Writing Functions

Programs are composed of functions, which are, in turn, made up of statements. Functions are **named blocks of code** which carry out an action, or calculate a value. In a previous lesson you **used** math functions in `<cmath>`, and I/O objects and functions from `<iostream>`. Now you're going to write some of your own.

Let's start with some vocabulary:

- **Declaring a function**: specifying the function name, type and parameter types. Also called a **prototype**.
- **Defining a function**: specifying the calculations (or actions) that take place when the function is used. The actions are C++ **statements** that appear inside the **body** of the function, which is surrounded by curly braces.
- **Calling a function**: executing, running or invoking the function. Write the name of the function, followed by a list of **arguments** enclosed in parentheses. This allows the **caller** to pass information to the function. When the function is done, it **returns to the caller**, possibly supplying a value.

Once a function has been defined, other parts of the program can run that code by using the function name; there is no need to repeat the code in different places.

Function Syntax

Here are the syntax rules for defining functions.

```
type name(parameters)
{
    ... body ...
}
```

- **type** is the kind of value returned by the function
- **name** is the function name used when calling it
- **parameters** are a list of variable declarations separated by commas, giving the type and name of each input to the function.

Here is an example function convert, from the *f2c* program which you saw earlier:

```
double convert(double temp)
{
  return (temp - 32) * 5.0 / 9.0;
}
```

1. The **type** of this function is `double`.
2. The **name** of the function is `convert`.
3. The function has **one parameter** of type `double`.

A **parameter** (*aka* **formal parameter**) is a placeholder for one of the **arguments** (*aka* **actual parameters**), supplied in the function **call**. It acts like a local variable.

Each parameter is initialized at the time the function is called, using a copy of the value of its corresponding argument. Matching is done **by position**, and not by name. If a function has no parameters, the parameter list in the header is empty.

The Function Body

The body of the function is a block consisting of the statements that implement the function, along with the declarations of any local variables. For functions that **return a value** to their caller, at least one of those statements must be a `return` statement:

```
return expression;
```

Executing the `return` statement causes the function to immediately to return to its caller, passing back the value of the expression as the value of the function.

Functions that return a value to their caller are called **fruitful functions**, because they **can be treated as an operand in expressions**. Functions can return values of any type. Once you have defined a fruitful function, it can be used **as if it were a value**. For instance, the ***f2c*** program **calls** `convert()` like this:

```
double celsius = convert(temperature);
```

In this case `temperature` is the **argument** that is used to initialize the **parameter** `temp`.

Functions **do not need to return a value**. Such a function is often called a **procedure**. Procedures must have some kind of **side-effect**, such as printing, to be useful.

To define a procedure, use `void` as the function's return type. Procedures ordinarily finish by reaching the end of the statements in the body, but you may leave the procedure early by executing a `return` statement by itself.

Two C++ Function Pitfalls

- Unlike Java and C#, **unreachable** code is not illegal. (It is a bug, though!)
- If you forget to add a `return` statement to a fruitful function, your code will still compile. The actual returned value will be random. This may cause your program to crash, or simply act erratically.

Functional Decomposition

To practice with functions, let's revisit Homework 00.

*A metric ton is **35,273.92** ounces. Write a program that will read the weight of a package of breakfast cereal in ounces and output the weight in metric tons as well as the number of boxes needed to yield one metric ton of cereal.*

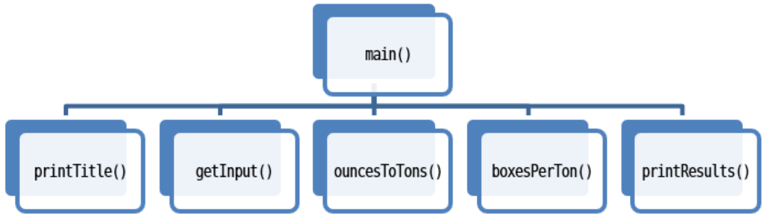
--Savitch, Absolute C++ 5th Edition, Chapter 2

On the next page, you'll see the `main` function for an **IPO program**, which starts by **calling functions** for input, output and processing.

```cpp
int main()
{
    printTitle();
    double ouncesPerBox = getInput();
    double tons = ouncesToTons(ouncesPerBox);
    double boxes = boxesPerTon(tons);
    printResults(tons, boxes);

    return 0;
}
```

This method, starting at the highest level, and breaking the program into smaller and smaller functions, is called **top down design** or **procedural decomposition**.



Declaring & Defining

The functions don't yet exist, but we can declare (or prototype) them right before the `main` function starts like this:

```
void printTitle();
double getInput();
double ouncesToTons(double ouncesPerBox);
double boxesPerTon(double tonsPerBox);
void printResults(double tons, double boxes);
```

Function Definitions

Once you have done that, make a copy of the prototypes **following** the `main` function. Replace each of the semicolons with a function body. Then, copy the original code (from your homework solution) into the appropriate body, and your program will work.

Here's a link to my version of this program if you want to compare it to yours.

Making Decisions

There are two kinds of control statements: selection (decision) and **iteration** (loops). Selection is also called **branching**, because any time you run the program you may take a different path through the code. C++ has the same five branching or selection statements that you met in Java.

Let's start with the `if` statement which is the simplest conditional statement in C++.

```
if (condition) { statements }
if (condition) { statements } else { statements }
```

Use the first form when you want to carry out an action when *condition* is **true**, but do nothing when it is **false**. This is known as a "**guarded action**" pattern.

Use the second form choose between **two mutually-exclusive** actions. This is the **either-or** version of the `if` statement; the "**alternative action**" idiom or pattern.

Here's an alternative-action example which tells if an integer `n` is even or odd.

```
cout << "The number " << n << " is ";
if (nt % 2 == 0)
{
    cout << "even." << endl;
}
else
{
    cout << "odd." << endl;
}
```

Blocks, Style & Indentation

In previous example, both the `if` body and the `else` body contain a single statement, so braces **are not required**, even though I would recommend adding them. When you want to have a **group of statements** in place of a single statement, place those statements in a **block**, sometimes called a **compound statement**, which is a collection of statements enclosed in curly braces.

The placements of braces and indentation are topics of "religious" fervor. You can read more about the "wars", and the different styles on Wikipedia.

The most common styles are **K&R style**, which places the opening brace on the same line as the header, and **Allman** (or **ANSI** or **BSD**) style, which places the opening brace on its own line.

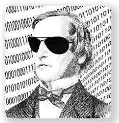
```
// K&R Formatted
cout << "The number " << n << " is ";
if (nt % 2 == 0) {
    cout << "even." << endl;
} else {
    cout << "odd." << endl;
}
```

The K&R style, shown here, is more compact, but, for me, the Allman style (which is what I normally use), is more readable.

Statements inside of a block are usually **indented**. The compiler ignores the indentation, but the visual effect is helpful since it emphasizes the program structure when reading it. Empirical research has shown that **indenting three or four spaces** at each new level makes the program structure easiest to see; in CS150 I'll use four spaces for each new level.

Indentation is critical to good programming, so you should strive to develop a consistent indentation style in your programs.

The *bool* Data Type



The *if* statement tests a condition, an expression whose value is either `true` or `false`. This is called a **Boolean** expression, after the mathematician George Boole, who developed the mathematical theories which underly much of Computer Science. In C++, the built-in Boolean data type is called `bool`.

You can create `bool` variables, just like other variables:

```
bool a = true;
bool b = false;
```

A Few Pitfalls

In Java, the `bool` type is called `boolean`, while in Python, the values are capitalized, as `True` and `False`. However, those are minor differences. The real pitfalls with the C++ `bool` type is that, for historical reasons, the `bool` type **implicitly converts** to many other types. This is not true in Java or Python, so it may be a source of confusion for you.

When the C++ compiler needs a Boolean value (such as in a an `if` statement, or a `while` condition), and it finds a value of another numeric, pointer or class type then:

1. If the value can be converted to `0` then it is treated as `false`.
2. Otherwise, the value is treated as `true`.

```
bool a = 5;            // 5 converted to true
int b = a;             // a converted to 1
bool c = 0;            // 0 converted to false
bool d = "hello";      // "hello" (a pointer) converted to true;
cout << d << endl;     // prints 1 (NOT true)
```

You'll notice that printing the `bool` variable `d` in this example does not print `true` or `false` as it would in Java and Python, but `1` and `0`. You can change that by using the `boolalpha` manipulator, like this:

```
cout << boolalpha << d << endl;
```

We'll revisit the effects of this behavior as we go on. You can run this example in an online IDE by clicking the link in this sentence.

The Relational Operators

The six relational operators are all binary operators which compare two values and return `true` if the relationship holds between the two, and `false` otherwise. Assume we have these variables:

```
int a = 3, b = 5, c = 2;
string s1 = "sam", s2 = "mary";
```

Here are the six operators. Each condition listed here is `true`.

- **Equals**: `==`. `if (a == b - c) ...`
- **Not-equals**: `!=`. `if (a != b) ...`
- **Less-than**: `<`. `if (s2 < s1) ...`
- **Less-than-or-Equals**: `<=`. `if (a <== b - c) ...`
- **Greater-than**: `>`. `if (s1 > s2) ...`
- **Greater-than-or-Equals**: `>=`. `if (b >== a + c) ...`

Relational operators compare primitive types, but they **also work with many of the types supplied by libraries**, such as `string` and `vector`. Again, this is different than Java, where you have to use `equals()` or `compareTo()` to compare `String` objects.

More Pitfalls

As in Java and Python, the equality (`==`) operator uses **two** `=` symbols.; a single is the **assignment** operator. Unlike those languages, accidentally using a `=` when you mean to use `==` creates an **embedded assignment**, which is legal, not what you expect.

```
if (area = 6) ... // always true
```

This would be a syntax error in Java or Python. In C++ it **assigns** the value `6` to the variable `area`, and then, when the condition is evaluated, converts that `6` to `true`.

Comparing floating-point numbers is legal (syntactically) using the relational operators, but it is also problematic. (This is actually true in any programming language; it's not unique to C++.) For instance, the following expressions evaluate to `false`, **not** `true`, even though they are both mathematically true:

```
1.0 == .1 + .1 + .1 + .1 + .1 + .1 + .1 + .1 + .1 + .1; // false
sqrt(2.0) * sqrt(2.0) == 2.0;  // false
```

These occur becuase of **representational errors** in binary numbers. Just as the number 1/3 can't be exactly represented in base-10 (decimal), many numbers cannot be precisely represented in base-2 (binary). When you do calculations with these numbers, those small errors are magnified, and you end up with nonsensical comparisons such as these.

*To correctly compare floating-point numbers, you must first calculate the absolute value of the difference between the two numbers, and then compare that to a predetermined limit, called **epsilon**.*

The Logical Operators

In addition to the relational operators, C++ defines three logical operators that take **Boolean operands** and **combine them** to form other Boolean values:

Logical Operators	
`!` or ***not***	Unary ***NOT*** (*true* if its operand is *false*)
`&&` or ***and***	Binary ***AND*** (*true* if **both** operands are *true*)
`||` or ***or***	Binary ***OR*** (*true* if either or both operands are *true*)

In C++ you can use either they operators `&&`, `||`, and `!` as you would in Java, **or** the English words ***and***, ***or***, and ***not***, as you would in Python.

Use the logical operators to **combine multiple conditions** like this:

```
if (percent >= 6.25 && percent < 78) { grade = "C"; }
```

Here, **both conditions** must be `true` for `grade` to be set to `"C"`. Here's another example:

```
if (c == 'a' || c == 'e' || c == 'i' || c == 'o' || c == 'u')
{
    result = "vowel";
}
```

Here, `result` is set to `"vowel"` if **any one** of the conditions is true.

Remember, `&&` *means all, and* `||` *means any!*

Short-circuit Expressions

When C++ evaluates an expression with the logical operators:

- the sub-expressions are **always evaluated from left to right**.
- **evaluation ends** as soon as the result can be determined.

For example, if *expr1* is `false` in the expression `expr1 && expr2`, there is no need to evaluate `expr2` since the result will **always** be `false`.

Similarly, with `expr1 || expr2`, there is no need to evaluate `expr2` **when** `expr1` is `true`.

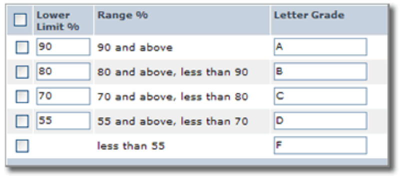
In both of these cases, evaluation which stops as soon as the result is known. This is called **short-circuit evaluation**.

Multi-way Branching

Often, your programs will need to handle many different conditions: in one case, you should "turn left", in another you should "turn right", while in a third, it should go "straight ahead". When you **have more than two branches**, there are three general techniques to use:

- **Sequential `if` statements** should be used when each test depends on the results of a previous test. The tests are **performed sequentially**.
- **Nested `if` statements** are used when the calculations or actions you need to carry out depend on **several different conditions**, of different types.
- **`switch` statements** allow you to easily write "menu style" code. You can place each action in a block (called a case **block**), and directly jump to (and execute) that block whenever the user enters the appropriate selection.

One **sequential comparison** which you're all familiar with is the "letter grading scale" used to assign marks in school, (including in this course), similar to that shown here:



☐	Lower Limit %	Range %	Letter Grade
☐	90	90 and above	A
☐	80	80 and above, less than 90	B
☐	70	70 and above, less than 80	C
☐	55	55 and above, less than 70	D
☐		less than 55	F

Typically, your letter grade is based on a percentage representing a **weighted average** for all of the work you've done during the term. To select one course of action from many possible alternatives (which is the case here), you employ **sequential `if` statements** following this pattern:

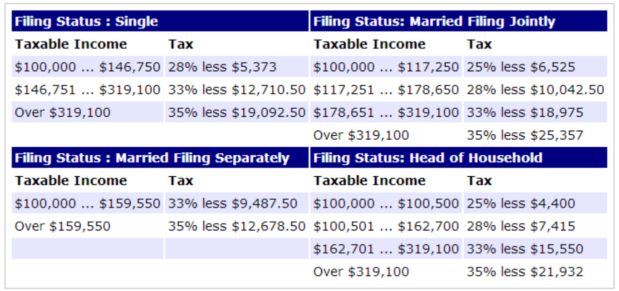
```
if (condition-1)        // condition-1 is true
  statement
else if (condition-2)   // condition-1 false, condition-2 true
  statement
...
else if (condition-n)   // conditions 1-n false, condition-n true
  statement
else                    // if no conditions are true
  statement
```

This is called the **"Multiple Selection"** pattern. It is also known as a "**ladder style**" if statement, because each of the conditions are formatted one under the other, like the rungs on a ladder.

Nested *if* Statements

Another way to code multiple-alternative decisions is with nesting. Nesting means that one `if` statement is **embedded** or **nested** inside the body of another `if` statement, much like the traditional Russian nesting dolls.

Use nesting when you have **different levels of decisions**. For instance, if you're one of those fortunate folks making more than a hundred thousand dollars a year, you calculate your taxes using the following formula, instead of using the tax tables:



Filing Status : Single		Filing Status: Married Filing Jointly	
Taxable Income	**Tax**	**Taxable Income**	**Tax**
$100,000 ... $146,750	28% less $5,373	$100,000 ... $117,250	25% less $6,525
$146,751 ... $319,100	33% less $12,710.50	$117,251 ... $178,650	28% less $10,042.50
Over $319,100	35% less $19,092.50	$178,651 ... $319,100	33% less $18,975
		Over $319,100	35% less $25,357
Filing Status : Married Filing Separately		**Filing Status: Head of Household**	
Taxable Income	**Tax**	**Taxable Income**	**Tax**
$100,000 ... $159,550	33% less $9,487.50	$100,000 ... $100,500	25% less $4,400
Over $159,550	35% less $12,678.50	$100,501 ... $162,700	28% less $7,415
		$162,701 ... $319,100	33% less $15,550
		Over $319,100	35% less $21,932

First locate the schedule for your filing status (Single), then find your income bracket. Use a set of **sequential** `if` statements to determine **which set** of calculations to use. Then, **nested inside** the body of each portion test the income levels, like this:

```
if (status == kSingle) // calculate single
{
  if (income <= kSingleBracket_1)
    tax = income * kSingleRate_1 - kSingleEx_1;
  else if (income <= kSingleBracket_2)
    tax = income * kSingleRate_2 - kSingleEx_2;
  else
    tax = income * kSingleRate_3 - kSingleEx-3;
}
else if (status == kMarriedJoint)  // married filing jointly
...
```