the next page. To complete the program, you just add the functions **selectionSort**, **getSmallest** and **swap**.

```
//sort list[lo] to list[hi] in ascending order
void selectionSort(int list[], int lo, int hi) {
   int getSmallest(int [], int, int);
   void swap(int [], int, int);
   for (int j = lo; j < hi; j++) {
      int s = getSmallest(list, j, hi);
      swap(list, j, s);
   }
}
```

The program requests up to 10 numbers (since the array is declared to be of size 10), stores them in the array **num**, calls **selectionSort**, then prints the sorted list.

Program P8.10

```
#include <stdio.h>
main() {
   void selectionSort(int [], int, int);
   int n, v, num[10];
   printf("Type up to 10 numbers followed by 0\n");
   n = 0;
   scanf("%d", &v);
   while (v != 0) {
      num[n++] = v;
      scanf("%d", &v);
   }
   //n numbers are stored from num[0] to num[n-1]
   selectionSort(num, 0, n-1);
   printf("\nThe sorted numbers are\n");
   for (v = 0; v < n; v++) printf("%d ", num[v]);
   printf("\n");
}
```

The following is a sample run of the program:

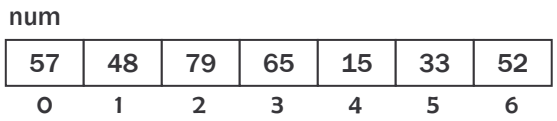
```
Type up to 10 numbers followed by 0
57 48 79 65 15 33 52 0

The sorted numbers are
15 33 48 52 57 65 79
```

Comments on Program P8.10:

The program illustrates how to read and store an unknown amount of values in an array. The program caters for up to 10 numbers but must work if fewer numbers

are supplied. We use **n** to subscript the array and to count the numbers. Initially, **n** is 0. The following describes what happens with the sample data:

- the 1st number, 57, is read; it is not 0 so we enter the **while** loop. We store 57 in **num[0]** then add 1 to **n**, making it 1; 1 number has been read and **n** is 1.
- the 2nd number, 48, is read; it is not 0 so we enter the **while** loop. We store 48 in **num[1]** then add 1 to **n**, making it 2; 2 numbers have been read and **n** is 2.
- the 3rd number, 79, is read; it is not 0 so we enter the **while** loop. We store 79 in **num[2]** then add 1 to **n**, making it 3; 3 numbers have been read and **n** is 3.
- the 4th number, 65, is read; it is not 0 so we enter the **while** loop. We store 65 in **num[3]** then add 1 to **n**, making it 4; 4 numbers have been read and **n** is 4.
- the 5th number, 15, is read; it is not 0 so we enter the **while** loop. We store 15 in **num[4]** then add 1 to **n**, making it 5; 5 numbers have been read and **n** is 5.
- the 6th number, 33, is read; it is not 0 so we enter the **while** loop. We store 33 in **num[5]** then add 1 to **n**, making it 6; 6 numbers have been read and **n** is 6.
- the 7th number, 52, is read; it is not 0 so we enter the **while** loop. We store 52 in **num[6]** then add 1 to **n**, making it 7; 7 numbers have been read and **n** is 7.
- the 8th number, 0, is read; it *is* 0 so we exit the **while** loop and the array looks like this:



At any stage, the value of **n** indicates how many numbers have been stored up to that point. At the end, **n** is 7 and 7 numbers have been stored in the array. The rest of the program can assume that **n** gives the number of values actually stored in the array.

For example, the call

```
selectionSort(num, 0, n-1);
```

is a request to sort **num[0]** to **num[n-1]** but, since **n** is 7, it is a request to sort **num[0]** to **num[6]**.

We use **v** to hold the numbers as they are read. Later, we use it as the **for** loop variable.

As written, the program will crash if the user enters more than 10 numbers before typing 0. When the 11th number is read, an attempt will be made to store it in **num[10]**, which does not exist, giving an "array subscript" error.

We can handle this by changing the **while** condition to

```
while (v != 0 && n < 10)
```

Now, if **n** reaches 10, the loop is not entered (since 10 is not less than 10) and no attempt will be made to store the 11th number. Indeed, all numbers after the 10th one will be ignored.

As usual, it is best to use a symbolic constant (**MaxNum**, say) set to 10, and use **MaxNum,** rather than the constant 10, throughout the program.

We have sorted an array in *ascending* order. We can sort **num[0]** to **num[n-1]** in *descending* order with the following algorithm:

```
for j = 0 to n - 2
  b = position of biggest number from num[j] to num[n-1]
  swap num[j] and num[b]
endfor
```

We urge you to try Exercises 16 and 17 to print the results of the voting problem (page 218) in ascending order by name and descending order by votes received.

Exercises 8

1. Explain the difference between a simple variable and an array variable.
2. Write array declarations for each of the following: (a) a floating-point array of size 25 (b) an integer array of size 50 (c) a character array of size 32.
3. What is a subscript? Name 3 ways in which we can write a subscript.
4. What values are stored in an array when it is first declared?
5. Name 2 ways in which we can store a value in an array element.
6. Write a function which, given a number from 1 to 12 and a character array, stores the name of the month in the array. For example, given 8, it stores **August** in the array. Store the empty string if the number given is not valid.
7. You have declared an array of size 500. Is it required that you store values in all elements of the array?
8. Write code to read 200 names from a file and store them in an array.
9. An array **num** is of size 100. You are given two values **i** and **j**, with $0 \le i < j \le 99$. Write code to find the average of the numbers from **num[i]** to **num[j]**.
10. Write a function which, given a string of arbitrary characters, returns the number of consonants in the string.
11. Modify the letter frequency count program (page 191) to count the number of non-letters as well. Make sure you do not count the end-of-line characters.
12. Write a function **indexOf** which, given a string **s** and a character **c**, returns the *position* of the first occurrence of **c** in **s**. If **c** is not in **s**, return **−1**. For example, **indexOf("brother", 'r')** returns 1 but **indexOf("brother", 'a')** returns -1.
13. Write a function **substring** which, given two strings **s1** and **s2**, returns the starting position of the first occurrence of **s1** in **s2**. If **s1** is not in **s2**, return **−1**. For example, **substring("mom", "thermometer")** returns 4 but **substring("dad", "thermometer")** returns **−1**.
14. Write a function which, given an array of integers and an integer **n**, reverses the first **n** elements of the array.

15. Write a function **remove** which, given a string **str** and a character **c**, removes all occurrences of **c** from **str**. For example, if **str** contains **"brother"**, **remove(str, 'r')** should change **str** to **"bothe"**.
16. In the voting problem of Section 8.14, print the results in alphabetical order by candidate name. Hint: in sorting the **name** array, when you move a name, make sure and move the corresponding item in the **vote** array.
17. In the voting problem of Section 8.14, print the results in descending order by candidate score.
18. Write a program to read names and phone numbers into two arrays. Request a name and print the person's phone number. Use at least one function.
19. Write a program to read English words and their equivalent Spanish words into two arrays. Request the user to type several English words. For each, print the equivalent Spanish word. Choose a suitable end-of-data marker. Modify the program so that the user types Spanish words instead.
20. Write a function to sort a **double** array in *ascending* order using selection sort. Do the sort by finding the *largest* number on each pass.
21. The number `27472` is said to be *palindromic* since it reads the same forwards or backwards. Write a function which, given an integer **n**, returns **1** if **n** is palindromic and **0** if it is not.
22. Write a program to find out, for a class of students, the number of families with 1, 2, 3, ... up to 8 or more children. The data consists of the number of children in each pupil's family, terminated by a `0`. (Why is `0` a good value to use?)
23. A survey of 10 pop artists is made. Each person votes for an artist by specifying the number of the artist (a value from 1 to 10). Write a program to read the names of the artists, followed by the votes, and find out which artist is the most popular. Choose a suitable end-of-data marker.
24. The *median* of a set of *n* numbers (not necessarily distinct) is obtained by arranging the numbers in order and taking the number in the middle. If *n* is odd, there is a unique middle number. If *n* is even, then the average of the two middle values is the median. Write a program to read a set of *n* positive integers (assume $n < 100$) and print their median; *n* is not given but `0` indicates the end of the data.
25. The *mode* of a set of *n* numbers is the number which appears most frequently. For example, the mode of `7 3 8 5 7 3 1 3 4 8 9` is `3`. Write a program to read a set of *n* positive integers (assume $n < 100$) and print their mode; *n* is not given but `0` indicates the end of the data.
26. A multiple-choice examination consists of twenty questions. Each question has five choices, labelled **A**, **B**, **C**, **D** and **E**. The first line of data contains the correct answers to the twenty questions in the first 20 *consecutive* character positions, for example:

    ```
    BECDCBAADEBACBAEDDBE
    ```

    Each subsequent line contains the answers for a candidate. Data on a line consists of a candidate number (an integer), followed by one or more spaces, followed by the twenty answers given by the candidate in the next twenty *consecutive* character positions. An **X** is used if a candidate did not answer a particular question. You may assume all data are valid and stored in a file **exam.dat**. A sample line is:

    ```
    4325    BECDCBAXDEBACCAEDXBE
    ```

There are at most 100 candidates. A line containing a "candidate number" 0 only indicates the end of the data.

Points for a question are awarded as follows:– correct answer: 4 points; wrong answer: -1 point; no answer: 0 points

Write a program to process the data and print a report consisting of candidate number and the total points obtained by the candidate, *in ascending order by candidate number*. At the end, print the average number of points gained by the candidates.

27. The children's game of 'count-out' is played as follows. *n* children (numbered 1 to *n*) are arranged in a circle. A sentence consisting of *m* words[32] is used to eliminate one child at a time until one child is left. Starting at child 1, the children are counted from 1 to *m* and the *m*th child is eliminated. Starting with the child after the one just eliminated, the children are again counted from 1 to *m* and the *m*th child eliminated. This is repeated until one child is left. Counting is done circularly and eliminated children are not counted. Write a program to read values for *n* (assumed <= 100) and *m* (> 0) and print the number of the last remaining child.
28. The prime numbers from 1 to 2500 can be obtained as follows. From a list of the numbers 1 to 2500, cross out all multiples of 2 (but not 2 itself). Then, find the next number (**n**, say) that is not crossed out and cross out all multiples of **n** (but not including **n**). Repeat this last step provided that **n** has not exceeded 50 (the square root of 2500). The numbers remaining in the list (except 1) are prime. Write a program which uses this method to print all primes from 1 to 2500. Store your output in a file called **primes.out**. This method is called the *Sieve of Eratosthenes*, named after the Greek mathematician, geographer and philosopher.
29. There are 500 light bulbs (numbered 1 to 500) arranged in a row. Initially, they are all OFF. Starting with bulb 2, all even numbered bulbs are turned ON. Next, starting with bulb 3, and visiting every third bulb, it is turned ON if it is OFF, and it is turned OFF if it is ON. This procedure is repeated for every fourth bulb, then every fifth bulb, and so on up to the 500th bulb. Write a program to determine which bulbs are OFF at the end of the above exercise. Is there anything special about the bulbs that are OFF? Can you explain why?
30. An array **num** contains **k** numbers in **num[0]** to **num[k-1]**, sorted in ascending order. Write a function **insertInPlace** which, given **num**, **k** and another number **x**, inserts **x** in its proper position such that **num[0]** to **num[k]** are sorted in ascending order. Assume the array has room for **x**.
31. Using **insertInPlace**, write a function called **insertionSort** to sort elements **num[0]** to **num[n-1]** of the array **num** using the following idea:

```
for j = 1 to n - 1 do
  insert num[j] among the previous numbers so that
  num[0] to num[j] are sorted
endfor
```

[32] For example, "eenie meenie mynie mo, sorry, child, you've got to go"; m = 10

Appendix A - Keywords in C

The following is a list of C keywords. Keywords are always written in lowercase.

auto	break	case	char
const	continue	default	do
double	else	enum	extern
float	for	goto	if
int	long	register	return
short	signed	sizeof	static
struct	switch	typedef	union
unsigned	void	volatile	while

Appendix B - The ASCII character set

The ASCII character set

The following are the character codes used in the ASCII character set. Codes 0 to 31, and 127, are used for control characters. Some common ones are:

0 NULL
8 backspace (BS)
10 line feed (LF)
12 form feed (FF)
13 carriage return (CR)

The characters from codes 32 to 127 are:

Dec	Binary	Char	Dec	Binary	Char	Dec	Binary	Char
32	0100000	space	64	1000000	@	96	1100000	`
33	0100001	!	65	1000001	A	97	1100001	a
34	0100010	"	66	1000010	B	98	1100010	b
35	0100011	#	67	1000011	C	99	1100011	c
36	0100100	$	68	1000100	D	100	1100100	d
37	0100101	%	69	1000101	E	101	1100101	e
38	0100110	&	70	1000110	F	102	1100110	f
39	0100111	'	71	1000111	G	103	1100111	g
40	0101000	(	72	1001000	H	104	1101000	h
41	0101001	)	73	1001001	I	105	1101001	i
42	0101010	*	74	1001010	J	106	1101010	j
43	0101011	+	75	1001011	K	107	1101011	k
44	0101100	,	76	1001100	L	108	1101100	l
45	0101101	-	77	1001101	M	109	1101101	m
46	0101110	.	78	1001110	N	110	1101110	n
47	0101111	/	79	1001111	O	111	1101111	o
48	0110000	0	80	1010000	P	112	1110000	p
49	0110001	1	81	1010001	Q	113	1110001	q
50	0110010	2	82	1010010	R	114	1110010	r
51	0110011	3	83	1010011	S	115	1110011	s
52	0110100	4	84	1010100	T	116	1110100	t
53	0110101	5	85	1010101	U	117	1110101	u
54	0110110	6	86	1010110	V	118	1110110	v
55	0110111	7	87	1010111	W	119	1110111	w
56	0111000	8	88	1011000	X	120	1111000	x
57	0111001	9	89	1011001	Y	121	1111001	y
58	0111010	:	90	1011010	Z	122	1111010	z
59	0111011	;	91	1011011	[	123	1111011	{
60	0111100	<	92	1011100	\	124	1111100	|
61	0111101	=	93	1011101	]	125	1111101	}
62	0111110	>	94	1011110	^	126	1111110	~
63	0111111	?	95	1011111	_	127	1111111	DEL

Appendix C - Representation of integers

Conversion of decimal numbers to binary

We know from ordinary arithmetic that the decimal (base 10) number 356 stands for 6 ones, 5 tens and 3 hundreds. As we go left, the value of each digit is increased by 10; we say the number is written in base 10. Also, to *write* a number in base 10, we must use the digits `0` to `9` (1 less than the base).

Similarly, to write a number in binary (base 2), we must use the digits `0` and `1`. And, as we go left, the value of each digit is increased by 2. For example, the value of the binary number `10011` is given by (reading from the right)

1 one, 1 two, 0 fours, 0 eights and 1 sixteen
i.e. 1 + 2 + 0 + 0 + 16 = 19

As another example, consider the binary number `110101`. We can work out the decimal equivalent using:

Binary digit	1	1	0	1	0	1
Value	32	16	8	4	2	1

Adding the values where the binary digits are 1's gives us

32 + 16 + 4 + 1 = 53

Thus, the decimal equivalent of `110101` is `53`.

How do we do the reverse? Given the decimal number, `43`, say, what is the binary equivalent?

One method is to write `43` as a sum of powers of 2 (1, 2, 4, 8, etc.), thus:

43 = 32 + 8 + 2 + 1

So `43` consists of: 1 one, 1 two, 0 fours, 1 eight, 0 sixteens and 1 thirty-two. Hence the binary equivalent of 43 is `101011`.

Note that we must be careful to put a 0 in those positions where a power of 2 is absent. In this example, these are the positions corresponding to 4 and 16.

Another method is to perform repeated divisions by 2 and save the remainders. The remainders, in order, form the binary equivalent from *right to left*. For example,

43/2 = 21 remainder 1
21/2 = 10 remainder 1
10/2 = 5 remainder 0
5/2 = 2 remainder 1
2/2 = 1 remainder 0
1/2 = 0 remainder 1

The remainders, from top to bottom, form the binary equivalent from right to left, thus: 101011.

Representation of integers

An integer is a whole number – positive, negative or zero – for example, 25, -16, 0, 32767, -1. We have just seen how to convert a positive integer from decimal to binary. Also, the bigger the number, the more bits we need to represent it. For instance, we needed 5 bits for 19 but 6 bits for 43.

A computer uses a fixed number of *bits* (short for binary digits) for storing integers. So we use terms such as 8-bit integers, 16-bit integers and 32-bit integers. Whatever the size, the principles remain the same; the only difference is that with more bits we can store a wider range of numbers. In order to keep things simple, we will consider 4-bit integers. The problem, therefore, is:

Using 4 bits, how can we store positive and negative integers?

The most common method for storing integers on a computer is called *two's complement*. Before we look at this method, let us say what is meant by *one's complement*.

The one's complement of a binary number is obtained by changing 1's to 0's and 0's to 1's (this is called *inverting the bits*). For example, the 4-bit one's complement of 0110 is 1001.

Note that if we were asked for the 4-bit one's complement of 11, we would need to write 11 as 0011 and *then* invert the bits, giving 1100.

Also note that it is *wrong* to simply say "the one's complement of 011"; we *must* specify how many bits are involved by saying, for instance, "the 4-bit one's complement of 011". As a matter of interest, observe that:

- the 3-bit one's complement of 011 is 100, and
- the 4-bit one's complement of 011 is 1100.

Two's complement

The two's complement of a binary number is obtained by adding 1 to its one's complement. Above, we saw that the 4-bit one's complement of 0110 is 1001. Therefore, the 4-bit two's complement of 0110 is:

```
1001  +
   1
----
1010
```

As another example, the 4-bit two's complement of 011 is 1100 + 1 = 1101.

Suppose we want to store integers on a computer using 4 bits. With 4 bits, we can have 16 different *bit patterns* - from 0000 to 1111. Therefore, we can represent 16 different integers using 4 bits. We just need to decide which integer to represent by which bit pattern.

Of the 16 bit patterns, 8 begin with 0 and 8 begin with 1. We will let those which begin with 0 represent the equivalent positive integer; for example, 0101 will represent +5. The full list is:

0000	represents	0
0001	represents	1
0010	represents	2
0011	represents	3
0100	represents	4
0101	represents	5
0110	represents	6
0111	represents	7

Note that the largest positive integer we can represent using 4 bits is 7. In general, the largest positive integer we can represent using n bits is $2^{n-1} - 1$.

Next, we need to decide which negative integers to represent by the bit patterns beginning with 1. In *two's complement representation*, we represent a negative integer by the two's complement of the bit pattern representing the corresponding positive integer. For example, to represent -5, we take the bit pattern for +5, that is, 0101, and find the two's complement, that is, 1011. So -5 is represented by 1011. Using this procedure, we find that:

-1	is represented by	1111
-2	is represented by	1110
-3	is represented by	1101
-4	is represented by	1100
-5	is represented by	1011
-6	is represented by	1010
-7	is represented by	1001

There is still one bit pattern, 1000, which has not been used. Since the 4-bit two's complement of 1000 is, indeed, 1000, we can let 1000 represent either +8 or -8. But since, in all other cases, positive numbers begin with 0 and negative numbers begin with 1, we let 1000 represent -8.

Hence, using two's complement, the largest negative number we can represent is 1 more than the largest positive number. In general, the *range* of integers we can store with n bits, using two's complement, is

$$-2^{n-1} \text{ to } +2^{n-1} - 1$$

For example, using 16 bits, the range of integers we can store is

-2^{15} to $+2^{15} - 1$, that is, -32768 to +32767

Appendix D – How to get a C compiler

There are many C compilers available for free on the Internet. Our favourite is the Tiny C compiler available at

http://www.tinycc.org

Tiny C is a blazingly fast compiler. The complete compiler with support files is about 1 megabyte. You can also obtain a copy by sending an email to nkalicharan@fsa.uwi.tt.

The following are also recommended:

- Miracle C compiler: **http://www.c-compiler.com**
- Borland Turbo C compiler: go to

  http://bdn.borland.com/museum

  Click on **Articles** if it is not already selected. A list of articles will be displayed. The two of interest are:

  Antique Software: Turbo C++ version 1.01

  Antique Software: Turbo C version 2.01

  Click on the one you prefer. You can use either one.

- You can also go to **http://www.google.com** or your favourite search engine and type **"c compiler"** in the Search Box. Many options will be made available to you. Choose the ones you prefer.

The sites listed above all come with full instructions on how to download and set up your compiler. If you have difficulty acquiring a compiler or setting up one you have downloaded, please ask your teacher for advice.

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