2 C Fundamentals

One man's constant is another man's variable.

This chapter introduces several basic concepts, including preprocessing directives, functions, variables, and statements, that we'll need in order to write even the simplest programs. Later chapters will cover these topics in much greater detail.

To start off, Section 2.1 presents a small C program and describes how to compile and link it. Section 2.2 then discusses how to generalize the program, and Section 2.3 shows how to add explanatory remarks, known as comments. Section 2.4 introduces variables, which store data that may change during the execution of a program, and Section 2.5 shows how to use the `scanf` function to read data into variables. Constants—data that won't change during program execution—can be given names, as Section 2.6 shows. Finally, Section 2.7 explains C's rules for creating names (identifiers) and Section 2.8 gives the rules for laying out a program.

2.1 Writing a Simple Program

In contrast to programs written in some languages, C programs require little "boilerplate"—a complete program can be as short as a few lines.

PROGRAM Printing a Pun

The first program in Kernighan and Ritchie's classic *The C Programming Language* is extremely short; it does nothing but write the message `hello, world`. Unlike other C authors, I won't use this program as my first example. I will, however, uphold another C tradition: the bad pun. Here's the pun:

```
To C, or not to C: that is the question.
```

The following program, which we'll name `pun.c`, displays this message each time it is run.

pun.c

```
#include <stdio.h>

int main(void)
{
  printf("To C, or not to C: that is the question.\n");
  return 0;
}
```

Section 2.2 explains the form of this program in some detail. For now, I'll just make a few brief observations. The line

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

is necessary to "include" information about C's standard I/O (input/output) library. The program's executable code goes inside `main`, which represents the "main" program. The only line inside `main` is a command to display the desired message. `printf` is a function from the standard I/O library that can produce nicely formatted output. The `\n` code tells `printf` to advance to the next line after printing the message. The line

```
return 0;
```

indicates that the program "returns" the value 0 to the operating system when it terminates.

Compiling and Linking

Despite its brevity, getting `pun.c` to run is more involved than you might expect. First, we need to create a file named `pun.c` containing the program (any text editor will do). The name of the file doesn't matter, but the `.c` extension is often required by compilers.

Next, we've got to convert the program to a form that the machine can execute. For a C program, that usually involves three steps:

- ***Preprocessing.*** The program is first given to a ***preprocessor***, which obeys commands that begin with `#` (known as ***directives***). A preprocessor is a bit like an editor; it can add things to the program and make modifications.
- ***Compiling.*** The modified program now goes to a ***compiler***, which translates it into machine instructions (***object code***). The program isn't quite ready to run yet, however.
- ***Linking.*** In the final step, a ***linker*** combines the object code produced by the compiler with any additional code needed to yield a complete executable program. This additional code includes library functions (like `printf`) that are used in the program.

Fortunately, this process is often automated, so you won't find it too onerous. In fact, the preprocessor is usually integrated with the compiler, so you probably won't even notice it at work.

The commands necessary to compile and link vary, depending on the compiler and operating system. Under UNIX, the C compiler is usually named `cc`. To compile and link the `pun.c` program, enter the following command in a terminal or command-line window:

```
% cc pun.c
```

(The `%` character is the UNIX prompt, not something that you need to enter.) Linking is automatic when using `cc`; no separate link command is necessary.

After compiling and linking the program, `cc` leaves the executable program in a file named `a.out` by default. `cc` has many options; one of them (the `-o` option) allows us to choose the name of the file containing the executable program. For example, if we want the executable version of `pun.c` to be named `pun`, we would enter the following command:

```
% cc -o pun pun.c
```

The GCC Compiler

One of the most popular C compilers is the GCC compiler, which is supplied with Linux but is available for many other platforms as well. Using this compiler is similar to using the traditional UNIX `cc` compiler. For example, to compile the `pun.c` program, we would use the following command:

```
% gcc -o pun pun.c
```

Q&A The Q&A section at the end of the chapter provides more information about GCC.

Integrated Development Environments

So far, we've assumed the use of a "command-line" compiler that's invoked by entering a command in a special window provided by the operating system. The alternative is to use an ***integrated development environment (IDE),*** a software package that allows us to edit, compile, link, execute, and even debug a program without leaving the environment. The components of an IDE are designed to work together. For example, when the compiler detects an error in a program, it can arrange for the editor to highlight the line that contains the error. There's a great deal of variation among IDEs, so I won't discuss them further in this book. However, I would recommend checking to see which IDEs are available for your platform.

2.2 The General Form of a Simple Program

Let's take a closer look at `pun.c` and see how we can generalize it a bit. Simple C programs have the form

```
directives

int main(void)
{
  statements
}
```

In this template, and in similar templates elsewhere in this book, items printed in `Courier` would appear in a C program exactly as shown; items in *italics* represent text to be supplied by the programmer.

Notice how the braces show where `main` begins and ends. C uses { and } in much the same way that some other languages use words like `begin` and `end`. This illustrates a general point about C: it relies heavily on abbreviations and special symbols, one reason that C programs are concise (or—less charitably—cryptic). **Q&A**

Even the simplest C programs rely on three key language features: directives (editing commands that modify the program prior to compilation), functions (named blocks of executable code, of which `main` is an example), and statements (commands to be performed when the program is run). We'll take a closer look at these features now.

Directives

Before a C program is compiled, it is first edited by a preprocessor. Commands intended for the preprocessor are called directives. Chapters 14 and 15 discuss directives in detail. For now, we're interested only in the `#include` directive.

The `pun.c` program begins with the line

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

This directive states that the information in `<stdio.h>` is to be "included" into the program before it is compiled. `<stdio.h>` contains information about C's standard I/O library. C has a number of ***headers*** like `<stdio.h>`; each contains information about some part of the standard library. The reason we're including `<stdio.h>` is that C, unlike some programming languages, has no built-in "read" and "write" commands. The ability to perform input and output is provided instead by functions in the standard library.

headers ➤*15.2*

Directives always begin with a # character, which distinguishes them from other items in a C program. By default, directives are one line long; there's no semicolon or other special marker at the end of a directive.

Functions

Functions are like "procedures" or "subroutines" in other programming languages—they're the building blocks from which programs are constructed. In fact, a C program is little more than a collection of functions. Functions fall into two categories: those written by the programmer and those provided as part of the C implementation. I'll refer to the latter as ***library functions***, since they belong to a "library" of functions that are supplied with the compiler.

The term "function" comes from mathematics, where a function is a rule for computing a value when given one or more arguments:

$$f(x) = x + 1$$
$$g(y, z) = y^2 - z^2$$

C uses the term "function" more loosely. In C, a function is simply a series of statements that have been grouped together and given a name. Some functions compute a value; some don't. A function that computes a value uses the `return` statement to specify what value it "returns." For example, a function that adds 1 to its argument might execute the statement

```
return x + 1;
```

while a function that computes the difference of the squares of its arguments might execute the statement

```
return y * y - z * z;
```

Although a C program may consist of many functions, only the `main` function is mandatory. `main` is special: it gets called automatically when the program is executed. Until Chapter 9, where we'll learn how to write other functions, `main` will be the only function in our programs.

The name `main` is critical; it can't be `begin` or `start` or even `MAIN`.

If `main` is a function, does it return a value? Yes: it returns a status code that is given to the operating system when the program terminates. Let's take another look at the `pun.c` program:

```
#include <stdio.h>

int main(void)
{
  printf("To C, or not to C: that is the question.\n");
  return 0;
}
```

The word `int` just before `main` indicates that the `main` function returns an integer value. The word `void` in parentheses indicates that `main` has no arguments.

The statement

```
return 0;
```

has two effects: it causes the `main` function to terminate (thus ending the program) and it indicates that the `main` function returns a value of 0. We'll have more to say about `main`'s return value in a later chapter. For now, we'll always have `main` return the value 0, which indicates normal program termination.

return value of main ➤9.5

Q&A

If there's no `return` statement at the end of the `main` function, the program will still terminate. However, many compilers will produce a warning message (because the function was supposed to return an integer but failed to).

Q&A

Statements

A ***statement*** is a command to be executed when the program runs. We'll explore statements later in the book, primarily in Chapters 5 and 6. The `pun.c` program uses only two kinds of statements. One is the `return` statement; the other is the ***function call***. Asking a function to perform its assigned task is known as ***calling*** the function. The `pun.c` program, for example, calls the `printf` function to display a string on the screen:

```
printf("To C, or not to C: that is the question.\n");
```

C requires that each statement end with a semicolon. (As with any good rule, there's one exception: the compound statement, which we'll encounter later.) The semicolon shows the compiler where the statement ends; since statements can continue over several lines, it's not always obvious where they end. Directives, on the other hand, are normally one line long, and they *don't* end with a semicolon.

compound statement ➤ 5.2

Printing Strings

`printf` is a powerful function that we'll examine in Chapter 3. So far, we've only used `printf` to display a ***string literal***—a series of characters enclosed in double quotation marks. When `printf` displays a string literal, it doesn't show the quotation marks.

`printf` doesn't automatically advance to the next output line when it finishes printing. To instruct `printf` to advance one line, we must include `\n` (the ***new-line character***) in the string to be printed. Writing a new-line character terminates the current output line; subsequent output goes onto the next line. To illustrate this point, consider the effect of replacing the statement

```
printf("To C, or not to C: that is the question.\n");
```

by two calls of `printf`:

```
printf("To C, or not to C: ");
printf("that is the question.\n");
```

The first call of `printf` writes `To C, or not to C: `. The second call writes `that is the question.` and advances to the next line. The net effect is the same as the original `printf`—the user can't tell the difference.

The new-line character can appear more than once in a string literal. To display the message

```
Brevity is the soul of wit.
  --Shakespeare
```

we could write

```
printf("Brevity is the soul of wit.\n  --Shakespeare\n");
```

2.3 Comments

Our `pun.c` program still lacks something important: documentation. Every program should contain identifying information: the program name, the date written, the author, the purpose of the program, and so forth. In C, this information is placed in ***comments***. The symbol `/*` marks the beginning of a comment and the symbol `*/` marks the end:

```
/* This is a comment */
```

Comments may appear almost anywhere in a program, either on separate lines or on the same lines as other program text. Here's what `pun.c` might look like with comments added at the beginning:

```
/* Name: pun.c                 */
/* Purpose: Prints a bad pun.  */
/* Author: K. N. King          */

#include <stdio.h>

int main(void)
{
  printf("To C, or not to C: that is the question.\n");
  return 0;
}
```

Comments may extend over more than one line; once it has seen the `/*` symbol, the compiler reads (and ignores) whatever follows until it encounters the `*/` symbol. If we like, we can combine a series of short comments into one long comment:

```
/* Name: pun.c
   Purpose: Prints a bad pun.
   Author: K. N. King */
```

A comment like this can be hard to read, though, because it's not easy to see where the comment ends. Putting `*/` on a line by itself helps:

```
/* Name: pun.c
   Purpose: Prints a bad pun.
   Author: K. N. King
*/
```

Even better, we can form a "box" around the comment to make it stand out:

```
/**********************************************************
 * Name: pun.c                                            *
 * Purpose: Prints a bad pun.                             *
 * Author: K. N. King                                     *
 **********************************************************/
```

Programmers often simplify boxed comments by omitting three of the sides:

```
/*
 * Name: pun.c
 * Purpose: Prints a bad pun.
 * Author: K. N. King
 */
```

A short comment can go on the same line with other program code:

```
int main(void)   /* Beginning of main program */
```

A comment like this is sometimes called a "winged comment."

Forgetting to terminate a comment may cause the compiler to ignore part of your program. Consider the following example:

```
printf("My ");    /* forgot to close this comment...
printf("cat ");
printf("has ");   /* so it ends here */
printf("fleas");
```

Because we've neglected to terminate the first comment, the compiler ignores the middle two statements, and the example prints `My fleas`.

C99 C99 provides a second kind of comment, which begins with `//` (two adjacent slashes):

```
// This is a comment
```

This style of comment ends automatically at the end of a line. To create a comment that's more than one line long, we can either use the older comment style (`/* … */`) or else put `//` at the beginning of each comment line:

```
// Name: pun.c
// Purpose: Prints a bad pun.
// Author: K. N. King
```

The newer comment style has a couple of important advantages. First, because a comment automatically ends at the end of a line, there's no chance that an unterminated comment will accidentally consume part of a program. Second, multiline comments stand out better, thanks to the `//` that's required at the beginning of each line.

2.4 Variables and Assignment

Few programs are as simple as the one in Section 2.1. Most programs need to perform a series of calculations before producing output, and thus need a way to store data temporarily during program execution. In C, as in most programming languages, these storage locations are called ***variables***.

Types

Every variable must have a ***type***, which specifies what kind of data it will hold. C has a wide variety of types. For now, we'll limit ourselves to just two: `int` and `float`. Choosing the proper type is critical, since the type affects how the variable is stored and what operations can be performed on the variable. The type of a numeric variable determines the largest and smallest numbers that the variable can store; it also determines whether or not digits are allowed after the decimal point.

A variable of type `int` (short for *integer*) can store a whole number such as 0, 1, 392, or –2553. The range of possible values is limited, though. The largest `int` value is typically 2,147,483,647 but can be as small as 32,767.

range of `int` values ➤*7.1*

Q&A

A variable of type `float` (short for *floating-point*) can store much larger numbers than an `int` variable. Furthermore, a `float` variable can store numbers with digits after the decimal point, like 379.125. `float` variables have drawbacks, however. Arithmetic on `float` numbers may be slower than arithmetic on `int` numbers. Most significantly, the value of a `float` variable is often just an approximation of the number that was stored in it. If we store 0.1 in a `float` variable, we may later find that the variable has a value such as 0.09999999999999987, thanks to rounding error.

Declarations

Variables must be ***declared***—described for the benefit of the compiler—before they can be used. To declare a variable, we first specify the *type* of the variable, then its *name*. (Variable names are chosen by the programmer, subject to the rules described in Section 2.7.) For example, we might declare variables `height` and `profit` as follows:

```
int height;
float profit;
```

The first declaration states that `height` is a variable of type `int`, meaning that `height` can store an integer value. The second declaration says that `profit` is a variable of type `float`.

If several variables have the same type, their declarations can be combined:

```
int height, length, width, volume;
float profit, loss;
```

Notice that each complete declaration ends with a semicolon.

Our first template for `main` didn't include declarations. When `main` contains declarations, these must precede statements:

```
int main(void)
{
  declarations
  statements
}
```

blocks ➤10.3

As we'll see in Chapter 9, this is true of functions in general, as well as blocks (statements that contain embedded declarations). As a matter of style, it's a good idea to leave a blank line between the declarations and the statements.

C99

In C99, declarations don't have to come before statements. For example, `main` might contain a declaration, then a statement, and then another declaration. For compatibility with older compilers, the programs in this book don't take advantage of this rule. However, it's common in C++ and Java programs not to declare variables until they're first needed, so this practice can be expected to become popular in C99 programs as well.

Assignment

A variable can be given a value by means of ***assignment***. For example, the statements

```
height = 8;
length = 12;
width = 10;
```

assign values to `height`, `length`, and `width`. The numbers `8`, `12`, and `10` are said to be ***constants.***

Before a variable can be assigned a value—or used in any other way, for that matter—it must first be declared. Thus, we could write

```
int height;
height = 8;
```

but not

```
height = 8;   /*** WRONG ***/
int height;
```

A constant assigned to a `float` variable usually contains a decimal point. For example, if `profit` is a `float` variable, we might write

```
profit = 2150.48;
```

Q&A It's best to append the letter `f` (for "float") to a constant that contains a decimal point if the number is assigned to a `float` variable:

```
profit = 2150.48f;
```

Failing to include the `f` may cause a warning from the compiler.

An `int` variable is normally assigned a value of type `int`, and a `float` variable is normally assigned a value of type `float`. Mixing types (such as assigning an `int` value to a `float` variable or assigning a `float` value to an `int` variable) is possible but not always safe, as we'll see in Section 4.2.

Once a variable has been assigned a value, it can be used to help compute the value of another variable:

```
height = 8;
length = 12;
width = 10;
volume = height * length * width;    /* volume is now 960 */
```

In C, `*` represents the multiplication operator, so this statement multiplies the values stored in `height`, `length`, and `width`, then assigns the result to the variable `volume`. In general, the right side of an assignment can be a formula (or ***expression***, in C terminology) involving constants, variables, and operators.

Printing the Value of a Variable

We can use `printf` to display the current value of a variable. For example, to write the message

Height: *h*

where *h* is the current value of the `height` variable, we'd use the following call of `printf`:

```
printf("Height: %d\n", height);
```

`%d` is a placeholder indicating where the value of `height` is to be filled in during printing. Note the placement of `\n` just after `%d`, so that `printf` will advance to the next line after printing the value of `height`.

`%d` works only for `int` variables; to print a `float` variable, we'd use `%f` instead. By default, `%f` displays a number with six digits after the decimal point. To force `%f` to display *p* digits after the decimal point, we can put `.`*p* between `%` and `f`. For example, to print the line

```
Profit: $2150.48
```

we'd call `printf` as follows:

```
printf("Profit: $%.2f\n", profit);
```

There's no limit to the number of variables that can be printed by a single call of `printf`. To display the values of both the `height` and `length` variables, we could use the following call of `printf`:

```
printf("Height: %d  Length: %d\n", height, length);
```

PROGRAM Computing the Dimensional Weight of a Box

Shipping companies don't especially like boxes that are large but very light, since they take up valuable space in a truck or airplane. In fact, companies often charge extra for such a box, basing the fee on its volume instead of its weight. In the United States, the usual method is to divide the volume by 166 (the allowable number of cubic inches per pound). If this number—the box's "dimensional" or "volumetric" weight—exceeds its actual weight, the shipping fee is based on the dimensional weight. (The 166 divisor is for international shipments; the dimensional weight of a domestic shipment is typically calculated using 194 instead.)

Let's say that you've been hired by a shipping company to write a program that computes the dimensional weight of a box. Since you're new to C, you decide to start off by writing a program that calculates the dimensional weight of a particular box that's 12″ × 10″ × 8″. Division is represented by `/` in C, so the obvious way to compute the dimensional weight would be

```
weight = volume / 166;
```

where `weight` and `volume` are integer variables representing the box's weight and volume. Unfortunately, this formula isn't quite what we need. In C, when one integer is divided by another, the answer is "truncated": all digits after the decimal point are lost. The volume of a 12″ × 10″ × 8″ box will be 960 cubic inches. Dividing by 166 gives the answer 5 instead of 5.783, so we have in effect rounded *down* to the next lowest pound; the shipping company expects us to round *up*. One solution is to add 165 to the volume before dividing by 166:

```
weight = (volume + 165) / 166;
```

A volume of 166 would give a weight of 331/166, or 1, while a volume of 167 would yield 332/166, or 2. Calculating the weight in this fashion gives us the following program.

dweight.c

```
/* Computes the dimensional weight of a 12" x 10" x 8" box */

#include <stdio.h>

int main(void)
{
```

```
  int height, length, width, volume, weight;

  height = 8;
  length = 12;
  width = 10;
  volume = height * length * width;
  weight = (volume + 165) / 166;

  printf("Dimensions: %dx%dx%d\n", length, width, height);
  printf("Volume (cubic inches): %d\n", volume);
  printf("Dimensional weight (pounds): %d\n", weight);

  return 0;
}
```

The output of the program is

```
Dimensions: 12x10x8
Volume (cubic inches): 960
Dimensional weight (pounds): 6
```

Initialization

variable initialization ➤18.5

Some variables are automatically set to zero when a program begins to execute, but most are not. A variable that doesn't have a default value and hasn't yet been assigned a value by the program is said to be ***uninitialized.***

Attempting to access the value of an uninitialized variable (for example, by displaying the variable using `printf` or using it in an expression) may yield an unpredictable result such as 2568, –30891, or some equally strange number. With some compilers, worse behavior—even a program crash—may occur.

We can always give a variable an initial value by using assignment, of course. But there's an easier way: put the initial value of the variable in its declaration. For example, we can declare the `height` variable and initialize it in one step:

```
int height = 8;
```

In C jargon, the value `8` is said to be an ***initializer***.

Any number of variables can be initialized in the same declaration:

```
int height = 8, length = 12, width = 10;
```

Notice that each variable requires its own initializer. In the following example, the initializer `10` is good only for the variable `width`, not for `height` or `length` (which remain uninitialized):

```
int height, length, width = 10;
```

Printing Expressions

`printf` isn't limited to displaying numbers stored in variables; it can display the value of *any* numeric expression. Taking advantage of this property can simplify a program and reduce the number of variables. For instance, the statements

```
volume = height * length * width;
printf("%d\n", volume);
```

could be replaced by

```
printf("%d\n", height * length * width);
```

`printf`'s ability to print expressions illustrates one of C's general principles: *Wherever a value is needed, any expression of the same type will do.*

2.5 Reading Input

Because the `dweight.c` program calculates the dimensional weight of just one box, it isn't especially useful. To improve the program, we'll need to allow the user to enter the dimensions.

To obtain input, we'll use the `scanf` function, the C library's counterpart to `printf`. The `f` in `scanf`, like the `f` in `printf`, stands for "formatted"; both `scanf` and `printf` require the use of a ***format string*** to specify the appearance of the input or output data. `scanf` needs to know what form the input data will take, just as `printf` needs to know how to display output data.

To read an `int` value, we'd use `scanf` as follows:

```
scanf("%d", &i);   /* reads an integer; stores into i */
```

& operator ➤*11.2*

The `"%d"` string tells `scanf` to read input that represents an integer; `i` is an `int` variable into which we want `scanf` to store the input. The `&` symbol is hard to explain at this point; for now, I'll just note that it is usually (but not always) required when using `scanf`.

Reading a `float` value requires a slightly different call of `scanf`:

```
scanf("%f", &x);   /* reads a float value; stores into x */
```

`%f` works only with variables of type `float`, so I'm assuming that `x` is a `float` variable. The `"%f"` string tells `scanf` to look for an input value in `float` format (the number may contain a decimal point, but doesn't have to).

PROGRAM Computing the Dimensional Weight of a Box (Revisited)

Here's an improved version of the dimensional weight program in which the user enters the dimensions. Note that each call of `scanf` is immediately preceded by a call of `printf`. That way, the user will know when to enter input and what input to enter.

dweight2.c

```
/* Computes the dimensional weight of a
   box from input provided by the user */

#include <stdio.h>

int main(void)
{
  int height, length, width, volume, weight;

  printf("Enter height of box: ");
  scanf("%d", &height);
  printf("Enter length of box: ");
  scanf("%d", &length);
  printf("Enter width of box: ");
  scanf("%d", &width);
  volume = height * length * width;
  weight = (volume + 165) / 166;

  printf("Volume (cubic inches): %d\n", volume);
  printf("Dimensional weight (pounds): %d\n", weight);

  return 0;
}
```

The output of the program has the following appearance (input entered by the user is underlined):

```
Enter height of box: 8
Enter length of box: 12
Enter width of box: 10
Volume (cubic inches): 960
Dimensional weight (pounds): 6
```

A message that asks the user to enter input (a ***prompt***) normally shouldn't end with a new-line character, because we want the user to enter input on the same line as the prompt itself. When the user presses the Enter key, the cursor automatically moves to the next line—the program doesn't need to display a new-line character to terminate the current line.

The `dweight2.c` program suffers from one problem: it doesn't work correctly if the user enters nonnumeric input. Section 3.2 discusses this issue in more detail.

2.6 Defining Names for Constants

When a program contains constants, it's often a good idea to give them names. The `dweight.c` and `dweight2.c` programs rely on the constant 166, whose meaning may not be at all clear to someone reading the program later. Using a feature known as ***macro definition***, we can name this constant:

```
#define INCHES_PER_POUND 166
```

`#define` is a preprocessing directive, just as `#include` is, so there's no semicolon at the end of the line.

When a program is compiled, the preprocessor replaces each macro by the value that it represents. For example, the statement

```
weight = (volume + INCHES_PER_POUND - 1) / INCHES_PER_POUND;
```

will become

```
weight = (volume + 166 - 1) / 166;
```

giving the same effect as if we'd written the latter statement in the first place.

The value of a macro can be an expression:

```
#define RECIPROCAL_OF_PI (1.0f / 3.14159f)
```

parentheses in macros ➤*14.3*

If it contains operators, the expression should be enclosed in parentheses.

Notice that we've used only upper-case letters in macro names. This is a convention that most C programmers follow, not a requirement of the language. (Still, C programmers have been doing this for decades; you wouldn't want to be the first to deviate.)

PROGRAM Converting from Fahrenheit to Celsius

The following program prompts the user to enter a Fahrenheit temperature; it then prints the equivalent Celsius temperature. The output of the program will have the following appearance (as usual, input entered by the user is underlined):

```
Enter Fahrenheit temperature: 212
Celsius equivalent: 100.0
```

The program will allow temperatures that aren't integers; that's why the Celsius temperature is displayed as `100.0` instead of `100`. Let's look first at the entire program, then see how it's put together.

celsius.c

```
/* Converts a Fahrenheit temperature to Celsius */

#include <stdio.h>

#define FREEZING_PT 32.0f
#define SCALE_FACTOR (5.0f / 9.0f)

int main(void)
{
  float fahrenheit, celsius;

  printf("Enter Fahrenheit temperature: ");
```

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

  celsius = (fahrenheit - FREEZING_PT) * SCALE_FACTOR;

  printf("Celsius equivalent: %.1f\n", celsius);

  return 0;
}
```

The statement

```
celsius = (fahrenheit - FREEZING_PT) * SCALE_FACTOR;
```

converts the Fahrenheit temperature to Celsius. Since `FREEZING_PT` stands for `32.0f` and `SCALE_FACTOR` stands for `(5.0f / 9.0f)`, the compiler sees this statement as

```
celsius = (fahrenheit - 32.0f) * (5.0f / 9.0f);
```

Defining `SCALE_FACTOR` to be `(5.0f / 9.0f)` instead of `(5 / 9)` is important, because C truncates the result when two integers are divided. The value of `(5 / 9)` would be 0, which definitely isn't what we want.

The call of `printf` writes the Celsius temperature:

```
printf("Celsius equivalent: %.1f\n", celsius);
```

Notice the use of `%.1f` to display `celsius` with just one digit after the decimal point.

2.7 Identifiers

As we're writing a program, we'll have to choose names for variables, functions, macros, and other entities. These names are called ***identifiers***. In C, an identifier may contain letters, digits, and underscores, but must begin with a letter or underscore. (In C99, identifiers may contain certain "universal character names" as well.)

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universal character names ➤*25.4*

Here are some examples of legal identifiers:

```
times10  get_next_char  _done
```

The following are *not* legal identifiers:

```
10times  get-next-char
```

The symbol `10times` begins with a digit, not a letter or underscore. `get-next-char` contains minus signs, not underscores.

C is ***case-sensitive:*** it distinguishes between upper-case and lower-case letters in identifiers. For example, the following identifiers are all different:

```
job  joB  jOb  jOB  Job  JoB  JOb  JOB
```

These eight identifiers could all be used simultaneously, each for a completely different purpose. (Talk about obfuscation!) Sensible programmers try to make identifiers look different unless they're somehow related.

Since case matters in C, many programmers follow the convention of using only lower-case letters in identifiers (other than macros), with underscores inserted when necessary for legibility:

```
symbol_table  current_page  name_and_address
```

Other programmers avoid underscores, instead using an upper-case letter to begin each word within an identifier:

```
symbolTable  currentPage  nameAndAddress
```

(The first letter is sometimes capitalized as well.) Although the former style is common in traditional C, the latter style is becoming more popular thanks to its widespread use in Java and C# (and, to a lesser extent, C++). Other reasonable conventions exist; just be sure to capitalize an identifier the same way each time it appears in a program.

Q&A C places no limit on the maximum length of an identifier, so don't be afraid to use long, descriptive names. A name such as `current_page` is a lot easier to understand than a name like `cp`.

Keywords

The ***keywords*** in Table 2.1 have special significance to C compilers and therefore
C99 can't be used as identifiers. Note that five keywords were added in C99.

Table 2.1
Keywords

auto	enum	restrict†	unsigned
break	extern	return	void
case	float	short	volatile
char	for	signed	while
const	goto	sizeof	_Bool†
continue	if	static	_Complex†
default	inline†	struct	_Imaginary†
do	int	switch	
double	long	typedef	
else	register	union	

†C99 only

Because of C's case-sensitivity, keywords must appear in programs exactly as shown in Table 2.1, with all letters in lower case. Names of functions in the standard library (such as `printf`) contain only lower-case letters also. Avoid the plight of the unfortunate programmer who enters an entire program in upper case, only to find that the compiler can't recognize keywords and calls of library functions.

Watch out for other restrictions on identifiers. Some compilers treat certain identifiers (`asm`, for example) as additional keywords. Identifiers that belong to the standard library are restricted as well. Accidentally using one of these names can cause an error during compilation or linking. Identifiers that begin with an underscore are also restricted.

restrictions on identifiers ➤21.1

2.8 Layout of a C Program

We can think of a C program as a series of ***tokens:*** groups of characters that can't be split up without changing their meaning. Identifiers and keywords are tokens. So are operators like + and `-`, punctuation marks such as the comma and semicolon, and string literals. For example, the statement

```
printf("Height: %d\n", height);
```

consists of seven tokens:

```
printf   (   "Height: %d\n"   ,   height   )   ;
  ①      ②         ③          ④     ⑤      ⑥   ⑦
```

Tokens ① and ⑤ are identifiers, token ③ is a string literal, and tokens ②, ④, ⑥, and ⑦ are punctuation.

The amount of space between tokens in a program isn't critical in most cases. At one extreme, tokens can be crammed together with no space between them at all, except where this would cause two tokens to merge into a third token. For example, we could delete most of the space in the `celsius.c` program of Section 2.6, provided that we leave space between tokens such as `int` and `main` and between `float` and `fahrenheit`:

```
/* Converts a Fahrenheit temperature to Celsius */
#include <stdio.h>
#define FREEZING_PT 32.0f
#define SCALE_FACTOR (5.0f/9.0f)
int main(void){float fahrenheit,celsius;printf(
"Enter Fahrenheit temperature: ");scanf("%f", &fahrenheit);
celsius=(fahrenheit-FREEZING_PT)*SCALE_FACTOR;
printf("Celsius equivalent: %.1f\n", celsius);return 0;}
```

In fact, if the page were wider, we could put the entire `main` function on a single line. We can't put the whole *program* on one line, though, because each preprocessing directive requires a separate line.

Compressing programs in this fashion isn't a good idea. In fact, adding spaces and blank lines to a program can make it easier to read and understand. Fortunately, C allows us to insert any amount of space—blanks, tabs, and new-line characters—between tokens. This rule has several important consequences for program layout:

- *Statements can be divided* over any number of lines. The following statement, for example, is so long that it would be hard to squeeze it onto a single line:

```
printf("Dimensional weight (pounds): %d\n",
  (volume + INCHES_PER_POUND - 1) / INCHES_PER_POUND);
```

- *Space between tokens* makes it easier for the eye to separate them. For this reason, I usually put a space before and after each operator:

```
volume = height * length * width;
```

  I also put a space after each comma. Some programmers go even further, putting spaces around parentheses and other punctuation.

- *Indentation* can make nesting easier to spot. For example, we should indent declarations and statements to make it clear that they're nested inside `main`. **Q&A**
- *Blank lines* can divide a program into logical units, making it easier for the reader to discern the program's structure. A program with no blank lines is as hard to read as a book with no chapters.

The `celsius.c` program of Section 2.6 illustrates several of these guidelines. Let's take a closer look at the `main` function in that program:

```
int main(void)
{
  float fahrenheit, celsius;

  printf("Enter Fahrenheit temperature: ");
  scanf("%f", &fahrenheit);

  celsius = (fahrenheit - FREEZING_PT) * SCALE_FACTOR;

  printf("Celsius equivalent: %.1f\n", celsius);

  return 0;
}
```

First, observe how the space around `=`, `-`, and `*` makes these operators stand out. Second, notice how the indentation of declarations and statements makes it obvious that they all belong to `main`. Finally, note how blank lines divide `main` into five parts: (1) declaring the `fahrenheit` and `celsius` variables; (2) obtaining the Fahrenheit temperature; (3) calculating the value of `celsius`; (4) printing the Celsius temperature; and (5) returning to the operating system.

While we're on the subject of program layout, notice how I've placed the { token underneath `main()` and put the matching } on a separate line, aligned with {. Putting } on a separate line lets us insert or delete statements at the end of the function; aligning it with { makes it easy to spot the end of `main`.

A final note: Although extra spaces can be added *between* tokens, it's not possible to add space *within* a token without changing the meaning of the program or causing an error. Writing

```
fl oat fahrenheit, celsius;   /*** WRONG ***/
```

or

```
fl
oat fahrenheit, celsius;      /*** WRONG ***/
```

produces an error when the program is compiled. Putting a space inside a string literal is allowed, although it changes the meaning of the string. However, putting a new-line character in a string (in other words, splitting the string over two lines) is illegal:

```
printf("To C, or not to C:
that is the question.\n");    /*** WRONG ***/
```

Continuing a string from one line to the next requires a special technique that we'll learn in a later chapter.

continuing a string ➤13.1

Q & A

Q: What does GCC stand for? [p. 11]

A: GCC originally stood for "GNU C compiler." It now stands for "GNU Compiler Collection," because the current version of GCC compiles programs written in a variety of languages, including Ada, C, C++, Fortran, Java, and Objective-C.

Q: OK, so what does GNU stand for?

A: GNU stands for "GNU's Not UNIX!" (and is pronounced *guh-NEW*, by the way). GNU is a project of the Free Software Foundation, an organization set up by Richard M. Stallman as a protest against the restrictions of licensed UNIX software. According to its web site, the Free Software Foundation believes that users should be free to "run, copy, distribute, study, change and improve" software. The GNU Project has rewritten much traditional UNIX software from scratch and made it publicly available at no charge.

GCC and other GNU software are crucial to Linux. Linux itself is only the "kernel" of an operating system (the part that handles program scheduling and basic I/O services); the GNU software is necessary to have a fully functional operating system.

For more information on the GNU Project, visit *www.gnu.org*.

Q: What's the big deal about GCC, anyway?

A: GCC is significant for many reasons, not least the fact that it's free and capable of compiling a number of languages. It runs under many operating systems and generates code for many different CPUs, including all the widely used ones. GCC is the primary compiler for many UNIX-based operating systems, including Linux, BSD, and Mac OS X, and it's used extensively for commercial software development. For more information about GCC, visit *gcc.gnu.org*.

Q: How good is GCC at finding errors in programs?

A: GCC has various command-line options that control how thoroughly it checks programs. When these options are used, GCC is quite good at finding potential trouble spots in a program. Here are some of the more popular options:

`-Wall`	Causes the compiler to produce warning messages when it detects possible errors. (`-W` can be followed by codes for specific warnings; `-Wall` means "all `-W` options.") Should be used in conjunction with `-O` for maximum effect.
`-W`	Issues additional warning messages beyond those produced by `-Wall`.
`-pedantic`	Issues all warnings required by the C standard. Causes programs that use nonstandard features to be rejected.
`-ansi`	Turns off features of GCC that aren't standard C and enables a few standard features that are normally disabled.
`-std=c89` `-std=c99`	Specifies which version of C the compiler should use to check the program.

These options are often used in combination:

```
% gcc -O -Wall -W -pedantic -ansi -std=c99 -o pun pun.c
```

Q: Why is C so terse? It seems as though programs would be more readable if C used `begin` and `end` instead of `{` and `}`, `integer` instead of `int`, and so forth. [p. 12]

A: Legend has it that the brevity of C programs is due to the environment that existed in Bell Labs at the time the language was developed. The first C compiler ran on a DEC PDP-11 (an early minicomputer); programmers used a teletype—essentially a typewriter connected to a computer—to enter programs and print listings. Because teletypes were very slow (they could print only 10 characters per second), minimizing the number of characters in a program was clearly advantageous.

Q: In some C books, the `main` function ends with `exit(0)` instead of `return 0`. Are these the same? [p. 14]

A: When they appear inside `main`, these statements are indeed equivalent: both terminate the program, returning the value 0 to the operating system. Which one to use is mostly a matter of taste.

Q: What happens if a program reaches the end of the `main` function without executing a `return` statement? [p. 14]

A: The `return` statement isn't mandatory; if it's missing, the program will still ter-

C99 minate. In C89, the value returned to the operating system is undefined. In C99, if `main` is declared to return an `int` (as in our examples), the program returns 0 to the operating system; otherwise, the program returns an unspecified value.

Q: Does the compiler remove a comment entirely or replace it with blank space?

A: Some old C compilers deleted all the characters in each comment, making it possible to write

```
a/**/b = 0;
```

and have the compiler interpret it as

```
ab = 0;
```

According to the C standard, however, the compiler must replace each comment by a single space character, so this trick doesn't work. Instead, we'd end up with the following (illegal) statement:

```
a b = 0;
```

Q: How can I tell if my program has an unterminated comment?

A: If you're lucky, the program won't compile because the comment has rendered the program illegal. If the program does compile, there are several techniques that you can use. Stepping through the program line by line with a debugger will reveal if any lines are being skipped. Some IDEs display comments in a distinctive color to distinguish them from surrounding code. If you're using such an environment, you can easily spot unterminated comments, since program text will have a different color if it's accidentally included in a comment. A program such as `lint` can also help.

`lint` ➤*1.2*

Q: Is it legal to nest one comment inside another?

A: Old-style comments (`/*` … `*/`) can't be nested. For instance, the following code is illegal:

```
/*
   /*** WRONG ***/
*/
```

The `*/` symbol on the second line matches the `/*` symbol on the first line, so the compiler will flag the `*/` symbol on the third line as an error.

C's prohibition against nested comments can sometimes be a problem. Suppose we've written a long program containing many short comments. To disable a portion of the program temporarily (during testing, say), our first impulse is to "comment out" the offending lines with `/*` and `*/`. Unfortunately, this method won't work if the lines contain old-style comments. C99 comments (those beginning with `//`) can be nested inside old-style comments, however—another advantage to using this kind of comment.

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In any event, there's a better way to disable portions of a program, as we'll see later.

disabling code ➤14.4

Q: Where does the `float` type get its name? [p. 17]

A: `float` is short for "floating-point," a technique for storing numbers in which the decimal point "floats." A `float` value is usually stored in two parts: the fraction (or mantissa) and the exponent. The number 12.0 might be stored as 1.5×2^3, for example, where 1.5 is the fraction and 3 is the exponent. Some programming languages call this type `real` instead of `float`.

Q: Why do floating-point constants need to end with the letter `f`? [p. 19]

A: For the full explanation, see Chapter 7. Here's the short answer: a constant that contains a decimal point but doesn't end with `f` has type `double` (short for "double precision"). `double` values are stored more accurately than `float` values. Moreover, `double` values can be larger than `float` values, which is why we need to add the letter `f` when assigning to a `float` variable. Without the `f`, a warning may be generated about the possibility of a number being stored into a `float` variable that exceeds the capacity of the variable.

***Q: Is it really true that there's no limit on the length of an identifier? [p. 26]**

A: Yes and no. The C89 standard says that identifiers may be arbitrarily long. However, compilers are only required to remember the first 31 characters (63 characters in C99). Thus, if two names begin with the same 31 characters, a compiler might be unable to distinguish between them.

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To make matters even more complicated, there are special rules for identifiers with external linkage; most function names fall into this category. Since these names must be made available to the linker, and since some older linkers can handle only short names, only the first six characters are significant in C89. Moreover, the case of letters may not matter. As a result, `ABCDEFG` and `abcdefh` might be treated as the same name. (In C99, the first 31 characters are significant, and the case of letters is taken into account.)

external linkage ➤18.2

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Most compilers and linkers are more generous than the standard, so these rules aren't a problem in practice. Don't worry about making identifiers too long—worry about making them too short.

Q: How many spaces should I use for indentation? [p. 28]

A: That's a tough question. Leave too little space, and the eye has trouble detecting indentation. Leave too much, and lines run off the screen (or page). Many C programmers indent nested statements eight spaces (one tab stop), which is probably too much. Studies have shown that the optimum amount of indentation is three spaces, but many programmers feel uncomfortable with numbers that aren't a power of two. Although I normally prefer to indent three or four spaces, I'll use two spaces in this book so that my programs will fit within the margins.

Exercises

Section 2.1

1. Create and run Kernighan and Ritchie's famous "hello, world" program:

```
#include <stdio.h>

int main(void)
{
  printf("hello, world\n");
}
```

Do you get a warning message from the compiler? If so, what's needed to make it go away?

Section 2.2

Ⓦ 2. Consider the following program:

```
#include <stdio.h>

int main(void)
{
  printf("Parkinson's Law:\nWork expands so as to ");
  printf("fill the time\n");
  printf("available for its completion.\n");
  return 0;
}
```

(a) Identify the directives and statements in this program.
(b) What output does the program produce?

Section 2.4

Ⓦ 3. Condense the `dweight.c` program by (1) replacing the assignments to `height`, `length`, and `width` with initializers and (2) removing the `weight` variable, instead calculating `(volume + 165) / 166` within the last `printf`.

Ⓦ 4. Write a program that declares several `int` and `float` variables—without initializing them—and then prints their values. Is there any pattern to the values? (Usually there isn't.)

Section 2.7

Ⓦ 5. Which of the following are not legal C identifiers?

(a) `100_bottles`
(b) `_100_bottles`
(c) `one__hundred__bottles`
(d) `bottles_by_the_hundred_`

6. Why is it not a good idea for an identifier to contain more than one adjacent underscore (as in `current___balance`, for example)?

7. Which of the following are keywords in C?

(a) `for`
(b) `If`
(c) `main`
(d) `printf`
(e) `while`

Ⓦ Answer available on the Web at *knking.com/books/c2*.

Section 2.8

8. How many tokens are there in the following statement?

```
answer=(3*q-p*p)/3;
```

9. Insert spaces between the tokens in Exercise 8 to make the statement easier to read.

10. In the `dweight.c` program (Section 2.4), which spaces are essential?

Programming Projects

1. Write a program that uses `printf` to display the following picture on the screen:

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

2. Write a program that computes the volume of a sphere with a 10-meter radius, using the formula $v = 4/3\pi r^3$. Write the fraction 4/3 as `4.0f/3.0f`. (Try writing it as `4/3`. What happens?) *Hint:* C doesn't have an exponentiation operator, so you'll need to multiply r by itself twice to compute r^3.

3. Modify the program of Programming Project 2 so that it prompts the user to enter the radius of the sphere.

4. Write a program that asks the user to enter a dollars-and-cents amount, then displays the amount with 5% tax added:

```
Enter an amount: 100.00
With tax added: $105.00
```

5. Write a program that asks the user to enter a value for x and then displays the value of the following polynomial:

$3x^5 + 2x^4 - 5x^3 - x^2 + 7x - 6$

Hint: C doesn't have an exponentiation operator, so you'll need to multiply x by itself repeatedly in order to compute the powers of x. (For example, `x * x * x` is `x` cubed.)

6. Modify the program of Programming Project 5 so that the polynomial is evaluated using the following formula:

$((((3x + 2)x - 5)x - 1)x + 7)x - 6$

Note that the modified program performs fewer multiplications. This technique for evaluating polynomials is known as ***Horner's Rule***.

7. Write a program that asks the user to enter a U.S. dollar amount and then shows how to pay that amount using the smallest number of $20, $10, $5, and $1 bills:

```
Enter a dollar amount: 93

$20 bills: 4
$10 bills: 1
 $5 bills: 0
 $1 bills: 3
```

Hint: Divide the amount by 20 to determine the number of $20 bills needed, and then reduce the amount by the total value of the $20 bills. Repeat for the other bill sizes. Be sure to use integer values throughout, not floating-point numbers.

8. Write a program that calculates the remaining balance on a loan after the first, second, and third monthly payments:

```
Enter amount of loan: 20000.00
Enter interest rate: 6.0
Enter monthly payment: 386.66

Balance remaining after first payment: $19713.34
Balance remaining after second payment: $19425.25
Balance remaining after third payment: $19135.71
```

Display each balance with two digits after the decimal point. *Hint:* Each month, the balance is decreased by the amount of the payment, but increased by the balance times the monthly interest rate. To find the monthly interest rate, convert the interest rate entered by the user to a percentage and divide it by 12.