# 5 Conditions, Logical Expressions, and Selection Control Structures

KNOWLEDGE GOALS

- To understand how the Boolean operators work.
- To understand the flow of control in a branching statement.
- To understand the flow of control in a nested branching statement.
- To know what preconditions and postconditions are.

SKILL GOALS

*To be able to:*

- Construct a simple logical (Boolean) expression to evaluate a given condition.
- Construct a complex logical expression to evaluate a given condition.
- Construct an If-Then-Else statement to perform a specific task.
- Construct an If-Then statement to perform a specific task.
- Construct a set of nested If statements to perform a specific task.
- Trace the execution of a C++ program.
- Test and debug a C++ program.

So far, the statements in our programs have been executed in their physical order. The first statement is executed, then the second, and so on, until all of the statements have been executed. But what if we want the computer to execute the statements in some other order? Suppose we want to check the validity of input data and then perform a calculation *or* print an error message, but not both. To do so, we must be able to ask a question and then, based on the answer, choose one or another course of action.

The If statement allows us to execute statements in an order that is different from their physical order. We can ask a question with it and do one thing if the answer is yes (true) or another thing if the answer is no (false). In the first part of this chapter, we deal with asking questions; in the second part, we deal with the If statement itself.

## 5.1 Flow of Control

**Flow of control** The order in which the computer executes statements in a program.

**Control structure** A statement used to alter the normally sequential flow of control.

The order in which statements are executed in a program is called the flow of control. In a sense, the computer is under the control of one statement at a time. When a statement has been executed, control is turned over to the next statement (like a baton being passed in a relay race).

Flow of control is normally sequential (see **FIGURE 5.1**). That is, when one statement is finished executing, control passes to the next statement in the program. When we want the flow of control to be nonsequential, we use control structures, special statements that transfer control to a statement other than the one that physically comes next. Control structures are so important that we focus on them in the remainder of this chapter and in the next four chapters.

### Selection

We use a selection (or branching) control structure when we want the computer to choose between alternative actions. Within the control structure, we make an assertion—a claim that is either true or false. We commonly refer to this assertion as the branching condition. If the assertion is true, the computer executes one statement. If it is false, it executes another (see **FIGURE 5.2**). The computer's ability to solve practical problems is a product of its ability to make decisions and execute different sequences of instructions.

The `LeapYear` program in Chapter 1 shows the selection process at work. The computer must decide whether a year is a leap year. It does so by testing the assertion that the year is

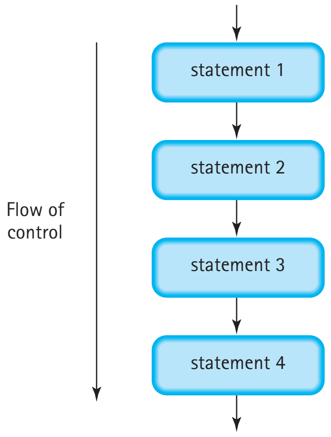


**FIGURE 5.1** Flow of Control

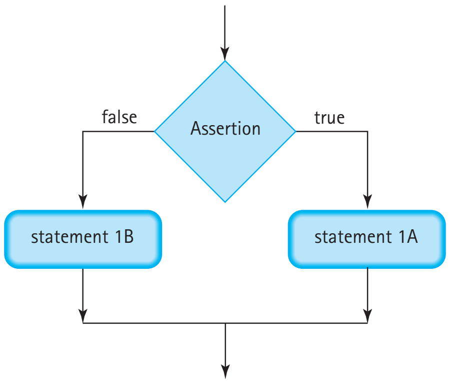
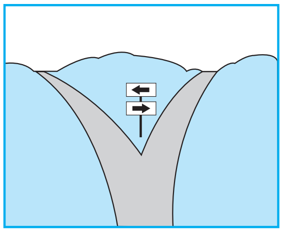


**FIGURE 5.2** Selection (Branching) Control Strucuture

not divisible by 4. If the assertion is true, the computer follows the instructions to return false, indicating that the year is not a leap year. If the assertion is false, the computer goes on to check the exceptions to the general rule. In Chapter 1, we said that this construct is like a fork in a road.



Before we examine selection control structures in C++, let's look closely at how we get the computer to make decisions.

**QUICK CHECK** ✓

- 5.1.1 What does "flow of control" mean? (p. 186)
- 5.1.2 What is the "normal" flow of control for a program? (p. 186)
- 5.1.3 What control structure do we use when we want a computer to choose between alternative actions? (p. 186)
- 5.1.4 What does a branch allow the computer to do? (pp. 186–187)

## 5.2 Conditions and Logical Expressions

To ask a question in C++, we don't phrase it as a question; we state it as an assertion. If the assertion we make is true, the answer to the question is yes. If the statement is not true, the answer to the question is no. For example, if we want to ask, "Are we having spinach for dinner tonight?" we would say, "We are having spinach for dinner tonight." If the assertion is true, the answer to the question is yes. If not, the answer is no.

So, asking questions in C++ means making an assertion that is either true or false. The computer *evaluates* the assertion, checking it against some internal condition (the values stored in certain variables, for instance) to see whether it is true or false.

## The `bool` Data Type

In C++, the **`bool`** data type is a built-in type consisting of just two values, the constants **`true`** and **`false`**. The reserved word **`bool`** is short for Boolean (pronounced "BOOL-e-un").[1] Boolean data is used for testing conditions in a program so that the computer can make decisions (with a selection control structure).

We declare variables of type **`bool`** in the same way we declare variables of other types—that is, by writing the name of the data type and then an identifier:

```
bool dataOK;    // True if the input data is valid
bool done;      // True if the process is done
bool taxable;   // True if the item has sales tax
```

Each variable of type **`bool`** can contain one of two values: **`true`** or **`false`**. It's important to understand right from the beginning that **`true`** and **`false`** are not variable names and they are not strings. They are special constants in C++ and, in fact, are reserved words.

## Logical Expressions

In programming languages, assertions take the form of *logical expressions* (also called *Boolean expressions*). Just as an arithmetic expression is made up of numeric values and operations, so a logical expression is made up of logical values and operations. Every logical expression has one of two values: true or false.

Here are some examples of logical expressions:

- A Boolean variable or constant
- An expression followed by a relational operator followed by an expression
- A logical expression followed by a logical operator followed by a logical expression

Let's look at each of these in detail.

### Boolean Variables and Constants

As we have seen, a Boolean variable is a variable declared to be of type **`bool`**, and it can contain either the value **`true`** or the value **`false`**. For example, if **`dataOK`** is a Boolean variable, then

```
dataOK = true;
```

is a valid assignment statement.

### Relational Operators

Another way of assigning a value to a Boolean variable is to set it equal to the result of comparing two expressions with a *relational operator.* Relational operators test a relationship between two values.

Let's look at an example. In the following program fragment, **`lessThan`** is a Boolean variable and **`i`** and **`j`** are **`int`** variables:

```
cin >> i >> j;
lessThan = (i < j);  // Compare i and j with the "less than"
                     // relational operator, and assign the
                     // resulting Boolean value to lessThan
```

1. The word *Boolean* is a tribute to George Boole, a nineteenth-century English mathematician who described a system of logic using variables with just two values: true and false. (See the "May We Introduce" feature on page 212.)

By comparing two values, we assert that a relationship (such as "less than") exists between them. If the relationship does exist, the assertion is true; if not, it is false. We can test for the following relationships in C++:

| *Operator* | *Relationship Tested* |
|---|---|
| `==` | Equal to |
| `!=` | Not equal to |
| `>` | Greater than |
| `<` | Less than |
| `>=` | Greater than or equal to |
| `<=` | Less than or equal to |

An expression followed by a relational operator followed by an expression is called a *relational expression*. The result of a relational expression is of type `bool`. For example, if `x` is 5 and `y` is 10, the following expressions all have the value `true`:

```
x != y
y > x
x < y
y >= x
x <= y
```

If `x` is the character `'M'` and `y` is `'R'`, the values of the expressions are still `true` because the relational operator `<`, used with letters, means "comes before in the alphabet," or, more properly, "comes before in the collating sequence of the character set." For example, in the widely used ASCII character set, all of the uppercase letters are in alphabetical order, as are the lowercase letters, but all of the uppercase letters come before the lowercase letters. So

```
'M' < 'R'
```

and

```
'm' < 'r'
```

have the value `true`, but

```
'm' < 'R'
```

has the value `false`.

Of course, we have to be careful about data types when we compare things. The safest approach is to always compare `int`s with `int`s, `float`s with `float`s, `char`s with `char`s, and so on. If you mix data types in a comparison, implicit type coercion takes place, just as it does in arithmetic expressions. If an `int` value and a `float` value are compared, the computer temporarily coerces the `int` value to its `float` equivalent before making the comparison. As with arithmetic expressions, it's wise to use explicit type casting to make your intentions known:

```
someFloat >= float(someInt)
```

If you compare a `bool` value with a numeric value (probably by mistake), the value `false` is temporarily coerced to the number 0, and `true` is coerced to 1. Therefore, if `boolVar` is a `bool` variable, the expression

```
boolVar < 5
```

yields `true` because 0 and 1 are both less than 5.

Until you learn more about the `char` type in Chapter 10, be careful to compare `char` values only with other `char` values. For example, the comparisons

```
'0' < '9'
```

and

```
0 < 9
```

are appropriate, but

```
'0' < 9
```

generates an implicit type coercion and a result that probably isn't what you expect.

We can use relational operators not only to compare variables or constants, but also to compare the values of arithmetic expressions. In the following table, we compare the results of adding 3 to `x` and multiplying `y` by 10 for different values of `x` and `y`.

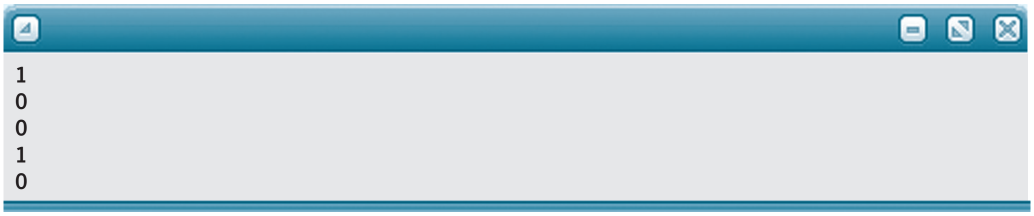
| Value of x | Value of y | Expression | Result |
|---|---|---|---|
| 12 | 2 | `x + 3 <= y * 10` | `true` |
| 20 | 2 | `x + 3 <= y * 10` | `false` |
| 7 | 1 | `x + 3 != y * 10` | `false` |
| 17 | 2 | `x + 3 == y * 10` | `true` |
| 100 | 5 | `x + 3 > y * 10` | `true` |

*Caution:* It's easy to confuse the assignment operator (=) and the == relational operator. These two operators have very different effects in a program. Some people pronounce the relational operator as "equals-equals" to remind themselves of the difference.

The following program shows the output from comparing five sets of integer values.

```
//****************************************
// This program compares integer values.
//****************************************
#include <iostream>
using namespace std;

int main ()
{
  cout << (2 == 2) << endl;
  cout << (3 == 2) << endl;
  cout << (-3 == 2) << endl;
  cout << (-3 == -3) << endl;
  cout << (-3 == -2) << endl;
  return 0;
}
```

Output from a test run:



```
1
0
0
1
0
```

What are those 1s and 0s? C++ stores **`true`** as the value 1 and **`false`** as the value 0. Later in the chapter, we will show you how to convert the numbers 1 and 0 to the words "true" and "false".

### Comparing Strings

In C++, the **`string`** type is an example of a class—a programmer-defined type from which you declare variables that are called objects. Recall that C++ is an object-oriented language. Contained within each **`string`** object is a character string. The **`string`** class is designed such that you can compare these strings using the relational operators. Syntactically, the operands of a relational operator can either be two **`string`** objects, as in

```
myString < yourString
```

or a **`string`** object and a C string, as in

```
myString >= "Johnson"
```

However, both operands cannot be C strings.

Comparison of strings follows the collating sequence of the machine's character set (ASCII, for instance). When the computer tests a relationship between two strings, it begins with the first character of each string, compares those characters according to the collating sequence, and if they are the same repeats the comparison with the next character in each string. The character-by-character test proceeds until either a mismatch is found or the final characters have been compared and are equal. If all their characters are equal, then the two strings are equal. If a mismatch is found, then the string with the character that comes before the other is the "lesser" string.

For example, given the statements

```
string word1;
string word2;

word1 = "Tremendous";
word2 = "Small";
```

the relational expressions in the following table have the indicated values.

| Expression | Value | Reason |
|---|---|---|
| `word1 == word2` | `false` | They are unequal in the first character. |
| `word1 > word2` | `true` | `'T'` comes after `'S'` in the collating sequence. |
| `word1 < "Tremble"` | `false` | Fifth characters don't match, and `'b'` comes before `'e'`. |
| `word2 == "Small"` | `true` | They are equal. |
| `"cat" < "dog"` | Unpredictable | The operands cannot both be C strings.[2] |

In most cases, the ordering of strings corresponds to alphabetical ordering. But when strings have mixed-case letters, we can get nonalphabetical results. For example, in a phone book we expect to see Macauley before MacPherson, but the ASCII collating sequence places all uppercase letters before the lowercase letters, so the string `"MacPherson"` compares as less than `"Macauley"`. To compare strings for strict alphabetical ordering, all the characters must be in the same case. In a later chapter we show an algorithm for changing the case of a string.

If two strings with different lengths are compared and the comparison is equal up to the end of the shorter string, then the shorter string compares as less than the longer string. For example, if `word2` contains `"Small"`, the expression

```
word2 < "Smaller"
```

yields `true`, because the strings are equal up to their fifth character position (the end of the string on the left), and the string on the right is longer.

**QUICK CHECK**

5.2.1 What are the two values that are the basis for Boolean logic? (p. 188)

5.2.2 Write a Boolean expression that is true when the value of the variable `temperature` is greater than 32. (pp. 188–190)

5.2.3 In C++, how many values does the bool data type consist of? (p. 188)

5.2.4 What is a logical expression made up of? (p. 188)

5.2.5 What are possible values for x and y such that the following boolean expression evaluates to false? (pp. 188–190)

```
(x + 3) * 2 <= x * (y - 5)
```

## 5.3 The If Statement

Now that we've seen how to write logical expressions, let's use them to alter the normal flow of control in a program. The If statement is the fundamental control structure that allows branches in the flow of control. With it, we can ask a question and choose a course of action: *If* a certain condition exists, *then* perform one action, *else* perform a different action.

At run time, the computer performs just one of the two actions, depending on the result of the condition being tested. Yet we must include the code for *both* actions in the program. Why? Because, depending on the circumstances, the computer can choose to execute *either* of them. The If statement gives us a way of including both actions in a program and gives the computer a way of deciding which action to take.

2. The expression is syntactically legal in C++ but results in a pointer comparison, not a string comparison. Pointers are not discussed until Chapter 10.

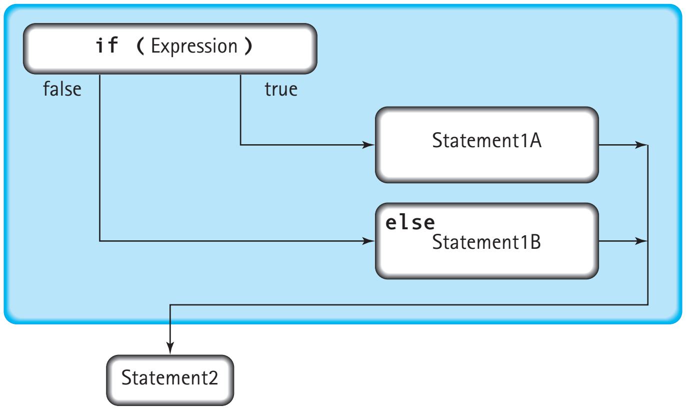


**FIGURE 5.3** If-Then-Else Flow of Control

## The If-Then-Else Form

In C++, the If statement comes in two forms: the *If-Then-Else* form and the *If-Then* form. Let's look first at the If-Then-Else. Here is its syntax template:

If Statement (the If-Then-Else form)

```
if ( Expression )
  Statement1A
else
  Statement1B
```

The expression in parentheses can be of any simple data type. Almost without exception, it will be a logical (Boolean) expression; if not, its value is implicitly coerced to type `bool`. At run time, the computer evaluates the expression. If the value is `true`, the computer executes Statement1A. If the value of the expression is `false`, it executes Statement1B. Statement1A often is called the *then-clause*; Statement1B, the *else-clause*. **FIGURE 5.3** illustrates the flow of control of the If-Then-Else. In the figure, Statement2 is the next statement in the program after the entire If statement.

Notice that a C++ If statement uses the reserved words `if` and `else` but does not include the word *then*. We use the term *If-Then-Else* because it corresponds to how we say things in English: "*If* something is true, *then* do this, *else* do that."

The following code fragment shows how to write an If statement in a program. Observe the indentation of the then-clause and the else-clause, which makes the statement easier to read. Also notice the placement of the statement following the If statement.

```
if (hours <= 40.0)
  pay = rate * hours;
else
  pay = rate * (40.0 + (hours - 40.0) * 1.5);
cout << pay;
```

In terms of instructions to the computer, this code fragment says, "If `hours` is less than or equal to 40.0, compute the regular pay and then go on to execute the output statement. But if `hours` is greater than 40, compute the regular pay and the overtime pay, and then go on to execute the output statement." **FIGURE 5.4** shows the flow of control of this If statement.

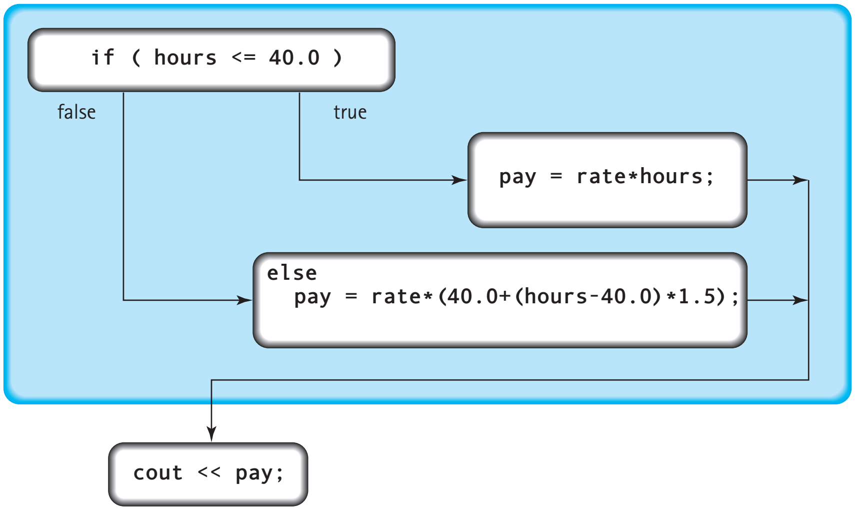


**FIGURE 5.4** Flow of Control for Calculating Pay

If-Then-Else often is used to check the validity of input. For example, before we ask the computer to divide by a data value, we should make sure that the value is not zero. (Even computers can't divide something by zero. If you try, most computers halt the execution of your program.) If the divisor is zero, our program should print out an error message. Here's the code:

```
if (divisor != 0)
  result = dividend / divisor;
else
  cout << "Division by zero is not allowed." << endl;
```

As another example of an If-Then-Else, suppose we want to determine where in a string variable the first occurrence (if any) of the letter *A* is located and the first occurrence (if any) of the letter *B*. Recall from Chapter 3 that the `string` class has a member function named `find`, which returns the position where the item was found (or the named constant `string::npos` if the item wasn't found). The following program outputs the result of such a search, including one that succeeds and one that doesn't.

```
//***************************************************************
// This program demonstrates the string function find with
// with one successful and one unsuccessful application.
//**************************************************************
#include <iostream>
#include <string>
using namespace std;

int main ()
{
  string myString = "CAT";
  int pos;
  pos = myString.find('A');
  if (pos == string::npos)
    cout << "No 'A' was found" << endl;
  else
    cout << "An 'A' was found in position " << pos << endl;
  pos = myString.find('B');
  if (pos == string::npos)
    cout << "No 'B' was found" << endl;
  else
    cout << "A 'B' was found in position " << pos << endl;
  return 0;
}
```

Here is the result of running the program:

```
An 'A' was found in position 1
No 'B' was found
```

Before we look any further at If statements, take another look at the syntax template for the If-Then-Else. According to the template, there is no semicolon at the end of an If statement. In all of the program fragments we have seen so far—the worker's pay, division-by-zero, and string search examples—there seems to be a semicolon at the end of each If statement. Actually, these semicolons belong to the statements in the else-clauses in those examples; assignment statements end in semicolons, as do output statements. The If statement doesn't have its own semicolon at the end.

## Blocks (Compound Statements)

In our division-by-zero example, suppose that when the divisor is equal to zero we want to do *two* things: print the error message *and* set the variable named **`result`** equal to a special value like 9999. We would need two statements in the same branch, but the syntax template seems to limit us to one.

What we really want to do is turn the else-clause into a *sequence* of statements. This is easy. Recall from Chapter 2 that the compiler treats the block (compound statement)

```
{
  :
}
```

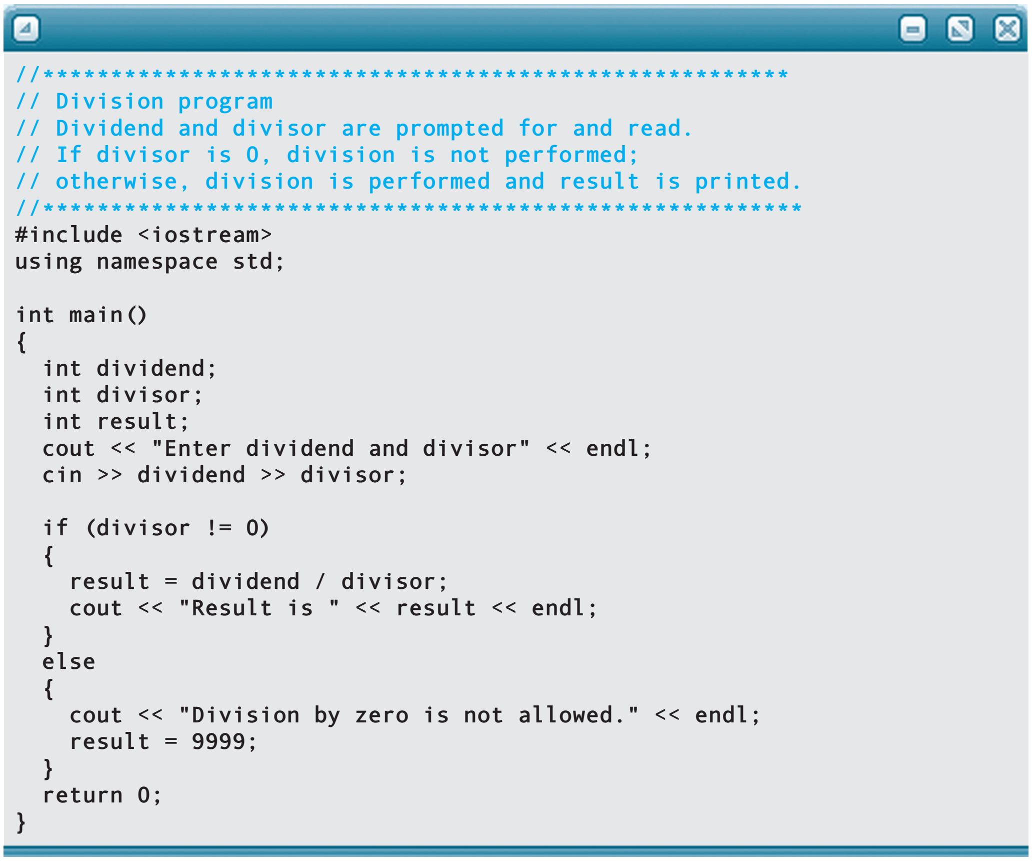
like a single statement. If you put a **`{ }`** pair around the sequence of statements you want in a branch of the If statement, the sequence of statements becomes a single block. For example:

```
if (divisor != 0)
  result = dividend / divisor;
```

```
else
{
  cout << "Division by zero is not allowed." << endl;
  result = 9999;
}
```

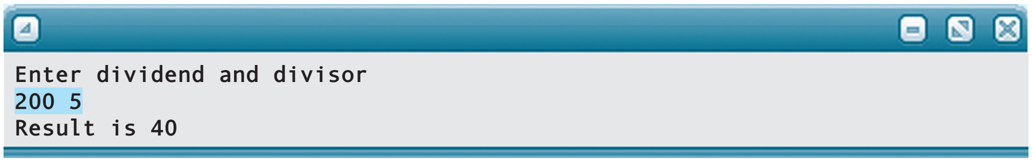
If the value of divisor is 0, the computer both prints the error message and sets the value of result to 9999 before continuing with whatever statement follows the If statement.

Blocks can be used in both branches of an If-Then-Else, as shown in the following program.



```
//******************************************************
// Division program
// Dividend and divisor are prompted for and read.
// If divisor is 0, division is not performed;
// otherwise, division is performed and result is printed.
//*******************************************************
#include <iostream>
using namespace std;

int main()
{
  int dividend;
  int divisor;
  int result;
  cout << "Enter dividend and divisor" << endl;
  cin >> dividend >> divisor;

  if (divisor != 0)
  {
    result = dividend / divisor;
    cout << "Result is " << result << endl;
  }
  else
  {
    cout << "Division by zero is not allowed." << endl;
    result = 9999;
  }
  return 0;
}
```

Here is an example that succeeds:



```
Enter dividend and divisor
200 5
Result is 40
```

Here is one in which the division fails:

```
Enter dividend and divisor
200 0
Division by zero is not allowed.
```

When you use blocks in an If statement, you must remember this rule of C++ syntax: *Never use a semicolon after the right brace of a block*. Semicolons are used only to terminate simple statements such as assignment statements, input statements, and output statements. If you look at the previous examples, you won't see a semicolon after the right brace that signals the end of each block.

### MATTERS OF STYLE Braces and Blocks

C++ programmers use different styles when it comes to locating the left brace of a block. The style we use in this book puts the left and right braces directly below the words **`if`** and **`else`**, with each brace appearing on its own line:

```
if (n >= 2)
{
  alpha = 5;
  beta = 8;
}
else
{
  alpha = 23;
  beta = 12;
}
```

Another popular style is to place the left braces at the end of the **`if`** line and the **`else`** line; the right braces still line up directly below the words **`if`** and **`else`**. This way of formatting the If statement originated with programmers using the C language, the predecessor of C++.

```
if (n >= 2) {
  alpha = 5;
  beta = 8;
}
else {
  alpha = 23;
  beta = 12;
}
```

It makes no difference to the C++ compiler which style you use (and there are other styles as well). It's a matter of personal preference. Whichever style you use, though, you should always use the same style throughout a program. Inconsistency can confuse the person reading your program and give the impression of carelessness.

## The If-Then Form

Sometimes you run into a situation where you want to say, "*If* a certain condition exists, *then* perform some action; otherwise, don't do anything." In other words, you want the computer to skip a sequence of instructions if a certain condition isn't met. You could do this by leaving the **else** branch empty, using only the null statement:

```
if (a <= b)
  c = 20;
else
  ;
```

Better yet, you can simply leave off the **else** part. The resulting statement is the If-Then form of the If statement. This is its syntax template:

If Statement (the If-Then form)

```
if    ( Expression )
  Statement
```

Here's an example of an If-Then. Notice the indentation and the placement of the statement that follows the If-Then.

```
if (age < 18)
  cout << "Not an eligible ";
cout << "voter." << endl;
```

This statement means that if **age** is less than 18, first print "Not an eligible " and then print "voter." If **age** is not less than 18, skip the first output statement and go directly to print "voter." **FIGURE 5.5** shows the flow of control for an If-Then statement.

Like the two branches in an If-Then-Else, the one branch in an If-Then can be a block. For example, suppose you are writing a program to compute income taxes. One of the lines

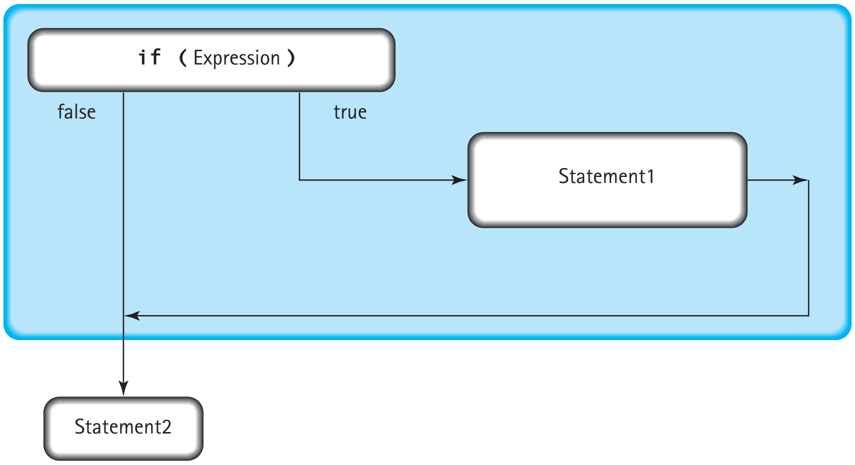


**FIGURE 5.5** If-Then Flow of Control

on the tax form reads "Subtract line 23 from line 17 and enter result on line 24; if result is less than zero, enter zero and check box 24A." You can use an If-Then to do this in C++:

```
result = line17 - line23;
if (result < 0.0)
{
  cout << "Check box 24A" << endl;
  result = 0.0;
}
line24 = result;
```

This code does exactly what the tax form says it should: It computes the result of subtracting line 23 from line 17. Then it looks to see if **`result`** is less than 0. If it is, the fragment prints a message telling the user to check box 24A and then sets **`result`** to 0. Finally, the calculated result (or 0, if the result is less than 0) is stored into a variable named **`line24`**.

What happens if we leave out the left and right braces in the code fragment? Let's look at it:

```
result = line17 - line23;        // Incorrect version
if (result < 0.0)
  cout << "Check box 24A" << endl;
  result = 0.0;
line24 = result;
```

Despite the way we have indented the code, the compiler takes the then-clause to be a single statement—the output statement. If **`result`** is less than 0, the computer executes the output statement, then sets **`result`** to 0, and then stores **`result`** into **`line24`**. So far, so good. But if **`result`** is initially greater than or equal to 0? Then the computer skips the then-clause and proceeds to the statement following the If statement—the assignment statement that sets **`result`** to 0. The unhappy outcome is that **`result`** ends up as 0 no matter what its initial value was!

The moral here is not to rely on indentation alone; you can't fool the compiler. If you want a compound statement for a then- or else-clause, you must include the left and right braces.

## A Common Mistake

Earlier we warned against confusing the = operator with the == operator. Here is an example of a mistake that every C++ programmer is guaranteed to make at least once in his or her career:

```
cin >> n;
if (n = 3)            // Wrong
  cout << "n equals 3";
else
  cout << "n doesn't equal 3";
```

This code segment *always* prints out

```
n equals 3
```

no matter what was input for **`n`**.

Here is the reason: We've used the wrong operator in the If test. The expression **`n = 3`** is not a logical expression; it's an *assignment expression*. (If an assignment is written as a separate statement ending with a semicolon, it's an assignment *statement*.) An assignment expression has a *value* (here, it's 3) and a *side effect* (storing 3 into `n`). In the If statement of our example, the computer finds the value of the tested expression to be 3. Because 3 is a nonzero value and thus is coerced to `true`, the then-clause is executed, no matter what the value of `n` is. Worse yet, the side effect of the assignment expression is to store 3 into `n`, destroying what was there.

Our intention is not to focus on assignment expressions; we discuss their use later in the book. What's important now is that you see the effect of using = when you meant to use ==. The program compiles correctly but runs incorrectly. When debugging a faulty program, always look at your If statements to see whether you've made this particular mistake.

## SOFTWARE MAINTENANCE CASE STUDY: Incorrect Output

**MAINTENANCE TASK:** When you were helping your parents with their mortgage loan, you wrote a program to determine the monthly payments given the amount to be borrowed, the interest rate, and the number of years. You gave the same program to a friend to use when she was buying a car. She says that the program gives very strange results. You ask for an example of the erroneous output. She said it gave a ridiculously high rate for an amount of $3000, for 2 years at an interest rate of 6.8%.

**VERIFYING THE BEHAVIOR:** Whenever a user reports a bug, you should begin by making sure that you can generate the reported behavior yourself. This sets up the necessary conditions for isolating the problem and testing your modifications. You run the program using the data your friend supplied and the answers seem reasonable.

```
Loan amount:      3000.00
Interest rate:    0.0680
Number of years: 2
Monthly payment: 134.05
```

Because you can't get the program to exhibit the bug, you go back to your friend to ask more questions. (Remember, that's one of our problem-solving strategies, and they apply just as much to debugging as to writing new applications.) "What sort of ridiculously high rate did you get?" you ask her. Your friend says that she got 1700.0355647311262 as the payment amount. Clearly, $1700.03 per month for 2 years is not correct. What could have gone wrong?

Just as a mechanic may have to go for a drive with a car's owner to understand what's wrong, sometimes you have to sit and watch a user run your application. You ask your friend to show you what happened. Here's what she did:

```
Loan amount:      3000.00
Interest rate:    6.8000
Number of years: 2
Monthly payment: 1700.04
```

Aha! You wrote the code to read the interest rate as a decimal fraction, and she is entering it as a percentage! There's an easy solution to this problem. You can tell her to enter the interest rate as a decimal fraction, and you won't have to change the code at all. Such a "fix" is known as a *workaround.*

She can do this, but says, "It's annoying to have to do the math in my head. Why can't you fix the program so that it takes the percentage the way that people normally write it?" She has a good point. As a programmer, you wrote the code in a way that made it easier for you. But a good application should be designed to make it easier for the user, which is what we mean by *user friendly.* If other people will be using your application, you must think in those terms.

To make your friend happy, you have to change the program to first divide the input percentage by 100. But then you remember that you've also given the program to a friend who is a math major and who prefers to enter percentages as decimal fractions. The program could ask the user for his or her preference, but again, that's more work for the user. What to do? How to accommodate both kinds of users with the least hassle?

Obviously, there has to be a branch somewhere in the application that chooses between dividing the percentage by 100 and using it as entered. Interest rates on loans are generally no more than about 25% and no less than one-quarter of a percent. So we could simply say that any number greater than or equal to 0.25 is assumed to be a percentage, and any number less than that is a decimal fraction. Thus, the necessary If statement would be written as follows:

```
if (yearlyInterest >= 0.25)           // Assume percent entered
  yearlyInterest = yearlyInterest / 100.0;
```

Is that the only change? That's all that's required to make the program do the proper calculations. However, your friend indicated that it would be nice to have a version that used the keyboard for input and output rather than files. Let's make this version use keyboard input and output and include our assumptions in the input prompts.

**MODIFIED CODE:** You call up the file with your source code so that you can modify it. You also refamiliarize yourself with the compound interest formula:

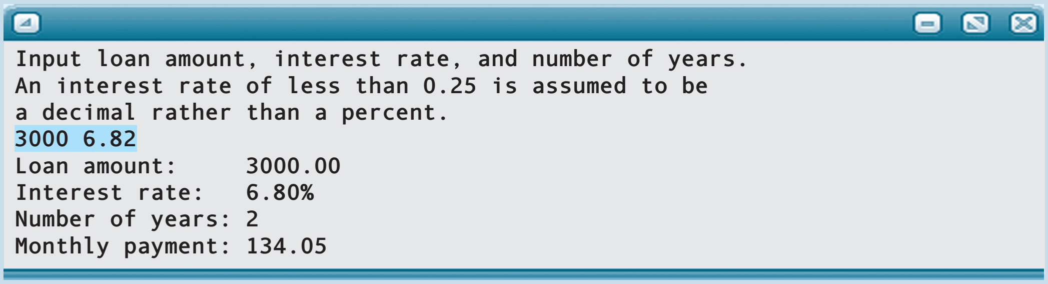
$$\frac{Amount \times (1 + Monthly\ Interest)^{Number\ of\ Payments} \times Monthly\ Interest}{(1 + Monthly\ Interest)^{Number\ of\ Payments} - 1}$$

You then insert the revised input and output and the If statement. The changes are highlighted in the code below.

```
//******************************************************************
// Mortgage Payment Calculator program
// This program determines the monthly payments on a loan given
// the loan amount, the yearly interest rate, and the number of
// years.
//******************************************************************
#include <cmath>
#include <iomanip>
#include <iostream>
using namespace std;

int main()
{
  // Input variables
  float loanAmount;
  float yearlyInterest;
  int numberOfYears;
```

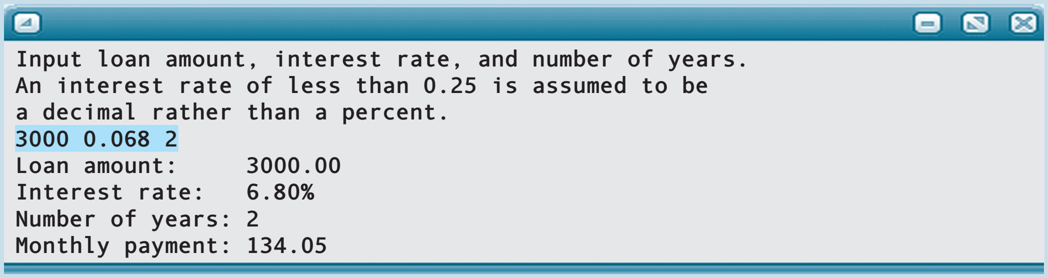
```
   // Local variables
   float monthlyInterest;
   int numberOfPayments;
   float payment;

   // Prompts
   cout << "Input loan amount, interest rate, and number of years."
        << endl;
   cout << "An interest rate of less than 0.25 is assumed to be "
        << endl;
   cout << "a decimal rather than a percent." << endl;

   // Read values
   cin >> loanAmount >> yearlyInterest >> numberOfYears;

   // Calculate values
   if (yearlyInterest >= 0.25)      // Assume percent entered
     yearlyInterest = yearlyInterest / 100.0;
   monthlyInterest = yearlyInterest / 12;
   numberOfPayments = numberOfYears * 12;
   payment = (loanAmount * pow(1 + monthlyInterest, numberOfPayments)
      * monthlyInterest)/
     (pow(1 + monthlyInterest, numberOfPayments) - 1 );

   // Output results
   cout << fixed << "Loan amount:         " << setprecision(2)
        << loanAmount << endl << "Interest rate:   "
        << setprecision(4) << yearlyInterest*100.0 << "%"  << endl
        << "Number of years: " << numberOfYears << endl;
   cout << fixed
        << "Monthly payment: " << setprecision(2) << payment << endl;
   return 0;
 }
```

Here is the output from two test runs of the application, one with data entered as a percentage and one with data entered as a decimal:



```
Input loan amount, interest rate, and number of years.
An interest rate of less than 0.25 is assumed to be
a decimal rather than a percent.
3000 6.82
Loan amount:     3000.00
Interest rate:   6.80%
Number of years: 2
Monthly payment: 134.05
```

**SOFTWARE MAINTENANCE CASE STUDY: Incorrect Output**



```
Input loan amount, interest rate, and number of years.
An interest rate of less than 0.25 is assumed to be
a decimal rather than a percent.
3000 0.068 2
Loan amount:      3000.00
Interest rate:    6.80%
Number of years: 2
Monthly payment: 134.05
```

**QUICK CHECK**

5.3.1 Write an If-Then-Else statement that uses the test from Question 5.2.2 to output either `"Above freezing."` or `"Freezing or below."`. (pp. 193–195)

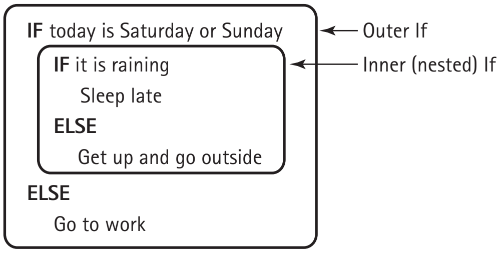
5.3.2 Why must we provide code for both actions of an If statement? (p. 192)

5.3.3 What data type must the expression in parentheses of an If statement evaluate to? (p. 193)

## 5.4 Nested If Statements

There are no restrictions on what the statements in an If can be. Therefore, an If within an If is okay. In fact, an If within an If within an If is legal. The only limitation here is that people cannot follow a structure that is too involved, and readability is one of the hallmarks of a good program.

When we place an If within an If, we are creating a *nested control structure*. Control structures nest much like mixing bowls do, with smaller ones tucked inside larger ones. Here's an example, written in pseudocode:



```
IF today is Saturday or Sunday            ← Outer If
    IF it is raining                      ← Inner (nested) If
        Sleep late
    ELSE
        Get up and go outside
ELSE
    Go to work
```

In general, any problem that involves a *multiway branch* (more than two alternative courses of action) can be coded using nested If statements. For example, to print out the name of a month given its number, we could use a sequence of If statements (unnested):

```
if (month == 1)
  cout << "January";
if (month == 2)
  cout << "February";
```

```
if (month == 3)
  cout << "March";
  ⋮
if (month == 12)
  cout << "December";
```

But the equivalent nested If structure,

```
if (month == 1)
  cout << "January";
else
  if (month == 2)       // Nested If
    cout << "February";
  else
    if (month == 3)       // Nested If
      cout << "March";
    else
      if (month == 4)       // Nested If
.
.
.
```

is more efficient because it makes fewer comparisons. The first version—the sequence of independent If statements—always tests every condition (all 12 of them), even if the first one is satisfied. In contrast, the nested If solution skips all remaining comparisons after one alternative has been selected. As fast as modern computers are, many applications require so much computation that inefficient algorithms can waste hours of computer time. Always be on the lookout for ways to make your programs more efficient, as long as doing so doesn't make them difficult for other programmers to understand. It's usually better to sacrifice a little efficiency for the sake of readability.

In the last example, notice how the indentation of the then- and else-clauses causes the statements to move continually to the right. Alternatively, we can use a special indentation style with deeply nested If-Then-Else statements to indicate that the complex structure is just choosing one of a set of alternatives. This general multiway branch is known as an *If-Then-Else-If* control structure:

```
if (month == 1)
  cout << "January";
else if (month == 2)      // Nested If
  cout << "February";
else if (month == 3)      // Nested If
  cout << "March";
else if (month == 4)      // Nested If
.
.
.
else
  cout << "December";
```

This style prevents the indentation from marching continuously to the right. More importantly, it visually conveys the idea that we are using a 12-way branch based on the variable `month`.

It's important to note one difference between the sequence of If statements and the nested If: More than one alternative can be taken by the sequence of Ifs, but the nested If can select only one option. To see why this is important, consider the analogy of filling out a questionnaire. Some questions are like a sequence of If statements, asking you to circle all the items in a list that apply to you (such as all your hobbies). Other questions ask you to circle only one item in a list (your age group, for example) and are thus like a nested If structure. Both kinds of questions occur in programming problems. Being able to recognize which type of question is being asked permits you to immediately select the appropriate control structure.

Another particularly helpful use of the nested If is when you want to select from a series of consecutive ranges of values. For example, suppose that we want to print out an appropriate activity for the outdoor temperature, given the following information:

| Activity | Temperature |
|---|---|
| Swimming | temperature > 85 |
| Tennis | 70 < temperature <= 85 |
| Golf | 32 < temperature <= 70 |
| Skiing | 0 < temperature <= 32 |
| Dancing | temperature <= 0 |

At first glance, you may be tempted to write a separate If statement for each range of temperatures. On closer examination, however, it is clear that these If conditions are interdependent. That is, if one of the statements is executed, none of the others should be executed. We are really selecting one alternative from a set of possibilities—just the sort of situation in which we can use a nested If structure as a multiway branch. The only difference between this problem and our earlier example of printing the month name from its number is that we must check ranges of numbers in the If expressions of the branches.

When the ranges are consecutive, we can take advantage of that fact to make our code more efficient. We arrange the branches in consecutive order by range. Then, if a particular branch has been reached, we know that the preceding ranges have been eliminated from consideration. Thus the If expressions must compare the temperature to only the lowest value of each range. To see how this works, look at the following `Activity` program.

```
//******************************************************************
// Activity program
// This program outputs an appropriate activity
// for a given temperature
//******************************************************************
#include <iostream>
using namespace std;

int main()
{
  int temperature;  // The outside temperature

  // Read and echo temperature
  cout << "Enter the outside temperature:" << endl;
  cin >> temperature;
  cout << "The current temperature is " << temperature << endl;

  // Print activity
  cout << "The recommended activity is ";
  if (temperature > 85)
    cout << "swimming." << endl;
  else if (temperature > 70)
    cout << "tennis." << endl;
  else if (temperature > 32)
    cout << "golf." << endl;
  else if (temperature > 0)
    cout << "skiing." << endl;
  else
    cout << "dancing." << endl;
  return 0;
}
```

To understand how the If-Then-Else-If structure in this program works, consider the branch that tests for **temperature** greater than **70**. If it has been reached, we know that **temperature** must be less than or equal to **85** because that condition causes this particular **else** branch to be taken. Thus we need to test only whether **temperature** is above the bottom of this range (**> 70**). If that test fails, then we enter the next else-clause knowing that **temperature** must be less than or equal to **70**. Each successive branch checks the bottom of its range until we reach the final **else**, which takes care of all the remaining possibilities.

If the ranges aren't consecutive, however, we must test the data value against both the highest and lowest values of each range. We still use an If-Then-Else-If because that is the best structure for selecting a single branch from multiple possibilities, and we may arrange the ranges in consecutive order to make them easier for a human reader to follow. In such a case, there is no way to reduce the number of comparisons when there are gaps between the ranges.

## The Dangling `else`

When If statements are nested, you may find yourself confused about the **if-else** pairings. That is, to which **if** does an **else** belong? For example, suppose that if a student's average is below 60, we want to print "Failing"; if the average is at least 60 but less than 70, we want to print "Passing but marginal"; and if it is 70 or greater, we don't want to print anything. We code this information with an If-Then-Else nested within an If-Then:

```
if (average < 70.0)
  if (average < 60.0)
    cout << "Failing";
  else
    cout << "Passing but marginal";
```

How do we know to which **if** the **else** belongs? Here is the rule that the C++ compiler follows: In the absence of braces, an **else** is always paired with the closest preceding **if** that doesn't already have an **else** paired with it. We indented the code to reflect this pairing.

Suppose we write the fragment like this:

```
if (average >= 60.0)     // Incorrect version
  if (average < 70.0)
    cout << "Passing but marginal";
else
  cout << "Failing";
```

Here we want the **else** branch attached to the outer If statement, not the inner If, so we indent the code as you see it. Of course, indentation does not affect the execution of the code. Even though the **else** aligns with the first **if**, the compiler pairs it with the second **if**. An **else** that follows a nested If-Then is called a *dangling* **else**. It doesn't logically belong with the nested If but is attached to it by the compiler.

To attach the **else** to the first **if**, not the second, you can turn the outer then-clause into a block:

```
if (average >= 60.0)     // Correct version
{
  if (average < 70.0)
  cout << "Passing but marginal";
}
else
  cout << "Failing";
```

The **{ }** pair indicates that the inner If statement is complete, so the **else** must belong to the outer **if**.

**QUICK CHECK**

5.4.1 What purpose does a nested branch serve? (pp. 203–205)

5.4.2 Write nested If statements to print messages indicating whether a temperature is below freezing, freezing, above freezing but not boiling, or boiling and above. (pp. 203–205)

5.4.3 What type of control structure do we have when an If statement is within another If statement? (p. 203)

5.4.4 What type of branching control structure is used when we have many (more than 2) alternative courses of action? (p. 204)

5.4.5 What problem does a C++ compiler solve using the rule: In the absence of braces, an **else** is always paired with the closest preceding **if** that doesn't already have an **else** paired with it. (p. 206)

## 5.5 Logical Operators

In mathematics, the *logical* (or *Boolean*) *operators* AND, OR, and NOT take logical expressions as operands. C++ uses special symbols for the logical operators: **&&** (for AND), **||** (for OR), and **!** (for NOT). By combining relational operators with logical operators, we can make more complex assertions. For example, in the last section we used two If statements to determine if an average was greater than 60.0 but less than 70.0. In C++, we would write the expression this way:

```
average >= 60.0  && average < 70.0
```

The AND operation (**&&**) requires both relationships to be true for the overall result to be true. If either or both of the relationships are false, the entire result is false.

The OR operation (**||**) takes two logical expressions and combines them. If *either* or *both* are true, the result is true. *Both* values must be false for the result to be false. For example, we can determine whether the midterm grade is an A *or* the final grade is an A. If either the midterm grade or the final grade equals A, the assertion is true. In C++, we write the expression like this:

```
midtermGrade == 'A' || finalGrade == 'A'
```

The **&&** and **||** operators always appear between two expressions; they are binary (two-operand) operators. The NOT operator (**!**) is a unary (one-operand) operator. It precedes a single logical expression and gives its opposite as the result. If **(grade == 'A')** is false, then **!(grade == 'A')** is true. NOT gives us a convenient way of reversing the meaning of an assertion. For example,

```
!(hours > 40)
```

is the equivalent of

```
hours <= 40
```

In some contexts, the first form is clearer; in others, the second makes more sense.

The following pairs of expressions are equivalent:

| Expression | Equivalent Expression |
|---|---|
| `!(a == b)` | `a != b` |
| `!(a == b \|\| a == c)` | `a != b && a != c` |
| `!(a == b && c > d)` | `a != b \|\| c <= d` |

Take a close look at these expressions to be sure you understand why they are equivalent. Try evaluating them with some values for `a`, `b`, `c`, and `d`. Notice the pattern: The expression on the left is just the one to its right with `!` added and the relational and logical operators reversed (for example, `==` instead of `!=` and `||` instead of `&&`). Remember this pattern. It allows you to rewrite expressions in the simplest form.[3]

Logical operators can be applied to the results of comparisons. They can also be applied directly to variables of type `bool`. For example, instead of writing

```
isElector = (age >= 18 && district == 23);
```

to assign a value to the Boolean variable `isElector`, we could use two intermediate Boolean variables, `isVoter` and `isConstituent`:

```
isVoter = (age >= 18);
isConstituent = (district == 23);
isElector = isVoter && isConstituent;
```

The following two tables summarize the results of applying `&&` and `||` to a pair of logical expressions (represented here by Boolean variables `x` and `y`).

| Value of x | Value of y | Value of x && y |
|---|---|---|
| `true` | `true` | `true` |
| `true` | `false` | `false` |
| `false` | `true` | `false` |
| `false` | `false` | `false` |

| Value of x | Value of y | Value of x \|\| y |
|---|---|---|
| `true` | `true` | `true` |
| `true` | `false` | `true` |
| `false` | `true` | `true` |
| `false` | `false` | `false` |

The following table summarizes the results of applying the `!` operator to a logical expression (represented by Boolean variable `x`):

| Value of x | Value of !x |
|---|---|
| `true` | `false` |
| `false` | `true` |

3. In Boolean algebra, the pattern is formalized by a theorem called *DeMorgan's law*.

Technically, the C++ operators `!`, `&&`, and `||` are not required to have logical expressions as operands. Their operands can be of any simple data type, even floating-point types. If an operand is not of type `bool`, its value is temporarily coerced to type `bool` as follows: A 0 value is coerced to `false`, and any nonzero value is coerced to `true`. As an example, you sometimes encounter C++ code that looks like this:

```
float height;
bool  badData;
.
.
.
cin >> height;
badData = !height;
```

The assignment statement says to set `badData` to `true` if the coerced value of `height` is `false`. That is, the statement is really saying, "Set `badData` to `true` if `height` equals 0.0." Although this assignment statement works correctly in the C++ language, the following statement is more readable:

```
badData = (height == 0.0);
```

Throughout this text we apply the logical operators *only* to logical expressions, not to arithmetic expressions.

*Caution:* It's easy to confuse the logical operators `&&` and `||` with two other C++ operators, `&` and `|`. We don't discuss the `&` and `|` operators here, but we'll tell you that they are used for manipulating individual bits within a memory cell—a role quite different from that of the logical operators. If you accidentally use `&` instead of `&&`, or `|` instead of `||`, you won't get an error message from the compiler, but your program probably will compute wrong answers. Some programmers pronounce `&&` as "and-and" and `||` as "or-or" to avoid making mistakes.

The preceding assignment statement can also be implemented using an If statement. That is,

```
badData = (height == 0.0);
```

can be implemented as

```
if (height == 0.0)
  badData = true;
else
  badData = false;
```

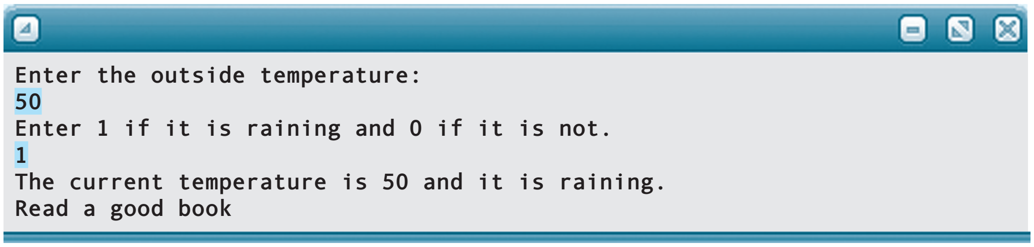
As you can see, the first form is simpler to write and, with a little practice, is easier to read.

The following application sets the Boolean variables `walk`, `movie`, and `book` to `true` or `false` depending on what the temperature is and whether it is raining. An If statement is then used to print the results.

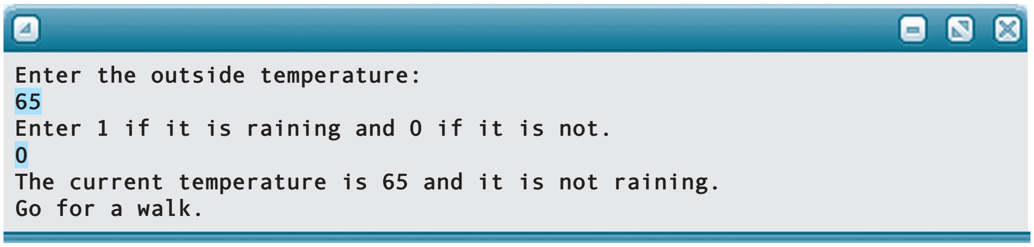
```
//******************************************************************
// Activity program
// This program outputs an appropriate activity
// for a given temperature
//******************************************************************
#include <iostream>
#include <string>
using namespace std;

int main()
{
  int temperature;    // The outside temperature
  bool raining;
  bool walk;
  bool movie;
  bool book;

  // Read and echo temperature
  cout << "Enter the outside temperature:" << endl;
  cin >> temperature;
  cout << "Enter 1 if it is raining and 0 if it is not.";
  cin >> raining;
  cout << "The current temperature is " << temperature;
  if (raining)
    cout << " and it is raining." << endl;
  else
    cout << " and it is not raining." << endl;

  // Print activity
  walk = temperature > 60 && !raining;
  movie = temperature > 60 && raining;
  book = temperature < 60;
  if (walk)
    cout << "Go for a walk." << endl;
  else
    if (movie)
      cout << "Go to a movie." << endl;
    else
      cout << "Read a good book" << endl;
  return 0;
}
```

Following are the results of running the program on four different sets of input:

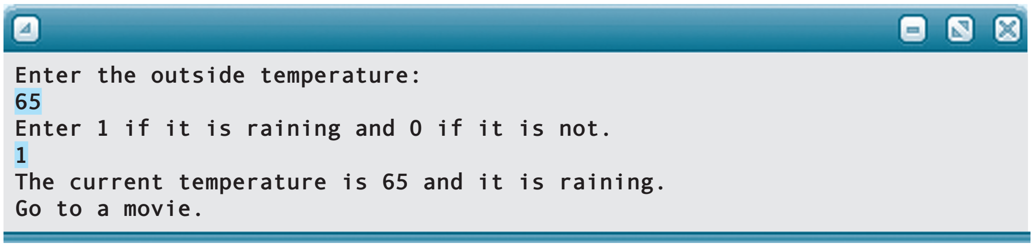
```
Enter the outside temperature:
50
Enter 1 if it is raining and 0 if it is not.
0
The current temperature is 50 and it is not raining.
Read a good book
```



```
Enter the outside temperature:
50
Enter 1 if it is raining and 0 if it is not.
1
The current temperature is 50 and it is raining.
Read a good book
```



```
Enter the outside temperature:
65
Enter 1 if it is raining and 0 if it is not.
0
The current temperature is 65 and it is not raining.
Go for a walk.
```



```
Enter the outside temperature:
65
Enter 1 if it is raining and 0 if it is not.
1
The current temperature is 65 and it is raining.
Go to a movie.
```

### Short-Circuit Evaluation

Consider the logical expression

```
i == 1 && j > 2
```

Some programming languages use *full evaluation* of logical expressions. With full evaluation, the computer first evaluates both subexpressions (both `i == 1` and `j > 2`) before applying the `&&` operator to produce the final result.

In contrast, C++ uses short-circuit (or conditional) evaluation of logical expressions. Evaluation proceeds from left to right, and the computer stops evaluating subexpressions as soon as possible—that is, as soon as it knows the Boolean value of the entire expression. How can the computer know if a lengthy logical expression yields `true` or `false` if it doesn't examine all the subexpressions? Let's look first at the AND operation.

**Short-circuit (conditional) evaluation** Evaluation of a logical expression in left-to-right order, with evaluation stopping as soon as the final truth value can be determined.

An AND operation yields the value `true` only if both of its operands are `true`. In the earlier expression, suppose that the value of `i` happens to be 95. The first subexpression yields `false`, so it isn't necessary even to look at the second subexpression. The computer stops evaluation and produces the final result of `false`.

With the OR operation, the left-to-right evaluation stops as soon as a subexpression yielding `true` is found. Remember that an OR produces a result of `true` if either one or both of its operands are `true`. Suppose we have this expression:

```
c <= d || e == f
```

If the first subexpression is `true`, evaluation stops and the entire result is `true`. The computer doesn't waste time with an unnecessary evaluation of the second subexpression.

## MAY WE INTRODUCE George Boole

Boolean algebra is named for its inventor, English mathematician George Boole, who was born in 1815. His father, a tradesman, began teaching George mathematics at an early age. But Boole initially was more interested in classical literature, languages, and religion—interests he maintained throughout his life. By the time he was 20, he had taught himself French, German, and Italian. He was well versed in the writings of Aristotle, Spinoza, Cicero, and Dante, and wrote several philosophical papers himself.

At 16, to help support his family, Boole took a position as a teaching assistant in a private school. His work there and a second teaching job left him little time to study. A few years later, he opened a school and began to learn higher mathematics on his own. In spite of his lack of formal training, his first scholarly paper was published in the *Cambridge Mathematical Journal* when he was just 24. Boole went on to publish more than 50 papers and several major works before he died in 1864, at the peak of his career.

Boole's *The Mathematical Analysis of Logic* was published in 1847. It would eventually form the basis for the development of digital computers. In the book, Boole set forth the formal axioms of logic (much like the axioms of geometry) on which the field of symbolic logic is built.

Boole drew on the symbols and operations of algebra in creating his system of logic. He associated the value 1 with the universal set (the set representing everything in the universe) and the value 0 with the empty set, and restricted his system to these two quantities. He then defined operations that are analogous to subtraction, addition, and multiplication. Variables in the system have symbolic values. For example, if a Boolean variable $P$ represents the set of all plants, then the expression $1 - P$ refers to the set of all things that are not plants. We can simplify the expression by using $-P$ to mean "*not* plants." ($0 - P$ is simply 0 because we can't remove elements from the empty set.) The subtraction operator in Boole's system corresponds to the ! (NOT) operator in C++. In a C++ program, we might set the value of the Boolean variable plant to true when the name of a plant is entered, whereas `!plant` is `true` when the name of anything else is input.

The expression $0 + P$ is the same as $P$. However, $0 + P + F$, where $F$ is the set of all foods, is the set of all things that are either plants or foods. So the addition operator in Boole's algebra is the same as the C++ `||` (OR) operator.

The analogy can be carried to multiplication: $0 \times P$ is 0, and $1 \times P$ is $P$. But what is $P \times F$? It is the set of things that are both plants and foods. In Boole's system, the multiplication operator is the same as the **&&** (AND) operator.

In 1854, Boole published *An Investigation of the Laws of Thought, on Which Are Founded the Mathematical Theories of Logic and Probabilities.* In the book, he described theorems built on his axioms of logic and extended the algebra to show how probabilities could be computed in a logical system. Five years later, Boole published *Treatise on Differential Equations,* then *Treatise on the Calculus of Finite Differences.* The latter book is one of the cornerstones of numerical analysis, which deals with the accuracy of computations. (In Chapter 10, we examine the important role numerical analysis plays in computer programming.)

Boole received little recognition and few honors for his work. Given the importance of Boolean algebra in modern technology, it is hard to believe that his system of logic was not taken seriously until the early twentieth century. George Boole was truly one of the founders of computer science.

## Precedence of Operators

In Chapter 3, we discussed the rules of precedence—the rules that govern the evaluation of complex arithmetic expressions. C++'s rules of precedence also govern relational and logical operators. Here's a list showing the order of precedence for the arithmetic, relational, and logical operators (with the assignment operator thrown in as well):

```
!  Unary +  Unary -      Highest precedence
*  /  %                        |
+  -                           |
<  <=  >  >=                   |
==  !=                         |
&&                             |
||                             ↓
=                        Lowest precedence
```

Operators on the same line in the list have the same precedence. If an expression contains several operators with the same precedence, most of the operators group (or *associate*) from left to right. For example, the expression

```
a / b * c
```

means `(a / b) * c`, not `a / (b * c)`. However, the unary operators (`!`, unary `+`, unary `-`) group from right to left. Although you'd never have occasion to use this expression,

```
!!badData
```

its meaning is `!(!badData)` rather than the meaningless `(!!)badData`. Appendix B, "Precedence of Operators," lists the order of precedence for all operators in C++. In skimming the appendix, you can see that a few of the operators associate from right to left (for the same reason we just described for the `!` operator).

Parentheses are used to override the order of evaluation in an expression. If you're not sure whether parentheses are necessary, use them anyway. The compiler disregards unnecessary parentheses. So, if they clarify an expression, use them. Some programmers like to include extra parentheses when assigning a relational expression to a Boolean variable:

```
dataInvalid = (inputVal == 0);
```

The parentheses are not actually needed here; the assignment operator has the lowest precedence of all the operators we've just listed. So we could write the statement as

```
dataInvalid = inputVal == 0;
```

Some people find the parenthesized version more readable, however.

One final comment about parentheses: C++, like other programming languages, requires that parentheses always be used in pairs. Whenever you write a complicated expression, take a minute to go through and pair up all of the opening parentheses with their closing counterparts.

## SOFTWARE ENGINEERING TIP Changing English Statements into Logical Expressions

In most cases, you can write a logical expression directly from an English statement or mathematical term in an algorithm. But you have to watch out for some tricky situations. Remember our sample logical expression:

```
midtermGrade == 'A' || finalGrade == 'A'
```

In English, you would be tempted to write this expression: "Midterm grade or final grade equals A." In C++, you can't write the expression as you would in English. That is,

```
midtermGrade || finalGrade == 'A'
```

won't work because the `||` operator is connecting a `char` value (`midtermGrade`) and a logical expression (`finalGrade == 'A'`). The two operands of `||` should be logical expressions. (Note that this expression is wrong in terms of logic, but it isn't "wrong" to the C++ compiler. Recall that the `||` operator may legally connect two expressions of any data type, so this example won't generate a syntax error message. The program will run, but it won't work the way you intended.)
A variation of this mistake is to express the English assertion "*i* equals either 3 or 4" as follows:

```
i == 3 || 4
```

Again, the syntax is correct but the semantics are not. This expression always evaluates to `true`. The first subexpression, `i == 3`, may be `true` or `false`. But the second subexpression, `4`, is nonzero and, therefore, is coerced to the value `true`. Thus the `||` operator causes the entire expression to be `true`. We repeat: Use the `||` operator (and the **&&** operator) only to connect two logical expressions. Here's what we want:

```
i == 3 || i == 4
```

In math books, you might see a notation like this:

```
12 < y < 24
```

which means "*y* is between 12 and 24." This expression is legal in C++ but gives an unexpected result. First, the relation `12 < y` is evaluated, giving the result `true` or `false`. The computer then coerces this result to 1 or 0 to compare it with the number 24. Because both 1 and 0 are less than 24, the result is always `true`. To write this expression correctly in C++, you must use the **&&** operator as follows:

```
12 < y && y < 24
```

## Relational Operators with Floating-Point Types

So far, we've talked about comparing `int`, `char`, and `string` values. Here we look at `float` values.

*Do not compare floating-point numbers for equality.* Because small errors in the rightmost decimal places are likely to arise when calculations are performed on floating-point numbers, two **float** values rarely are exactly equal. For example, consider the following code that uses two **float** variables named **oneThird** and **x**:

```
oneThird = 1.0 / 3.0;
x = oneThird + oneThird + oneThird;
```

We would expect **x** to contain the value 1.0, but it probably doesn't. The first assignment statement stores an *approximation* of 1/3 into **oneThird**, perhaps 0.333333. The second statement stores a value like 0.999999 into **x**. If we now ask the computer to compare **x** with 1.0, the comparison yields **false**.

Instead of testing floating-point numbers for equality, we test for *near* equality. To do so, we compute the difference between the two numbers and test whether the result is less than some maximum allowable difference. For example, we often use comparisons like this:

```
fabs(r - s) < 0.00001
```

where **fabs** is the floating-point absolute value function from the C++ standard library. The expression **fabs(r - s)** computes the absolute value of the difference between two float variables **r** and **s**. If the difference is less than 0.00001, the two numbers are close enough to call them equal.

**QUICK CHECK**

5.5.1 What are the C++ boolean operators that correspond to the logical operators AND, OR, and NOT? (p. 207)

5.5.2 Write an equivalent boolean expression for **(a != b && c < d)** that uses the operators == and >= and **!**. (p. 208)

5.5.3 Write a single assignment statement that corresponds to the following If statement (assuming that grade is type **float** and failed is type **bool**): (p. 209)

```
if (grade <= 50.0)
    failed = true;
else
    failed = false;
```

5.5.4 Which direction is a logical expression evaluated in in C++? (p. 211)

5.5.5 Write a boolean expression such that it demonstrates short-circuit evaluation. Highlight the part of the expression that *is not executed*. (p. 211)

## 5.6 Testing the State of an I/O Stream

In Chapter 4, we talked about the concept of input and output streams in C++. As part of that discussion, introduced the classes **istream**, **ostream**, **ifstream**, and **ofstream**. We said that any of the following can cause an input stream to enter the fail state:

- Invalid input data
- An attempt to read beyond the end of a file
- An attempt to open a nonexistent file for input

C++ provides a way to check whether a stream is in the fail state. In a logical expression, you simply use the name of the stream object (such as **cin**) as if it were a Boolean variable:

```
if (cin)
.
.
.
```

```
if (!inFile)
.
.
.
```

**Testing the state of a stream** The act of using a C++ stream object in a logical expression as if it were a Boolean variable; the result is true if the last I/O operation on that stream succeeded, and false otherwise.

When you do this, you are said to be testing the state of the stream. The result of the test is either `true` (meaning the last I/O operation on that stream succeeded) or `false` (meaning the last I/O operation failed). Conceptually, you want to think of a stream object in a logical expression as being a Boolean variable with a value `true` (the stream state is okay) or `false` (the state isn't okay).

In an If statement, the way you phrase the logical expression depends on what you want the then-clause to do. The statement

```
if (inFile)
.
.
.
```

executes the then-clause if the last I/O operation on `inFile` succeeded. The statement

```
if (!inFile)
.
.
.
```

executes the then-clause if `inFile` is in the fail state. (Remember that once a stream is in the fail state, it remains so. Any further I/O operations on that stream are null operations.)

Here's an example that shows how to check whether an input file was opened successfully:

```
//******************************************************************
// StreamState program
// This program demonstrates testing the state of a stream
//******************************************************************
#include <iostream>
#include <fstream>  // For file I/O

using namespace std;

int main()
{
  int height;
  int width;
  ifstream inFile;

  inFile.open("measures.dat");              // Attempt to open file
  if (!inFile)                              // Was it opened?
  {
    cout << "Can't open the input file.";   // No--print message
    return 1;                               // Terminate program
  }
  inFile >> height >> width;
  cout << "For a height of " << height << endl
       << "and a width of " << width << endl
       << "the area is " << height * width << endl;
  return 0;
}
```

In this program, we begin by attempting to open the file `measures.dat` for input. Immediately, we check whether the attempt succeeded. If it was successful, the value of the expression `!inFile` in the If statement is `false` and the then-clause is skipped. The program proceeds to read data from the file and then perform a computation. It concludes by executing the statement

```
return 0;
```

With this statement, the `main` function returns control to the operating system. Recall that the function value returned by `main` is known as the exit status. The value 0 signifies normal completion of the program. Any other value (typically 1, 2, 3, . . .) means that something went wrong.

Let's trace through the program again, assuming we weren't able to open the input file. Upon return from the `open` function, the stream `inFile` is in the fail state. In the If statement, the value of the expression `!inFile` is `true`. Thus the then-clause is executed. The program prints an error message to the user and then terminates, returning an exit status of 1 to inform the operating system of an abnormal termination of the program. (Our choice of the value 1 for the exit status is purely arbitrary. System programmers sometimes use several different values in a program to signal different reasons for program termination. But most people just use the value 1.)

Whenever you open a data file for input, be sure to test the stream state before proceeding. If you forget to do so, and the computer cannot open the file, your program quietly continues executing, and ignores any input operations on the file.

**QUICK CHECK**

**5.6.1** Write an If statement that tests if the standard input stream is in the fail state. (pp. 215–217)
**5.6.2** What terminology is used when you are trying to determine if a stream is in the fail state? (p. 216)
**5.6.3** What happens if you **do not** test the state of a file input stream before using it? (p. 216)

**Problem-Solving Case Study**

## BMI Calculator

**PROBLEM:** A great deal has been said about how overweight much of the American population is today. You can't pick up a magazine that doesn't have an article on the health problems caused by obesity. Rather than looking at a chart that shows the average weight for a particular height, a measure called the body mass index (BMI), which computes a ratio of your weight and height, has become a popular tool to determine an appropriate weight. The formula for nonmetric values is

$$\text{BMI} = \text{weight} \times 703 / \text{height}^2$$

BMI correlates with the amount of body fat, which can be used to determine whether a weight is unhealthy for a certain height.

Although the discussion of the BMI in the media is a fairly recent phenomenon, the formula was actually developed by Adolphe Quetelet, a nineteenth-century Belgian statistician. Do a search of the Internet for

## Problem-Solving Case Study

"body mass index" and you will find more than a million hits. In these references, the formula remains the same but the interpretation of the result varies, depending upon age and gender. Here is the most commonly used generic interpretation:

| BMI | Interpretation |
|---|---|
| < 20 | Underweight |
| 20–25 | Normal |
| 26–30 | Overweight |
| > 30 | Obese |

Write a program that calculates the BMI given a weight and height and prints out an appropriate message.

**INPUT:** The problem statement says that the formula is for nonmetric values. In other words, the weight should be in pounds and the height should be in inches. Thus the input should be two float values: `weight` and `height`.

**OUTPUT**

- Prompts for the input values
- A message based on the BMI

**DISCUSSION:** To calculate the BMI, you read in the weight and height and plug them into the formula. If you square the height, you must include `<cmath>` to access the `pow` function. It is more efficient to just multiply height by itself.

$$\text{BMI} = \text{weight} \times 703 \,/\, (\text{height} \times \text{height})$$

If you were calculating this index by hand, you would probably notice if the weight or height were negative and question it. If the semantics of your data imply that the values should be nonnegative, then your program should test to be sure that they are. The program should test each value and use a Boolean variable to report the results. Here is the main module for this algorithm.

**Main** **Level 0**

```
Test data
IF data are okay
   Calculate BMI
   Print message indicating status
ELSE
   Print "Invalid data; weight and height must be positive."
```

Which of these steps require expansion? Get data, Test data, and Print message indicating status all require multiple statements to solve their particular subproblem. By contrast, we can translate Print "Invalid data; . . ." directly into a C++ output statement. What about the step Calculate BMI? We can write it as a single C++ statement, but there's another level of detail that we must fill in—the actual formula to be used. Because the formula is at a lower level of detail than the rest of the main module, we choose to expand Calculate BMI as a Level 1 module.

## Problem-Solving Case Study

### Get Data — Level 1

```
Prompt for weight
Read weight
Prompt for height
Read height
```

### Test Data

```
IF weight < 0 OR height < 0
   Set dataAreOk to false
ELSE
   Set dataAreOk to true
```

### Calculate BMI

```
Set bodyMassIndex to weight * 703 / (height * height)
Print Message Indicating Status
```

### Print Message Indicating Status

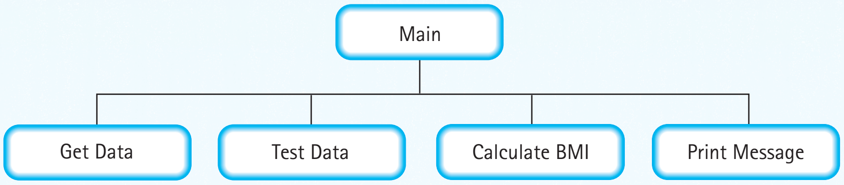
The problem doesn't say exactly what the message should be, other than reporting the status. Why not jazz up the output a little by printing an appropriate message along with the status.

| *Status* | *Message* |
|---|---|
| Underweight | Have a milk shake. |
| Normal | Have a glass of milk. |
| Overweight | Have a glass of iced tea. |
| Obese | See your doctor. |

```
Print "Your body mass index is ", bodyMassIndex, "."
Print "Interpretation and instructions."
IF bodyMassIndex <20
   Print "Underweight: Have a milk shake."
ELSE IF bodyMassIndex <= 25
   Print "Normal: Have a glass of milk."
ELSE IF bodyMassIndex <= 30
   Print "Overweight: Have a glass of iced tea."
ELSE
   Print "Obese: See your doctor."
```

## Problem-Solving Case Study

### MODULE STRUCTURE CHART

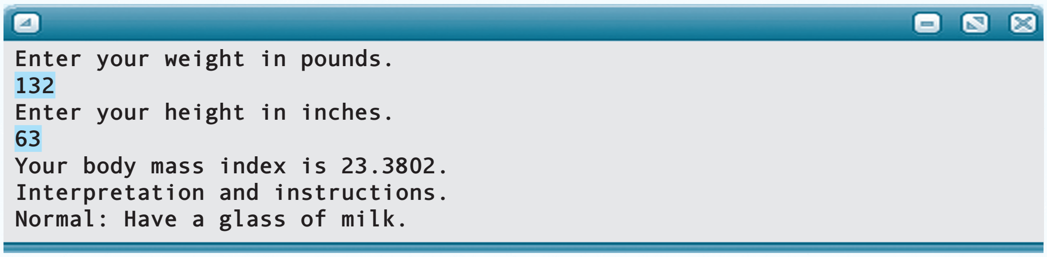


```
//******************************************************************
// BMI Program
// This program calculates the body mass index (BMI) given a weight
// in pounds and a height in inches and prints a health message
// based on the BMI. Input in English measures.
//******************************************************************

#include <iostream>

using namespace std;

int main()
{
  const int BMI_CONSTANT = 703;  // Constant in nonmetric formula
  float weight;                  // Weight in pounds
  float height;                  // Height in inches
  float bodyMassIndex;           // Appropriate BMI
  bool dataAreOK;                // True if data are nonnegative

  // Prompt for and input weight and height
  cout << "Enter your weight in pounds. " << endl;
  cin >> weight;
  cout << "Enter your height in inches. " << endl;
  cin >> height;

  // Test data
  if (weight < 0 || height < 0)
    dataAreOK = false;
  else
    dataAreOK = true;

  if ( dataAreOK)
  {
    // Calculate body mass index
    bodyMassIndex = weight * BMI_CONSTANT / (height * height);

    // Print message indicating status
    cout << "Your body mass index is " << bodyMassIndex
        << ". " << endl;
    cout << "Interpretation and instructions. " << endl;
```

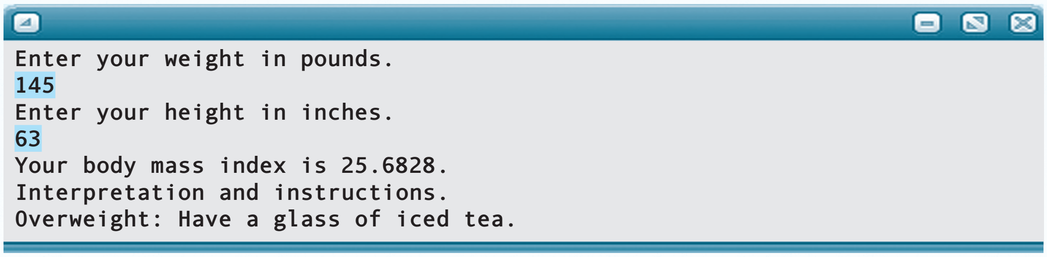
## Problem-Solving Case Study

```
    if (bodyMassIndex < 20)
      cout << "Underweight: Have a milk shake." << endl;
    else if (bodyMassIndex <= 25)
      cout << "Normal: Have a glass of milk."  << endl;
    else if (bodyMassIndex <=  30)
      cout << "Overweight: Have a glass of iced tea."  << endl;
    else
      cout << "Obese: See your doctor." << endl;
  }
  else
    cout << "Invalid data; weight and height must be positive."
         << endl;
  return 0;
}
```

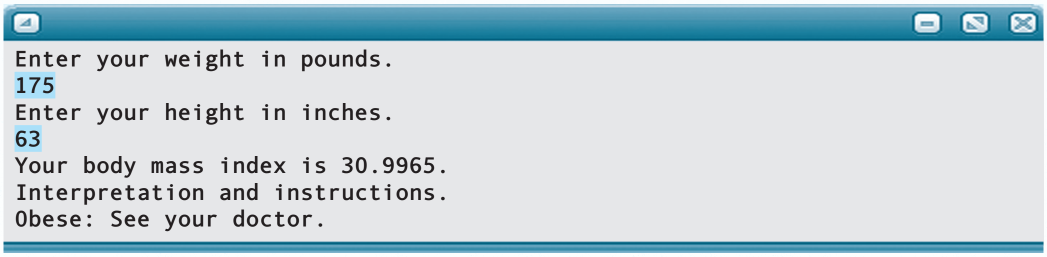
Here are outputs of runs with various heights and weights and with both good and bad data.



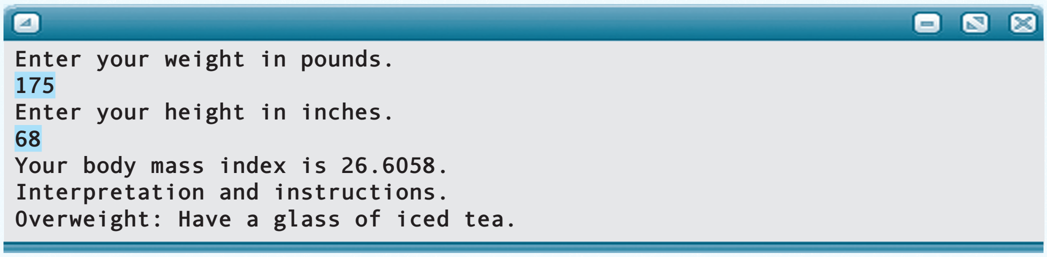
```
Enter your weight in pounds.
132
Enter your height in inches.
63
Your body mass index is 23.3802.
Interpretation and instructions.
Normal: Have a glass of milk.
```

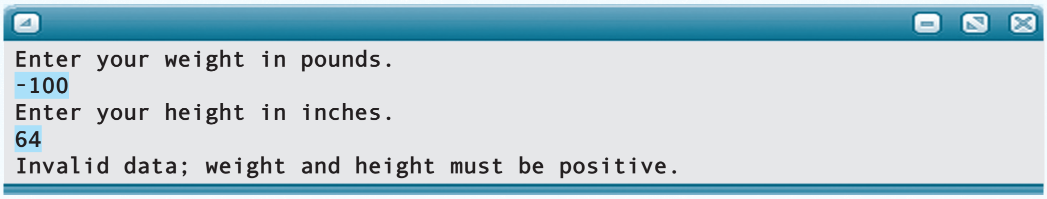


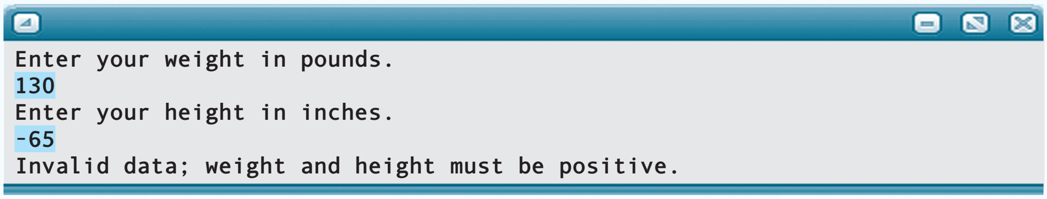
```
Enter your weight in pounds.
145
Enter your height in inches.
63
Your body mass index is 25.6828.
Interpretation and instructions.
Overweight: Have a glass of iced tea.
```



```
Enter your weight in pounds.
175
Enter your height in inches.
63
Your body mass index is 30.9965.
Interpretation and instructions.
Obese: See your doctor.
```


```
Enter your weight in pounds.
175
Enter your height in inches.
68
Your body mass index is 26.6058.
Interpretation and instructions.
Overweight: Have a glass of iced tea.
```


```
Enter your weight in pounds.
-100
Enter your height in inches.
64
Invalid data; weight and height must be positive.
```


```
Enter your weight in pounds.
130
Enter your height in inches.
-65
Invalid data; weight and height must be positive.
```

In this program, we use a nested *If* structure that is easy to understand although somewhat inefficient. We assign a value to **`dataAreOK`** in one statement before testing it in the next. We could reduce the code by writing

```
dataAreOK = !(weight < 0 || height < 0);
```

Using DeMorgan's law, we also could write this statement as

```
dataAreOK = (weight >= 0 && height >= 0);
```

In fact, we could reduce the code even more by eliminating the variable **`dataAreOK`** and using

```
if (weight => 0 && height >= 0)
.
.
.
```

in place of

```
if (dataAreOK)
.
.
.
```

To convince yourself that these three variations work, try them by hand with some test data. If all of these statements do the same thing, how do you choose which one to use? If your goal is efficiency, the final variation—the compound condition in the main If statement—is the best choice. If you are trying to express as clearly as possible what your code is doing, the longer form shown in the program may be the best option. The other variations lie somewhere in between. (Some people would find the compound condition in the main If statement to be not only the most efficient, but also the clearest to understand.) There are no absolute rules to follow here, but the general guideline is to strive for clarity, even if you must sacrifice a little efficiency.

## Testing and Debugging

In Chapter 1, we discussed the problem-solving and implementation phases of computer programming. Testing is an integral part of both phases. Here, we test both phases of the process used to develop the BMI program. Testing in the problem-solving phase is done after the solution is developed but before it is implemented. In the implementation phase, we do testing after the algorithm is translated into a program, and again after the program has compiled successfully. The compilation itself constitutes another stage of testing that is performed automatically.

### Testing in the Problem-Solving Phase: The Algorithm Walk-Through

#### Determining Preconditions and Postconditions

To test during the problem-solving phase, we do a *walk-through* of the algorithm. For each module in the functional decomposition, we establish an assertion called a precondition and another called a postcondition. A precondition is an assertion that must be true before a module is executed for the module to execute correctly. A postcondition is an assertion that should be true after the module has executed, if it has done its job correctly. To test a module, we "walk through" the algorithmic steps to confirm that they produce the required postcondition, given the stated precondition.

Precondition An assertion that must be true before a module begins executing.

Postcondition An assertion that should be true after a module has executed.

Our algorithm has five modules: the `main` module, Get Data, Test Data, Calculate BMI, and Print Message Indicating Status. Usually there is no precondition for a `main` module. Our `main` module's postcondition is that it outputs the correct results, given the correct input. More specifically, the postcondition for the `main` module is as follows:

- The computer has input two real values into `weight` and `height`.
- If the input is invalid, an error message has been printed; otherwise, the body mass index has been calculated and an appropriate message has been printed based on the result.

Because Get Data is the first module executed in the algorithm and because it does not assume anything about the contents of the variables it is about to manipulate, it has no precondition. Its postcondition is that it has input two real values into `weight` and `height`.

The precondition for module Test Data is that `weight` and `height` have been assigned meaningful values. Its postcondition is that `dataAreOK` contains `true` if the values in `weight` and `height` are nonnegative; otherwise, `dataAreOK` contains `false`.

The precondition for module Calculate BMI is that `weight` and `height` contain meaningful values. Its postcondition is that the variable named `dataAreOK` contains the evaluation of the BMI formula (`weight * 703 / (height * height)`).

The precondition for module Print Message Indicating Status is that `dataAreOK` contains the result of evaluating the BMI formula. Its postcondition is that appropriate documentation and the value in `dataAreOK` have been printed, along with the messages: "Underweight: Have a milk shake." if the BMI value is less than 20; "Normal: Have a glass of milk." if the value is less than or equal to 26; "Overweight: Have a glass of iced tea." if the value is less than or equal to 30; and "Obese: See your doctor." if the value is greater than 30.

The module preconditions and postconditions are summarized in the following table. In the table, we use *AND* with its usual meaning in an assertion—the logical AND operation. Also, a phrase like "`someVariable` is assigned" is an abbreviated way of asserting that `someVariable` has already been assigned a meaningful value.

| Module | Precondition | Postcondition |
|---|---|---|
| Main | | Two float values have been input AND if the input is valid, the BMI formula is calculated and the value is printed with an appropriate message; otherwise, an error message has been printed. |
| Get Data | | `weight` and `height` have been input. |
| Test Data | `weight` and `height` are assigned values. | `dataAreOK` contains `true` if `weight` and `height` are nonnegative; otherwise, `dataAreOK` contains `false`. |
| Calculate BMI | `weight` and `height` are assigned values. | `bodyMassIndex` contains the evaluation of the BMI formula. |
| Print Message | `bodyMassIndex` contains the evaluation of the BMI formula. | The value of `bodyMassIndex` has been printed, along with a message interpreting the value. |

### Performing the Algorithm Walk-Through

Now that we've established the preconditions and postconditions, we walk through the `main` module. At this point, we are concerned only with the steps in the `main` module, so for now we assume that each lower-level module executes correctly. At each step, we must determine the current conditions. If the step is a reference to another module, we must verify that the precondition of that module is met by the current conditions.

We begin with the first statement in the `main` module. Get Data does not have a precondition, and we assume that Get Data satisfies its postcondition that it correctly inputs two real values into `weight` and `height`.

The precondition for module Test Data is that `weight` and `height` are assigned values. This must be the case if Get Data's postcondition is true. Again, because we are concerned only with the step at Level 0, we assume that Test Data satisfies its postcondition that `dataAreOK` contains `true` or `false`, depending on the input values.

Next, the If statement checks to see if `dataAreOK` is `true`. If it is, the algorithm performs the then-clause. Assuming that Calculate BMI correctly evaluates the BMI formula and that Print Message Indicating Status prints the result and the appropriate message (remember, we're assuming that the lower-level modules are correct for now), then the If statement's then-clause is correct. If the value in `dataAreOK` is `false`, the algorithm performs the else-clause and prints an error message.

We now have verified that the **main** (Level 0) module is correct, assuming the Level 1 modules are correct. The next step is to examine each module at Level 1 and answer this question: If the Level 2 modules (if any) are assumed to be correct, does this Level 1 module do what it is supposed to do? We simply repeat the walk-through process for each module, starting with its particular precondition. In this example, there are no Level 2 modules, so the Level 1 modules must be complete.

Get Data correctly reads in two values—**weight** and **height**—thereby satisfying its postcondition. (The next refinement is to code this instruction in C++. Whether it is coded correctly is *not* an issue in this phase; we deal with the code when we perform testing in the implementation phase.)

Test Data checks whether both variables contain nonnegative values. The If condition correctly uses OR operators to combine the relational expressions so that if either of them is **true**, the then-clause is executed. It thus assigns **false** to **dataAreOK** if either of the numbers is negative; otherwise, it assigns **true**. The module, therefore, satisfies its postcondition.

Calculate BMI evaluates the BMI formula: **weight * 703 / (height * height)**. The required postcondition, therefore, is true. But what if the value of **height** is 0? Oh, dear! We checked that the inputs are nonnegative, but forgot that **height** is used as a divisor and thus cannot be 0. We'll need to fix this problem before we release this program for general use.

Print Message Indicating Status outputs the value in **bodyMassIndex** with appropriate documentation. It then compares the result to the standards and prints the appropriate interpretation. "Underweight: Have a milk shake." is printed if the value is less than 20; "Normal: Have a glass of milk." is printed if the value is less than or equal to 26; "Overweight: Have a glass of iced tea." is printed if the value is less than or equal to 30; and "Obese: See your doctor." is printed if the value is greater than 30. Thus the module satisfies its postcondition.

Once we've completed the algorithm walk-through, we have to correct any discrepancies and repeat the process. When we know that the modules do what they are supposed to do, we start translating the algorithm into our programming language.

A standard postcondition for any program is that the user has been notified of invalid data. You should *validate* every input value for which any restrictions apply. A data-validation If statement tests an input value and outputs an error message if the value is not acceptable. (We validated the data when we tested for negative scores in the BMI program.) The best place to validate data is immediately after it is input. To satisfy the data-validation postcondition, the algorithm should also test the input values to ensure that they aren't too large or too small.

## Testing in the Implementation Phase

Now that we've talked about testing in the problem-solving phase, we turn to testing in the implementation phase. In this phase, you need to test at several points.

### Code Walk-Through

After the code is written, you should go over it line by line to be sure that you've faithfully reproduced the algorithm—a process known as a *code walk-through*. In a team programming situation, you ask other team members to walk through the algorithm and code with you, to double-check the design and code.

### Execution Trace

You also should take some actual values and hand-calculate what the output should be by doing an *execution trace* (or *hand trace*). When the program is executed, you can use these same values as input and check the results.

The computer is a very literal device—it does exactly what we *tell* it to do, which may or may not be what we *want* it to do. We try to make sure that a program does what we want by tracing the execution of the statements.

We use a nonsense program below to demonstrate the technique. We keep track of the values of the program variables on the right-hand side. Variables with undefined values are indicated with a dash. When a variable is assigned a value, that value is listed in the appropriate column.

| | Value of | | |
|---|---|---|---|
| Statement | a | b | c |
| `const int X = 5;` | | | |
| `int main()` | | | |
| `{` | | | |
| `  int a, b, c;` | — | — | — |
| `  b = 1;` | — | 1 | — |
| `  c = X + b;` | — | 1 | 6 |
| `  a = X + 4;` | 9 | 1 | 6 |
| `  a = c;` | 6 | 1 | 6 |
| `  b = c;` | 6 | 6 | 6 |
| `  a = a + b + c;` | 18 | 6 | 6 |
| `  c = c % X;` | 18 | 6 | 1 |
| `  c = c * a;` | 18 | 6 | 18 |
| `  a = a % b;` | 0 | 6 | 18 |
| `  cout << a << b << c;` | 0 | 6 | 18 |
| `  return 0;` | 0 | 6 | 18 |
| `}` | | | |

Now that you've seen how the technique works, let's apply it to the BMI program. We list only the executable statement portion here. The input values are 124 and 63.5.

The then-clause of the first If statement is not executed for these input data, so we do not fill in any of the variable columns to its right. The then-clause of the second If statement is executed; thus the else-clause is not. The else-clause of the third If statement is executed, which is another If statement. The then-clause is executed here, leaving the rest of the code unexecuted.

We always create columns for all of the variables, even if we know that some will stay empty. Why? Because it's possible that later we'll encounter an erroneous reference to an empty variable; having a column for the variable reminds us to check for just such an error.

| Statement | weight | height | BMI | dataAreOK |
|---|---|---|---|---|
| `cout << "Enter your weight in pounds. " << endl;` | — | — | — | — |
| `cin >> weight;` | 124 | — | — | — |
| `cout << "Enter your height in inches. " << endl;` | 124 | — | — | — |
| `cin >> height;` | 124 | 63.5 | — | — |
| `if (weight < 0 \|\| height < 0)` | 124 | 63.5 | — | — |
| `  dataAreOK = false;` | | | | |
| `else` | | | | |
| `  dataAreOK = true;` | 124 | 63.5 | — | true |
| `if (dataAreOK)` | 124 | 63.5 | — | true |
| `{` | | | | |
| `  bodyMassIndex = weight * BMI_CONSTANT /` | | | | |
| `    (height * height);` | 124 | 63.5 | 21.087 | true |

| Statement | weight | height | BMI | dataAreOK |
|---|---|---|---|---|
| `  cout << "Your body mass index is "` | | | | |
| `       << bodyMassIndex << ". " << endl;` | 124 | 63.5 | 21.087 | true |
| `  cout << "Interpretation and instructions. "` | | | | |
| `       << endl;` | 124 | 63.5 | 21.087 | true |
| `  if (bodyMassIndex < 20)` | 124 | 63.5 | 21.087 | true |
| `    cout << "Underweight: Have a milk shake."` | | | | |
| `         << endl;` | | | | |
| `  else if (bodyMassIndex <= 25)` | 124 | 63.5 | 21.087 | true |
| `    cout << "Normal: Have a glass of milk."` | | | | |
| `         << endl;` | 124 | 63.5 | 21.087 | true |
| `  else if (bodyMassIndex <= 30)` | | | | |
| `    cout` | | | | |
| `      << "Overweight: Have a glass of iced tea."` | | | | |
| `      << endl;` | | | | |
| `  else` | | | | |
| `    cout << "Obese: See your doctor." << endl;` | | | | |
| `}` | | | | |
| `else` | | | | |
| `  cout << "Invalid data; weight "` | | | | |
| `       << "and height must be positive."` | | | | |
| `       << endl;` | | | | |
| `return 0;` | 124 | 63.5 | 21.087 | true |

When a program contains branches, it's a good idea to retrace its execution with different input data so that each branch is traced at least once. In the next section, we describe how to develop data sets that test all of a program's branches.

### Testing Selection Control Structures

To test a program with branches, we need to execute each branch at least once and verify the results. For example, the BMI program contains five If-Then-Else statements (see **FIGURE 5.6**). We need a series of data sets to test the different branches. For example, the following sets of input values for `weight` and `height` cause all of the branches to be executed:

| Data Set | Weight in Pounds | Height in Inches | Status |
|---|---|---|---|
| 1 | 110.0 | 67.5 | Underweight |
| 2 | 120.0 | 63.0 | Normal |
| 3 | 145.0 | 62.0 | Overweight |
| 4 | 176.6 | 60.0 | Obese |
| 5 | -100 | 65.0 | Error message |

**FIGURE 5.7** shows the flow of control through the branching structure of the BMI program for each of these data sets. Every branch in the program is executed at least once through this series of test runs; eliminating any of the test data sets would leave at least one branch untested. This series of data sets provides what is called *minimum complete coverage* of the program's branching structure. Whenever you test a program with branches in it, you should design a series of tests that cover all of the branches. It may help to draw diagrams like those in Figure 5.7 so that you can see which branches are being executed.

Because an action in one branch of a program often affects processing in a later branch, it is critical to test as many *combinations of branches*, or paths, through a program as possible. By doing so, we can be sure that there are no interdependencies that could cause problems. Of course, some combinations of branches may be impossible to follow. For example, if the else-clause is executed in the first branch of the BMI program, the else-clause in the second

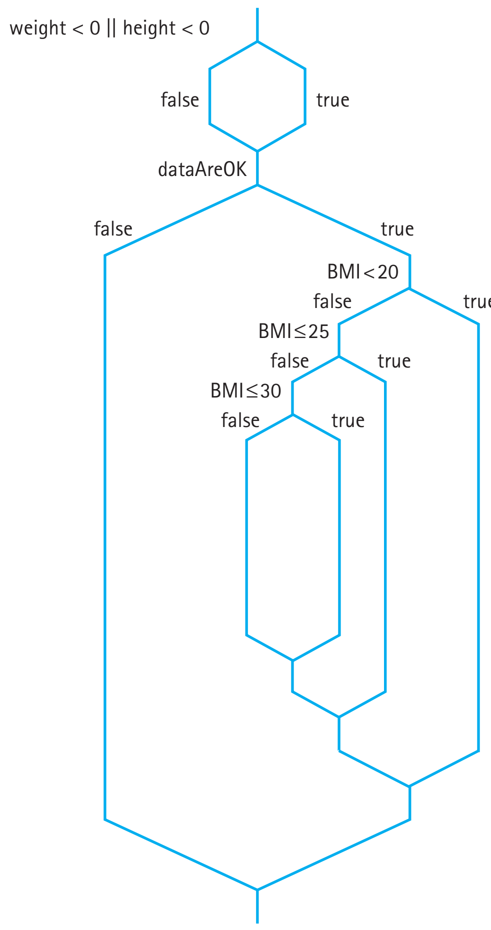


**FIGURE 5.6** Branching Structure for BMI Program

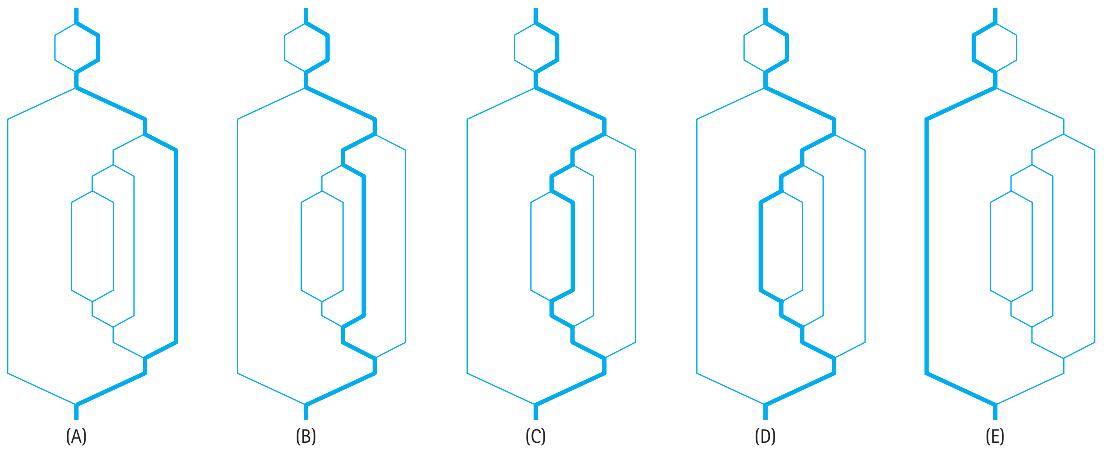


**FIGURE 5.7** Flow of Control Through BMI Program for Each of Five Data Sets

branch cannot be executed. Shouldn't we try all possible paths? Yes, in theory we should. However, even in a small program the number of paths can be very large.

The approach to testing that we've used here is called *code coverage* because the test data are designed by looking at the code of the program. Code coverage also is called *white-box* (or *clear-box*) *testing* because we are allowed to see the program code while designing the tests. Another approach to testing, called *data coverage*, attempts to test as many allowable data values as possible without regard to the program code. Because we need not see the code in this form of testing, it also is called *black-box testing*—we would design the same set of tests even if the code were hidden in a black box.

Complete data coverage is as impractical as complete code coverage for many programs. For example, if a program has four `int` input values, there are approximately $(2 \times \texttt{INT\_MAX})^4$ possible inputs. (`INT_MAX` and `INT_MIN` are constants declared in the header file `<climits>`. They represent the largest and smallest possible `int` values, respectively, on your particular computer and C++ compiler.)

Often, testing entails a combination of these two strategies. Instead of trying every possible data value (data coverage), we examine the code (code coverage) and look for ranges of values for which processing is identical. Then we test the values at the boundaries and, sometimes, a value in the middle of each range. For example, a simple condition such as

```
alpha < 0
```

divides the integers into two ranges:

1. `INT_MIN` through `-1`
2. `0` through `INT_MAX`

Thus we should test the four values `INT_MIN`, `-1`, `0`, and `INT_MAX`. A compound condition such as

```
alpha >= 0 && alpha <= 100
```

divides the integers into three ranges:

1. `INT_MIN` through `-1`
2. `0` through `100`
3. `101` through `INT_MAX`

Thus we have six values to test. In addition, to verify that the relational operators are correct, we should test for values of `1` (`> 0`) and `99` (`< 100`).

Conditional branches are only one factor in developing a testing strategy. We consider more of these factors in later chapters.

## The Test Plan

We've discussed strategies and techniques for testing programs, but how do you approach the testing of a specific program? You do it by designing and implementing a test plan—a document that specifies the test cases that should be tried, the reason for each test case, and the expected output. Implementing a test plan involves running the program using the data specified by the test cases in the plan and checking and recording the results.

**Test plan** A document that specifies how a program is to be tested.

**Test plan implementation** Using the test cases specified in a test plan to verify that a program outputs the predicted results.

The test plan should be developed together with the functional decomposition. As you create each module, write out its precondition and postcondition and note the test data required to verify them. Consider code coverage and data coverage to see if you've left out tests for any aspects of the program (if you've forgotten something, it probably indicates that a precondition or postcondition is incomplete).

The following table shows a partial test plan for the BMI program. It has six test cases. The first four cases test the different paths through the program for valid data. Two more test cases check that `weight` and `height` are validated appropriately by separately entering an invalid score for each.

We should test the program on the end cases—that is, where the BMI is exactly 20, 25, and 30. Because the BMI is calculated and not input, it is difficult to come up with the appropriate input values. The Case Study Follow-Up Exercises ask you to look at this problem, complete this test plan, and implement it.

**Test Plan for BMI Program**

| Reason for Test Case | Input Values | Expected Output | Observed Ouput |
|---|---|---|---|
| Underweight case | 110, 67.5 | Your body mass index is 16.9723.<br>Interpretation and instructions.<br>Underweight: Have a milk shake. | |
| Normal case | 120, 63 | Your body mass index is 21.2547.<br>Interpretation and instructions.<br>Normal: Have a glass of milk. | |
| Overweight case | 145, 62 | Your body mass index is 26.518.<br>Interpretation and instructions.<br>Overweight: Have a glass of iced tea. | |
| Obese case | 176.6, 60 | Your body mass index is 34.4861.<br>Interpretation and instructions.<br>Obese: See your doctor. | |
| Negative weight | −120, 63 | Invalid data; weight and height must be positive. | |
| Negative height | 120, −63 | Invalid data; weight and height must be positive. | |

Implementing a test plan does not guarantee that a program is completely correct. It means only that a careful, systematic test of the program has not demonstrated any bugs.

## Tests Performed Automatically During Compilation and Execution

Once a program is coded and test data has been prepared, it is ready for compiling. The compiler has two responsibilities: to report any errors and (if there are no errors) to translate the program into object code.

Errors can be syntactic or semantic. The compiler finds syntactic errors. For example, the compiler warns you when reserved words are misspelled, identifiers are undeclared, semicolons are missing, and operand types are mismatched. But it won't find all of your typing errors. If you type > instead of <, for example, you won't get an error message; instead, you will get erroneous results when you test the program. It's up to you to design a test plan and carefully check the code to detect errors of this type.

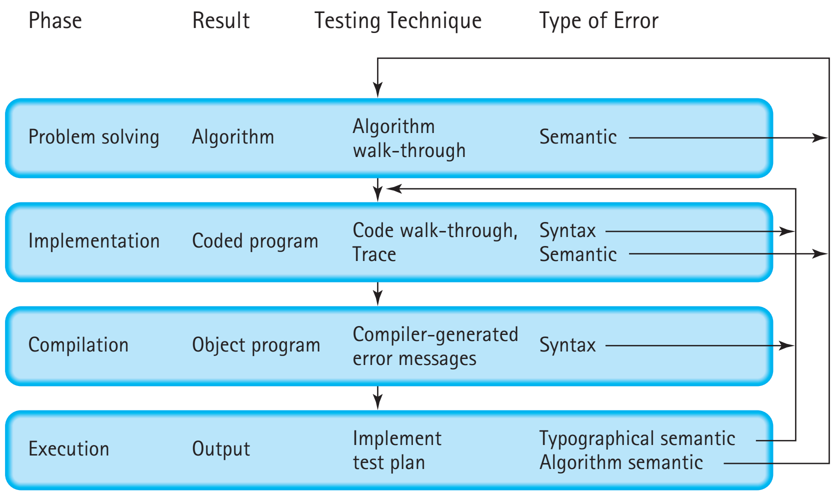


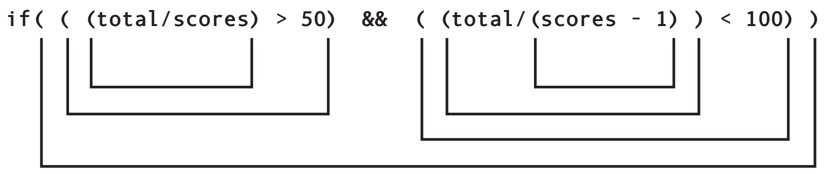
**FIGURE 5.8** Testing Process

Semantic errors (also called *logic errors*) are mistakes that give you the wrong answer. They are more difficult to locate than syntactic errors and usually surface when a program is executing. C++ detects only the most obvious semantic errors—those that result in an invalid operation (dividing by zero, for example). Although semantic errors sometimes are caused by typing errors, they are more often a product of a faulty algorithm design. The lack of checking whether `height` is 0—the potential problem that we found in the algorithm walk-through for the BMI problem—is a typical semantic error. By walking through the algorithm and the code, tracing the execution of the program, and developing a thorough test strategy, you should be able to avoid, or at least quickly locate, semantic errors in your programs.

**FIGURE 5.8** illustrates the testing process we've been discussing. The figure shows where syntax and semantic errors occur and in which phase they can be corrected.

## Testing and Debugging Hints

1. C++ has three pairs of operators that are similar in appearance but very different in effect: `==` and `=`, `&&` and `&`, and `||` and `|`. Double-check all of your logical expressions to be sure you're using the "equals-equals," "and-and," and "or-or" operators.
2. If you use extra parentheses for clarity, be sure that the opening and closing parentheses match up. To verify that parentheses are properly paired, start with the innermost pair and draw a line connecting them. Do the same for the others, working your way out to the outermost pair. For example,



```
if( ( (total/scores) > 50)  &&  ( (total/(scores - 1) ) < 100) )
```

Here is a quick way to tell whether you have an equal number of opening and closing parentheses. The scheme uses a single number (the "magic number"), whose value initially is 0. Scan the expression from left to right. At each opening parenthesis, add 1 to the magic number; at each closing parenthesis, subtract 1. At the final closing parenthesis, the magic number should be 0. For example,

```
if (((total/scores) > 50) && ((total/(scores - 1)) < 100))
0  123            2     1    23      4          32      10
```

3. Don't use =< to mean "less than or equal to"; only the symbol <= works for this purpose. Likewise, => is invalid for "greater than or equal to"; you must use >= for this operation.
4. In an If statement, remember to use a `{ }` pair if the then-clause or else-clause is a sequence of statements. Also, be sure not to put a semicolon after the right brace.
5. Echo print all input data. By doing so, you know that your input values are what they are supposed to be.
6. Test for bad data. If a data value must be positive, use an If statement to test the value. If the value is negative or 0, an error message should be printed; otherwise, processing should continue. For example, the following code segment tests whether three test scores are less than 0 or greater than 100:

```
dataOK = true;
if (test1 < 0 || test2 < 0 || test3 < 0)
{
  cout << "Invalid Data:  Score(s) less than zero." << endl;
  dataOK = false;
}
if (test1 > 100 || test2 > 100 || test3 > 100)
{
  cout << "Invalid Data:  Score(s) greater than 100." << endl;
  dataOK = false;
}
```

   These If statements test the limits of reasonable scores, and the rest of the program continues only if the data values are reasonable.
7. When an If statement is inadvertently applied to an `int` value, it returns `true` if the value is nonzero and `false` otherwise. The compiler does not report this result as an error.
8. Take some sample values and try them by hand as we did for the BMI program. (There's more on this method in Chapter 6.)
9. If your program reads data from an input file, it should verify that the file was opened successfully. Immediately after the call to the `open` function, an If statement should test the state of the file stream.
10. If your program produces an answer that does not agree with a value you've calculated by hand, try these suggestions:
    a. Redo your arithmetic.
    b. Recheck your input data.
    c. Carefully go over the section of code that does the calculation. If you're in doubt about the order in which the operations are performed, insert clarifying parentheses.
    d. Check for integer overflow. The value of an `int` variable may have exceeded `INT_MAX` in the middle of a calculation. Some systems give an error message when this happens, but most do not.
    e. Check the conditions in branching statements to be sure that the correct branch is taken under all circumstances.

## Summary

Using logical expressions is a way of asking questions while a program is running. The program evaluates each logical expression, producing the value `true` if the expression is true or the value `false` if the expression is not true.

The If statement allows you to take different paths through a program based on the value of a logical expression. The If-Then-Else statement is used to choose between two courses of action; the If-Then statement is used to choose whether to take a particular course of action. The branches of an If-Then or If-Then-Else can be any statement, simple or compound. They can even be other If statements.

The algorithm walk-through requires us to define a precondition and a postcondition for each module in an algorithm. Then we need to verify that those assertions are true at the beginning and end of each module. By testing our design in the problem-solving phase, we can eliminate errors that can be more difficult to detect in the implementation phase.

An execution trace is a way of finding program errors once we've entered the implementation phase. It's a good idea to trace a program before you run it, so that you have some sample results against which to check the program's output. A written test plan is an essential part of any program development effort.

## Quick Check Answers

**5.1.1** The order in which statements are executed in a program. **5.1.2** sequential **5.1.3** selection or branching control structure **5.1.4** It allows the computer to choose between alternative courses of action, depending on a test of certain conditions. **5.2.1** `true` and `false`.
**5.2.2** `temperature > 32` **5.2.3** 2 **5.2.4** logical values and logical operations. **5.2.5** $x = 1$, $y = 5$
**5.3.1**
```
if (temperature > 32)
   cout << "Above freezing.";
else
   cout << "Freezing or below.";
```
**5.3.2** Because the computer can choose to execute either of them depending on the circumstances. **5.3.3** It must evaluate to a `bool` data type. **5.4.1** It allows the computer to select among any number of alternative courses of action.
**5.4.2**
```
if (temperature < 32)
   cout << "Below freezing.";
else if (temperature = = 32)
   cout << "Freezing.";
else if (temperature < 212)
   cout << "Above freezing and below boiling.";
else
   cout << "Boiling and above.";
```
**5.4.3** A nested control structure. **5.4.4** A multiway branch **5.4.5** The dangling `else` problem. **5.5.1** `&&`, `||`, `!` **5.5.2** `!(a == b || c >= d)` **5.5.3** `failed = (grade <= 50.0);` **5.5.4** From left to right **5.5.5** `5 >= 2 && x != 7` **5.6.1** `if (cin)` ... **5.6.2** Testing the state of the stream **5.6.3** Your program will quietly continue to execute and ignore any input/output operations on the file.

## Exam Preparation Exercises

1. Define the term "flow of control."
2. The values `true` and `false` are keywords in C++. True or false?
3. The "equals or greater" operator in C++ is written =>. True or false?
4. Why is it that `'A' < 'B'` and `'a' < 'b'` are both `true`, but `'a' < 'B'` is `false`?

5. If `int1` has the value 12, `int2` has the value 18, and `int3` has the value 21, what is the result of each of the following Boolean expressions?
   a. `int1 < int2 && int2 < int3`
   b. `int1 < int3 || int3 < int2`
   c. `int1 <= int2 - 6`
   d. `int2 <= int1 + 5 || int3 >= int2 + 5`
   e. `!(int1 < 30)`
   f. `!(int2 == int1 && int3 == int1)`
   g. `!(int1 > 25) && !(int2 < 17)`
6. If `string1` has the value `"miniscule"`, `string2` has the value `"minimum"`, and `string3` has the value `"miniature"`, what is the result of each of the following expressions?
   a. `string1 > string2`
   b. `string1 > string2 && string2 > string3`
   c. `string1.substr(0, 4) == string2.substr(0, 4)`
   d. `string1 > "maximum"`
   e. `string3.substr(0, 4) == "mini" || string1 == string2`
   f. `string3.length() > string1.length() && string1 > string3`
   g. `!((string1.substr(8, 1) == string3.substr(8, 1)) && string1.length() == 9)`
7. Why won't the following expression result in a division-by-zero error when `someInt` has the value `0`?

```
someInt != 0 && 5/someInt > 10
```

8. The `bool` operators have lower precedence than the arithmetic operators, with the exception of the `!` operator, which has the same precedence as unary minus. True or false?
9. We enclose the logical expression in an If statement in parentheses only to make the code more readable. C++ doesn't require the parentheses. True or false?
10. What does the following If statement do when the value in `someInt` is `77`?

```
if (someInt <= 44) || (someInt - 37 < 40)
  cout << "The data is within range.";
else
  cout << "The data doesn't make sense.";
```

11. What does the following If statement do when the value in `string1` is `"The"`?

```
if (string1.length() == 3 && string1.substr(0, 1) = "T")
  cout << "The word may be \"The\"";
else
{
  string1 = "The";
  cout << "The word is now \"The\"";
}
```

12. What does the following If statement do when the value in `float1` is `3.15`?

```
if (fabs(float1 - 3.14) < 0.00000001)
{
  cout << "The area of the circle of radius 6.0 "
       << "is approximately:" << endl;
  cout << 6.0 * 6.0 * float1;
}
```

13. Why does the following If statement always output `"false"` regardless of the value in `someInt`?

```
if (someInt = 0)
  cout << "true";
else
  cout << "false";
```

14. What is output by the following code segment when `score` has the value `85`?

```
if (score < 50)
  cout << "Failing";
else if (score < 60)
  cout << "Below average";
else if (score < 70)
  cout << "Average";
else if (score < 80)
  cout << "Above average";
else if (score < 90)
  cout << "Very good";
else if (score < 100)
  cout << "Excellent";
```

15. What is output by the following code segment when `score` has the value `85`?

```
if (score < 50)
  cout << "Failing";
if (score < 60)
  cout << "Below average";
if (score < 70)
  cout << "Average";
if (score < 80)
  cout << "Above average";
if (score < 90)
  cout << "Very good";
if (score < 100)
  cout << "Excellent";
```

16. How do you fix a nested If statement that has a dangling `else`?
17. How would you write a Boolean expression in an If statement if you want the statement's then-clause to execute when file `inData` is in the fail state?
18. Is there any limit to how deeply we can nest If statements?

## ■ Programming Warm-Up Exercises

1. Write a Boolean expression that is true when the `bool` variable `moon` has the value `"blue"` or the value `"Blue"`.

2. Write a Boolean expression that is true when both **inFile1** and **inFile2** are in the fail state.
3. Write a branching statement that reads into a string variable called **someString**, from a file called **inFile**, if the file is not in the fail state.
4. Write a branching statement that tests whether one date comes before another. The dates are stored as integers representing the month, day, and year. The variables for the two dates are called **month1**, **day1**, **year1**, **month2**, **day2**, and **year2**. The statement should output an appropriate message depending on the outcome of the test. For example:

   ```
   12/21/01 comes before 1/27/05
   ```

   or

   ```
   7/14/04 does not come before 7/14/04
   ```

5. Change the branching statement that you wrote for Exercise 4 so that when the first date doesn't come before the second, it sets the first date equal to the second date in addition to printing the message.
6. Write a Boolean expression that is **true** when either of the **bool** variables **bool1** or **bool2** is **true**, but is **false** whenever both of them are **true** or neither of them is **true**.
7. Write a branching statement that tests whether **score** is in the range of 0 to 100, and outputs an error message if it is not within that range.
8. Change the branching statement that you wrote for Exercise 7 so that when **score** is in the proper range, it adds **score** to a running total variable called **scoreTotal** and increments a counter called **scoreCount**.
9. Write a code segment that reads an **int** value from each of two files, **infile1** and **infile2**. If neither file is in the fail state, the program writes the lesser value of the two to a file called **outfile**, and reads another value from the file that had the lesser value. If either of the files is in the fail state, then the value from the file that is not in the fail state is written to **outfile**. If both files are in the fail state, then an error message is output to **cout**. The **int** values can be input into variables **value1** and **value2**.
10. Change the following series of If-Then statements into a nested If-Else-If structure.

    ```
    if (score > 100)
      cout << "Duffer.";
    if (score <= 100 && score > 80)
      cout << "Weekend regular.";
    if (score <= 80 && score > 72)
      cout << "Competitive player.";
    if (score <= 72 && score > 68)
      cout << "Turn pro!";
    if (score <= 68)
      cout << "Time to go on tour!";
    ```

11. Write an If structure that outputs the least of three values, **count1**, **count2**, and **count3**. If more than one variable has the same lowest value, then output the value as many times as it is found in those variables.

12. The following program segment is not supposed to print anything, yet it outputs the first error message, `"Error in maximum: 100"`. What's wrong, and how would you correct it? Why doesn't the code output both error messages?

```
maximum = 75;
minimum = 25;
if (maximum = 100)
  cout << "Error in maximum: " << maximum << endl;
if (minimum = 0)
  cout << "Error in minimum: " << minimum << endl;
```

13. Write an If statement that takes the square root of the variable **`area`** only when its value is nonnegative. Otherwise, the statement should set **`area`** equal to its absolute value and then take the square root of the new value. The result should be assigned to the variable **`root`**.
14. Write a test plan for the following branching structure.

```
cout << "The water is a ";
if (temp >= 212)
  cout << "gas.";
else if (temp > 32)
  cout << "liquid.";
else
  cout << "solid.";
```

15. Write a test plan for the following branching structure. (Note that the test for a leap year given here does not include the special rules for century years.)

```
if (month == 2 && day > 28)
  if (year%4 != 0)
    cout << "Date error. Not a leap year."
  else
    if (day > 29)
      cout << "Date error. Improper day for February."
```

## Programming Problems

1. Write a C++ program that computes a student's grade for an assignment as a percentage given the student's score and the total points. The final score should be rounded up to the nearest whole value using the **`ceil`** function in the **`<cmath>`** header file. You should also display the floating-point result up to 5 decimal places. The input to the program must come from a file containing a single line with the score and total separated by a space. In addition, you should print to the console "Excellent" if the grade is greater than 90, "Well Done" if the grade is greater than 80, "Good" if the grade is greater than 70, "Need Improvement" if the grade is greater than or equal to 60, and "Fail" if the grade is less than 50.

2. ROT13 (rotate by 13 places) is a simple letter substitution cipher that is an instance of a Caesar cipher developed in ancient Rome and used by Julius Caesar who used it in

his private correspondence. ROT13 replaces a letter with the letter 13 letters after it in the alphabet. The following table demonstrates the translation in ROT13:

| | | |
|---|---|---|
| A | ↔ | N |
| B | ↔ | O |
| C | ↔ | P |
| D | ↔ | Q |
| E | ↔ | R |
| F | ↔ | S |
| G | ↔ | T |
| H | ↔ | U |
| I | ↔ | V |
| J | ↔ | W |
| K | ↔ | X |
| L | ↔ | Y |
| M | ↔ | Z |

Thus, the translation of the word JULIUS using ROT13 would be WHYVHF. Write a C++ program that inputs a letter and outputs the corresponding letter using the ROT13 encoding scheme above. Your output should look like `G -> T`.

3. Use functional decomposition to write a C++ program that inputs a letter and outputs the corresponding International Civil Aviation Organization alphabet word (these are the words that pilots use when they need to spell something out over a noisy radio channel). The alphabet is as follows:

| | |
|---|---|
| A | Alpha |
| B | Bravo |
| C | Charlie |
| D | Delta |
| E | Echo |
| F | Foxtrot |
| G | Golf |
| H | Hotel |
| I | India |
| J | Juliet |
| K | Kilo |
| L | Lima |
| M | Mike |
| N | November |
| O | Oscar |
| P | Papa |
| Q | Quebec |
| R | Romeo |
| S | Sierra |

| | |
|---|---|
| T | Tango |
| U | Uniform |
| V | Victor |
| W | Whiskey |
| X | X-ray |
| Y | Yankee |
| Z | Zulu |

Be sure to use proper formatting and appropriate comments in your code. Provide appropriate prompts to the user. The output should be labeled clearly and formatted neatly.

4. Use functional decomposition to write a C++ program that asks the user to enter his or her weight and the name of a planet. The program then outputs how much the user would weigh on that planet. The following table gives the factor by which the weight must be multiplied for each planet. The program should output an error message if the user doesn't type a correct planet name. The prompt and the error message should make it clear to the user how a planet name must be entered. Be sure to use proper formatting and appropriate comments in your code. The output should be labeled clearly and formatted neatly.

| | |
|---|---|
| Mercury | 0.4155 |
| Venus | 0.8975 |
| Earth | 1.0 |
| Moon | 0.166 |
| Mars | 0.3507 |
| Jupiter | 2.5374 |
| Saturn | 1.0677 |
| Uranus | 0.8947 |
| Neptune | 1.1794 |
| Pluto | 0.0899 |

5. Use functional decomposition to write a C++ program that takes a number in the range of 1 to 12 as input, and outputs the corresponding month of the year, where 1 is January, and so on. The program should output an error message if the number entered is not in the required range. The prompt and the error message should make it clear to the user how a month number must be entered. Be sure to use proper formatting and appropriate comments in your code. The output should be labeled clearly and formatted neatly.

6. Use functional decomposition to write a C++ program that takes a number in the range of 0 to 6 and a second number in the range of 1 to 366 as input. The first number represents the day of the week on which the year begins, where 0 is Sunday, and so on. The second number indicates the day of the year. The program then outputs the name of the day of the week corresponding to the day of the year. The number of the day of the week can be computed as follows:

```
(start day + day of year – 1) % 7
```

The program should output an error message if the numbers entered are not in the required ranges. The prompt and the error message should make it clear to the user how the numbers must be entered. Be sure to use proper formatting and appropriate comments in your code. The output should be labeled clearly and formatted neatly.

7. Use functional decomposition to write a C++ program that takes a number in the range of 1 to 365 as input. The number represents the day of the year. The program then outputs the name of the month (assume the year is not a leap year). You can do this by comparing the day of the year to the number of days in the year that precede the start of each month. For example, 59 days precede March, which has 31 days. So, if the day of the year is in the range of 60 through 91, then your program would output `March`. The program should output an error message if the number entered is not in the required range. The prompt and the error message should make it clear to the user how the number must be entered. Be sure to use proper formatting and appropriate comments in your code. The output should be labeled clearly and formatted neatly.
8. Use functional decomposition to write a C++ program that takes as input three numbers representing the number of pins knocked down by a bowler in three throws. The rules of bowling are that if the first throw is a strike (all 10 pins knocked down), then the score is equal to those 10 points plus the number knocked down in the next two throws. Thus the maximum score (three strikes) is 30. If the first throw knocks down fewer than 10 pins, but the second throw knocks down the remainder of the 10 pins (a spare), then the score is those 10 points plus the number of pins knocked down on the third throw. If the first two throws fail to knock down all of the pins (a blow), then the score is just the total number of pins knocked down in the first two throws. Your program should output the computed score, and also should check for erroneous input. For example, a throw may be in the range of 0 through 10 points, and the total of the first two throws must be less than or equal to 10, except when the first throw is a strike. Be sure to use proper formatting and appropriate comments in your code. The output should be labeled clearly and formatted neatly, and the error messages should be informative.
9. Use functional decomposition to write a C++ program that computes a dance competition score. There are four judges who mark the dancers in the range of 0 to 10, and the overall score is the average of the three highest scores (the lowest score is excluded). Your program should output an error message, instead of the average, if any of the scores are not in the correct range. Be sure to use proper formatting and appropriate comments in your code. The output should be labeled clearly and formatted neatly, and the error message should indicate clearly which score was invalid.
10. Use functional decomposition to write a C++ program that determines the median of three input numbers. The median is the middle number when the three numbers are arranged in order by size. However, the user can input the values in any order, so your program must determine which value is between the other two. For example, if the user enters

    ```
    41.52 27.18 96.03
    ```

    then the program would output

    ```
    The median of 41.52, 27.18, and 96.03 is 41.52.
    ```

    Once you have the three-number case working, extend the program to handle five numbers. Be sure to use proper formatting and appropriate comments in your code. The output should be labeled clearly and formatted neatly.

## Case Study Follow-Up

1. How might you go about choosing values for `weight` and `height` so that the BMI values of 20, 25, and 30 are tested?
2. Change the program so that the BMI is rounded. Choose appropriate cases to test the end conditions. Implement your test plan.
3. Change the program so that it takes metric values for the weight and height. Go on the Internet to find the correct formula.
4. Change the original program so that the height is entered in feet and inches. Prompt for and enter them separately.
5. A negative input value for `weight` or `height` was considered an error condition in the BMI program. Are there other values for `weight` or `height` that should be considered error conditions? Explain.