Chapter

4

Writing Functions

Programs are composed of functions, which are made up in turn of statements. Functions are named blocks of code that carry out an action or calculate a value. You've **used** math functions in `<cmath>`, `string` functions in `<string>` and I/O objects and functions from `<iostream>`.

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 or 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. It has **one parameter** of type **double**.

Parameters

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, by 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 return immediately to its caller, passing back the value of the expression as the value of the function.

Fruitful Functions & Procedures

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, ***f2c*** (from Chapter 0), **calls** **convert()** like this:

```
double celcius = convert(fahr);
```

In this case **fahr** 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 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 an earlier homework assignment.

> *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*

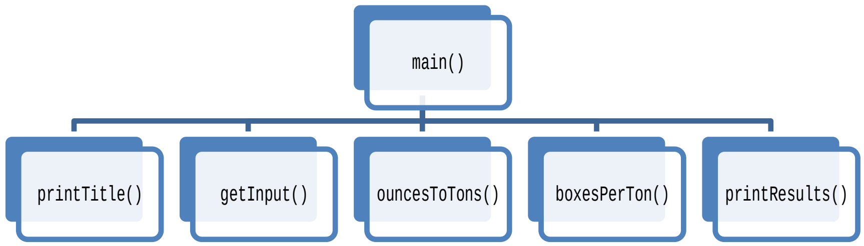
Click the link on the left to open a version in an online coding environment.

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

    return 0;
}
```

Top-level design for H00.

This is an **IPO program**, so start by **calling functions** for input, output and processing, following the comments. This is **top down design** with **procedural decomposition**.



Function Prototypes

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 weightInTons(double ouncesPerBox);
double boxesPerTon(double tons);
void printResults(double tons, double boxes);
```

Function prototypes for H00.

Function Definitions

Once you have done that, make a copy of the prototypes following the main function, and replace each of the semicolons with a function body. Then, copy the original code 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 the condition is true, but do nothing if the condition is false. This is known as a "**guarded action**" pattern.

Use the second form choose between **two mutually-exclusive** actions. This as 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 (n % 2 == 0)
{
    cout << "even." << endl;
}
else
{
    cout << "odd." << endl;
}
```

Blocks, Style & Indentation

In the example above, 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 a **group of statements**, 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 (n % 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. 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.

Conditions & the *bool* Data Type

The `if` statement tests a **condition**, an expression whose value is either `true` or `false`. This is called **Boolean** data, after the mathematician George Boole, who developed the underlying algebra. In C++, the built-in Boolean type is called `bool`.

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

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

Usually, though, you'll use the **relational** and **logical** **operators** in **Boolean** expressions for use as conditions in `if` statements and in loops.

The Relational Operators

The six **relational operators compare two values**. These are `==`, `!=`, `<`, `>`, `<=` and `>=`.

The equality (==) operator uses **two = symbols**.; a single is the **assignment** operator. Unlike Java, accidentally using a `=` when you mean to use `==` creates an **embedded assignment**, which is legal in C++; it just isn't what you want.

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 strings.

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

Although the operators `&&`, `||`, and `!` closely resemble the English words **and**, **or**, and **not**, it is important to remember that English can be imprecise when it comes to logic.

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

```
if (percent >= 62.5 && percent < 78) { grade = "C"; }
if (c == 'a' || c == 'e' || c == 'i' ||
    c == 'o' || c == 'u')
{
    result = "vowel";
}
```

In line 1, **all conditions** must be **true** for `grade` to be set to **"C"**. In line 2, `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 ***exp1*** is `false` in the expression **exp1 && exp2**, there is no need to evaluate ***exp2*** since the result will **always** be `false`. Similarly, with **exp1 || exp2**, there is no need to evaluate ***exp2*** if ***exp1*** is `true`. Evaluation which stops as soon as the result is known, is called **short-circuit evaluation**.

Multi-way Branching

Often, **your program will need to handle many different conditions:** in one case, the program should do `x`; in another, it should do `y`; in a third, it should do `z`; and so on.

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 some 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), is to employ **sequential if statements** following this pattern:

```
if (condition-1)
   statement
else if (condition-2)
   statement
...
else if (condition-n)
   statement
else     // if no matches have been found
   statement
```

This is called the **"Multiple Selection"** pattern, aka "**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, shown here.

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:

```
if (status == SINGLE) { /* calculate for single taxpayer */ }
else if (status == MARRIED_JOINT) { /* for married */ }
... and so on
```

Then, nested inside the body of each portion test the income levels, like this:

```
if (status == SINGLE) // calculate tax for a single taxpayer
{
    if (taxableIncome <= SINGLE_BRACKET1)
        tax = taxableIncome * SINGLE_RATE1 - SINGLE_EX1;
    else if (taxableIncome <= SINGLE_BRACKET2)
        tax = taxableIncome * SINGLE_RATE2 - SINGLE_EX2;
    else
        tax = taxableIncome * SINGLE_RATE3 - SINGLE_EX3;
}
... and so on
```

The *string* Type

As in Java, `string` **is a library class type; it is not part of the C++ language. The** C++ **`string` type** is a sequence of characters. The class is declared in the `<string>` header, which you **must include**.

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

Creating String Objects

There are several different ways you to **create** **string** objects:

```
string s1;                  // empty string
string s2{"Hello"};         // initialized
string s3 = "World";        // legacy C-style
string s4{s3};              // A copy of s3
string s5{'c', 'a', 't'};   // A sequence of chars
string s6{R"("bob")"};      // a raw string
string s7(20, '-');         // 20 dashes
```

Let's look the most useful ones.

1. In Java, **s1** is a **null** string. In C++, it is the **empty string**.
2. **Explicitly** converts a **string literal** (character array) to a **string** object.
3. **Implicitly** converts a string literal to a **string** object.
4. Produces a **string** that is **a copy** of the **string s3**.
5. A **string** that constructed from **a sequence** of **chars**.
6. Produces a **string** object from a **raw string literal**. Raw string literals begin with **R"(** and end with **)"**. Inside you may store **any** character without using escape sequences.
7. Produces a **string** made of 20 **'-'** **chars**. **char** literals use single quotes. Note that **you must use parentheses**, not braces.

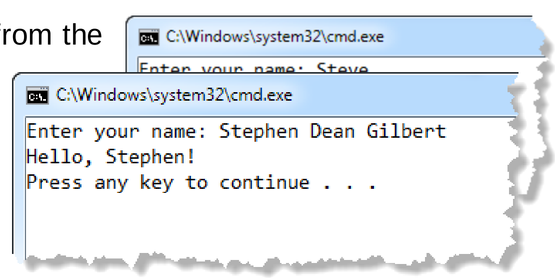
Whenever a **{}** is used above, you may use a **()**. For the 2-argument, (**int**, **char**) **string** constructor, you **must use parentheses**. The uniform initialization syntax was added in C++ 11. Raw strings also were added in C++ 11.

String Input and Output

You may use **>>** and **<<** to read and write data values of type **string**:

```
cout << "Enter your name: ";
string name;
cin >> name;
cout << "Hello, " << name << "!" << endl;
```

This version of the program reads a **string** from the user into the variable **name** and then includes that name as part of the greeting, as shown in the following sample run.



However, if you enter a **full name** instead of just the first, only the first is read.

Even though the program contains no code to split the name apart, it somehow still uses **only** the first name when it prints its greeting.

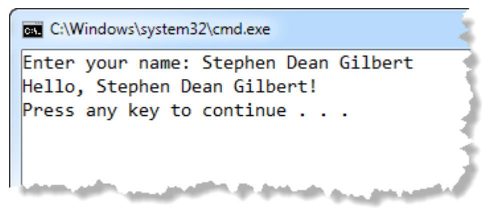
Why? Because `>>` **stops reading** as soon as it sees the first **whitespace character**. A whitespace character is any that appears as blank space on the screen.

The getline Function

To read **an entire line of text**, use the `string` function `getline()` like this:

```
cout << "Enter your name: ";
string name;
getline(cin, name);
cout << "Hello, " << name << "!" << endl;
```

This **reads an entire line** from `cin` into the variable `name`. And, when run, the program allows you to display the full name of the user instead of just the first name.



String Operations

The `<string>` library **redefines** several **standard operators** using a C++ feature called **operator overloading**. When you use the `+` operator with numbers, it means addition, but, when you use it with the `string` type, it means **concatenation**.

The shorthand `+=` operator concatenates new text to the end of an existing `string`. You may concatenate `char` values to a string object, but you **cannot** concatenate numbers to strings as you can in Java.

```
string s{"abc"};
s += s;             // ok, "abcabc"
s += "def";         // literal ok
s += 'g';           // char ok
s = s + 2;          // Error; no conversion
```

You **cannot** concatenate two string literals: `"a" + "b"` is **illegal**. However, separating them with whitespace, like `"a" "b"`, is legal. Use this is used to join long lines together.

Comparisons

C++ overloads the **relational operators** so that you can **compare** string values just like primitive types. To see if the value of `str` is equal to `"quit"`, just write this:

```
if (str == "quit") . . .
```

There is no need to use `equals()` or `compareTo()` as in Java.

Strings are compared using **lexicographic order**. Informally that means a string is smaller, if it would appear earlier in the dictionary. However, case is significant, so `"abc"` is **not** equal to `"ABC"`. Upper-case characters are "smaller" than lower because they have smaller ASCII values.

Value Assignment & Mutability

In C++ `string` objects **are mutable**; **you may** change the individual characters inside a **string**. In C++, defines assignment so that assigning one `string` to another, **copies the underlying characters** into a new `string`, in the same way that assigning one `int` variable to another creates a new, independent variable and value.

Languages (like C++) that work like this have **value semantics**. In C++, the statement

```
str2 = str1;
```

overwrites any previous contents of `str2` with a **copy** of the characters contained in `str1`. The variables `str1` and `str2` therefore remain **independent**, which means that changing the characters in `str1` does not affect `str2`.

Member Functions

Because `string` is a library or class type, it also has **methods**, just like the Java `String` class has methods such as `length()`, `toUpper()` and `charAt()`. **Member function is the term used in C++ for what is called a method in Java**. Let's look at the difference between a regular (or "free") function in C++, and a member function.

In the `string` class, you've already seen the `getline()` function. The prototype for `getline()` function looks like this:

```
istream& getline(istream& in, string& str);
```

The function has **two parameters**: the input stream to read from, and the `string` object to modify; it returns a reference to its input stream (which may be ignored).

```
string line;
getline(cin, line);
```

Though `getline()` is declared inside the `<string>` header, it **is not** part of the `string` class; it is just a function. **Member functions**, in contrast, **are part of a class**, and, as in Java, they are called by using a special syntax:

```
receiver.request(arguments)
```

In this case, `receiver` is an **object**, and `request` is a member function defined in that class. When compiled, the address of the `receiver` object is passed to the member function as an **invisible** or **implicit** first parameter. Inside the member function, that implicit parameter is accessed using the keyword `this`, similar to Java.

Let's look at a few `string` member functions that you are likely to use regularly.

String Members

Below are the member functions **you should memorize**. You can look up the rest.

- `size`: the number of characters in the `string` (may also use `length`)
- `empty`: `true` if the `string` contains no characters
- `at`: an individual character at a particular position (may also use `[]`)
- `front`, `back`: the character at the front, and at the back (C++11)
- `substr`: a new `string` created from a portion of an existing string
- `find`, `rfind`: index of the substring searched for (from front or back)

The *size* Member Function

`s.size()` returns the **number of characters** in the `string` `s`. For historical reasons, you can also use `length()`, but all of the other collections in the library use `size()`, so you should probably get used to using that. (Plus, it's less typing.☺).

The `size()` (or `length()`) member functions returns a `string::size_type` object, an **unsigned** integer, which may be defined differently on different platforms. The `::` is called the **scope resolution operator**. Read this as "the `size_type` defined inside the `string` class". Other library types often have their own, such as `vector::size_type`.

On an embedded platform, with little memory, **string::size_type** could use an **unsigned** 16-bit short. More commonly, strings can be as big as 4 billion characters, so an **unsigned int** is large enough. You can't assume that is true. I recently recompiled some older code and discovered several places where I had assumed string sizes were **unsigned int**, but XCode used a 64-bit **unsigned long**.

Type Inference and *size_t*

This seems complex, but it is not. Here are three different ways to store the value returned from calling `size()` on a string of unknown size:

```
string str{. . .};      // any size
string::size_type len1{str.size()};
auto len2 = str.size();
size_t len3{str.size()};
```

1. To be slavishly, pedantically correct, use **`string::size_type`**.
2. Use **`auto`** which **infers** the type from the initializer. (Use `=`, not braces.)
3. Use the type **`size_t`**. This is the **`unsigned`** machine type.

I believe that the easiest method is the last, and that's what I'll do in this class.

Finish Up

- Complete the **reading exercises** **(REX)** for this chapter.
- Complete the **homework** using the **CS50 IDE**. The link is on Canvas.
  a. Make sure you submit the assignment using **`make submit`**.
  b. Make sure you check the CS150 Homework Console to see that your scores got reported, before the beginning of the next lecture.
- Take the **pre-class reading quiz** on Canvas. You have two attempts.

See you in class or on the Canvas discussion board.