Library Mechanics

Functions are named "chunks" of code that calculate a value or that carry out an action. I think of them like the "Magic 8-ball"; you ask a question, and get an answer, never knowing how it is accomplished.

In C++, a function associates a computation—specified by a block of code that forms the body of the function—with a particular name. If a function calculates a value, what we call a **fruitful** function, then it may be used in an expression; if it carries out an action (called a void function in C++ or **procedure** in other languages), it cannot.

Using functions reduces bugs and make maintenance more effective by allowing you to reuse proven code, instead of duplicating it. Placing related functions **into a library**, allows you to reuse them in many different contexts.

Organization

Programs using functions can be organized in several different ways. The question is, "Where do definitions and declarations go?"

1. You may **define** your functions before calling them. If you have only one or two functions in a "throw-away" program, this is fine. Because your functions need to appear in a particular order, though, your code is often harder to understand and maintain. In general, you **will not to do this**.
2. You can **prototype** (or declare) your functions at the top of your file (usually under the library `#include` statements) and then **define** the functions later in the file, usually after the `main` function. This makes it easier to read and understand your program, because the primary logic appears before the function details.

   It also makes your code much easier to maintain, because you can then define your functions in any order you like. **Do this for small programs** and for functions that are unique to a particular program.

3. If you have functions which you want to **reuse** in different programs, you should **place those function in a library**, (a collection of similar functions) and **place the prototype into a header file**. That is what you'll generally do in this class for all of your functions from now on.

In the next Lesson, you will learn to use **separate compilation** for your programs.

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Separate Compilation

To define a library in C++, you'll supply four parts:

- the **client** or **test** program, which **uses** the functions in the library.
- the **interface**, which provides information needed to use the library. The interface consists of **declarations** or **prototypes**, and will go into a **header** file.
- the **implementation**, which provides the details. The implementation consists of **function definitions**.
- the **makefile** which puts the parts together to produce the executable.

To try this out, we'll write a library containing three functions:

- `int firstDigit(int n)`, returning the **first** digit of its argument
- `int lastDigit(int n)`, returning the **last** digit of its argument
- `int numDigits(int n)` returning the **number of digits** in its argument

Calling `firstDigit(1729)` will return **1**; calling `lastDigit(1729)` will return **9**; calling `numDigits(1729)` returns **4**.

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The Client or Test Program

Open your CodeSpace IDE, (or, you can do this in Replit if you like), and create a folder. Add a file named `client.cpp`. Add the usual `#include` statements and an empty `main()`. In the `main()` function you need to:

1. **Call** each of your functions with some known input.
2. Compare the value returned (this is called the**actual value**), with the value that**should have been returned** (this is called the **expected value**).
3. Print a message indicating whether you got it right or wrong.

Here's some code, which calls each function, compares it to the expected value, and then uses the **conditional operator** to print `PASS` or `FAIL`. Note that each expression needs to be enclosed in parentheses:

```
cout << "Testing digits library" << endl;
cout << ((firstDigit(1729) == 1) ? "PASS" : "FAIL") << endl;
cout << ((lastDigit(1729) == 9) ? "PASS" : "FAIL") << endl;
cout << ((numDigits(1729) == 4) ? "PASS" : "FAIL") << endl;
```

When you compile with `make client`, you'll get the error message:

```
client.cpp:7:14: error: ‘firstDigit’ was not declared in this
scope
```

An **undeclared** error message is a **compiler** syntax error whic means you are missing a prototype or you are calling a function incorrectly.

Basically, the compiler is saying "I don't know what the word **firstDigit** means. It's up to us to tell it what that means. Which leads us to the interface file.

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The Interface or Header File

A library may contain several definitions: functions, types, and constants. In C++, the interface and implementation are in two files: a **header (or interface) file** and an **implementation** file. The **interface** file usually ends with the extension `.h`.

Add `#include "digits.h"` in your client file right after the `using namespace std` line. Then, create and open **`digits.h`** and let's look at header guards.

Preprocessor Header Guards

It is possible for one header file to include another. You must do **something** to **make sure that the compiler doesn't include the same interface twice**. You do that by adding three lines to every header file that are known as the **interface boilerplate**, or **header guards**. They look like this:

```
#ifndef FILE_IDENTIFIER
#define FILE_IDENTIFIER
    // Entire contents of the header file
#endif
```

This pattern appears **in every interface**. These are **instructions to the preprocessor**, a program that examines and modifies your code before it is sent to the compiler. The boilerplate consists of the **`#ifndef`** and **`#define`** at the beginning and the **`#endif`** at the end.

1. The **`#ifndef`** preprocessor directive checks whether the **`FILE_IDENTIFIER`** symbol has been defined in the **current translation unit**. When the preprocessor reads this interface file **for the first time**, the answer is no.
2. The next line **defines the symbol**, using **`#define`**. Thus, if asked later to **`#include`** the same interface, the **`FILE_IDENTIFIER`** **will already be defined**, and the preprocessor will **skip over the contents** of the interface this time around, not including them a second time.

A common convention to create **`FILE_IDENTIFIER`** is to simply **capitalize the name of the file itself**, replacing the dot with an underscore. You may use another convention if you like, but make sure that the name will be unique when you build your project.

Go ahead and add the header guards to **`digits.h`** now.

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Adding the Prototypes

When the compiler encounters a function call in your program, it needs information in order to generate the correct code; the compiler doesn't need to know **how** the function is implemented, but it **does** need to know:

- what types each of the **arguments** to the function are (and how many)
- what type of value the function **returns**

That information is provided by a **prototype**, or **function declaration** (as opposed to a function definition).

```
#ifndef DIGITS_H
#define DIGITS_H
int firstDigit(int);
int lastDigit(int);
int numDigits(int);
#endif
```

These prototypes associate the names `firstDigit`, `lastDigit`, and `numDigits` each with a function that **takes** a single `int` as an argument and which **returns** an `int` as its result. These are **function declarations**. **Go ahead and complete the prototypes now.**

In a prototype, **parameter names are optional**. The compiler doesn't care about the names, but they help **you remember** which parameter matches which argument.

```
double focalLength(double d, rouble r1, double r2, double n);
```

Supplying names in a prototype often helps the reader. The parameter names in a prototype are in **prototype scope**; they have no meaning after the prototype ends, and, specifically, they do not need to match the names used in the definition.

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Library Types in Interfaces

If the prototype includes any types from the standard library (such as `string` or `vector`), then you must `#include` the correct header, and fully qualify the name of the type. Here's an example:

```
// Header file
std::string zipZap(const std::string& str);
// Implementation file
string zipZap(const string& str) { . . . }
```

Header files **should never** use identifiers from the standard library without explicitly including the `std::` qualifier. In the implementation file, you may use the name as is, because your implementation file will contain a `using` declaration or directive.

Here are **three rules to remember**.

- **Never** add `using namespace std` to a header file. Header files are `#included` in other files; doing so changes the environment of that file.
- **Always** add `std::` in front of **every** library type, such as `std::string`, but **never** in front of primitive types like `double`.
- For all library types, `#include` the appropriate header file inside of your header file. If you use the `std::string` type, you must `#include <string>` Note that when including standard libraries, you enlose them in angle brackets (`<>`), while your header files use double quotes when included.

Linker Errors

Once you have finished prototyping all three functions, build your project again by by typing `make client`. When you do, you **won't** see any compiler error messages; the client program compiles. However, you will see some **linker error messages**. Your function was **declared** correctly, but the **definition** could not be found at linking time.

```
$ make client
client.cpp:(.text+0x32): undefined reference to
`firstDigit(int)'
```

> *If you still see **undeclared** (instead of **undefined**), make sure you have added the line `#include "digit.h"` to the top of the client program.*

Two words to note in your compiler's error messages: **undefined** and **undeclared**. Recognizing these will help you locate and fix the problem.

- An **undeclared** error message is a **compiler** syntax error. It means you are missing a prototype or you are calling a function incorrectly.
- An **undefined** error message comes from the **linker** and means that you are missing the definition for a function.

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The Implementation File

Place your definitions in an implementation file. The implementation file has the same root or **base name** as the header file, but a different extension. You'll use `.cpp` in this class but other conventions include `.cxx`, `.cc`, and `.C` (a capital **'c'**).

1. Create an **implementation file** using the extension `.cpp`.
2. Add a file comment to the top of the file.
3. `#include` the interface file for the library you are implementing.
4. If you use other libraries, such as `string`, you should include them as well. This example does not.
5. Add a **using directive** if you are using any library types. This library does not.
6. **Copy the prototypes** from each of the functions in the header file into the implementation file. You don't need to bring across the documentation. Make sure, also, that you **don't copy the header guards**.
7. **Stub out each of the functions**.

This is **purely mechanical**. You want to practice it until it becomes second nature. You should **memorize** this part, so you don't have to expend any brain cells to complete it.

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Stubbing the Implementation

Always start by writing a "skeleton" or stub for your function. Make sure your code starts out syntactically correct, and then stays that way.

1. **Copy the prototype or declaration** into the implementation file. You don't need to bring the documentation with the prototype, but you may.
2. **Remove the semicolon** at the end of the prototype and **add some braces** to supply a **body** for the function.
3. Unless your function is a procedure (`void` function), you must create a return variable to hold the result. Look at the function return type to decide what type to make this variable. Initialize it to the "empty" value.
4. Add a `return` statement at the very end of your function.

> ***Warning.*** *Make sure your stubs always include a `return` statement of the correct type, or your function may crash at runtime.*

Here's a **stubbed-out** version of one function:

```
#include "digits.h"

int firstdigit(int n)
{
    int result{};
    return result;
}
```

Once you've stubbed out the two other functions, you'd expect your program to compile and link, but it does not. You get the same linker errors that appeared earlier.

Why? Since you now have two, separately compiled portions of object code, you have to tell the compiler **how to link them together**. You do that with a **makefile**.

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The Make File

For the homework your instructor provides a project or make file. For this lesson, though, you'll get to build one on your own. Create a new file named `makefile`. It has no extension. Then, add the following code:

```
1  EXE=digit-tester
2  OBJS=client.o digits.o
3
4  $(EXE): $(OBJS)
5      $(CXX) $(CXXFLAGS) $(OBJS) -o $(EXE)
6
7  run: $(EXE)
8      ./$(EXE)
```

Here are what these three sections mean:

1. **Macros**: these are like variables that can be **expanded** later. `EXE` is the name of the executable, and `OBJS` contains the names of the object files. Since you have two `.cpp` files in your project, you'll have two object files.
2. Both of the next two sections contain **targets**, **dependencies** and **actions**.
   →Line 4 **expands** the macros `EXE` and `OBJS`, producing a line that says: `digit-tester : client.o digits.o`
   →Interpret this line as meaning : "to build `digit-tester`, make sure that `client.o` and `digits.o` are both up to date."
   →`digit-tester` is a **target** (what we are trying to build), while `client.o` and `digits.o` are **dependencies**
   →Line 5 is the action to perform to produce `digit-tester`. Each action line must start with a **tab character**, not spaces. Your editor may do this already, but if not, you'll need to configure it. Line 5 expands a few other macros meaning "run the compiler with these object files and produce t his executable".
3. Line 7 is called a **pseudo target**. When you type `make run`, the action line is executed. If you just type `make`, only the first target is built.

Once you've saved your make file, type `make` and the linker errors should disappear. If they don't then go over the previous steps (or reach out on the Discussion Board). Type `make run`, and the client program should run (even if you have some warnings about unused parameters).

Even though all of your tests fail, **that's OK**. The purpose of the stub is to get the mechanical details out of the way, so that you can **use all of your brainpower** to concentrate on solving the problems.

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int lastDigit(int);
int numDigits(int);
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```

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Planning & Implementation

The documentation in the header file is for the client-what us necessary to use the function. In the implementation file, add **implementation comments**, in the form of a **function plan**, to help you to write the function.

These comments **are intended for programmers**, not for the clients of the function. Don't use Doxygen, but describe the algorithms and important implementation details.

For instance, here is my plan for **`lastDigit()`**, placed inside the body of the function:

```
// result <- |n| % 10
```

> *Single-line comments are simplest for this, since editors will comment and un-comment a portion of code, using only a single keystroke. In many editors, the keystroke is **Shift+/**.*

Implementing *lastDigit*

You should write your comments first, and then implement the function. The most straightforward solution just an ***if*** statement to select one path path for positive numbers, and another for negative numbers.

```
if (n < 0) { result = -(n % 10); }
else { result = n % 10; }
```

You could write a shorter version using the **conditional operator** like this, instead of an ***if*** statement.

```
result = (n < 0 ? -n : n) % 10;
```

For another short, one-line solution, which almost exactly matches the function plan, you can use the **`abs()`** function like this:

```
result = abs(n % 10);
```

However, a new C++ programmer might not realize that there are separate versions of the function in **`<cmath>`** (for floating-point numbers), and in **`<cstdlib>`** for (integers), and end up with an answer that was wrong, or code that does not compile.

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The *while* Loop

The other two functions in our library are more difficult. Both of them require you to learn about a new kind of loop bounds, called **limit bounds**. Loops that do some processing and then check the results against a boundary condition are **limit loops**.

To write a limit loop, use the `while` loop, which executes a statement repeatedly **while its condition remains true**. The general form of the while loop looks like this:

```
while (condition)
{
    statements;
}
```

A `while` loop first evaluates the condition. If `false`, the loop terminates and the program continues with the next statement after the loop body. If `true`, the actions in the body are run, after which control **returns to the loop condition**. One pass through the body constitutes a **cycle or iteration of the loop**.

1. The test is performed **before every cycle of the loop**, including the first. If the test is `false` initially, the body of the loop is **not executed at all**. That's why this is known as a **guarded** loop.
2. The test is performed **only** at the beginning of a loop cycle. If the condition **becomes** `false` at some point during the loop, the **program won't notice** that fact until it completes the entire cycle. When the program evaluates the test condition again, if it is still `false`, only then does the loop terminate.

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Limit Bounds

A limit loop first does a calculation, and then checks to see if the calculation has reached a limit. Limit loops are used extensively in scientific, financial and graphical computing. Kinds of limits include reduction to zero, bisection, non-convergence tests (as in Calculus) and successive approximations. You'll use several of those in Lecture.

Here is a limit loop whose limit is the reduction to zero. This computes the sum of the digits in an integer, `n`:

```
int temp = n;
while (temp > 0)
{
    sum += temp % 10;
    temp /= 10;
}
cout << "The sum of the digits in " << n << " is " << sum << endl;
```

- The expression `temp % 10` always returns the last digit in the positive integer `temp`.
- The expression `temp / 10` returns the number without its final digit.

In this case, the condition that is being tested is the value of `temp`, which is changed each time through the loop. Once `n` reach its **limit** (`0`), the loop terminates.

> *Note that instead of changing `n` itself, the solution creates a separate variable named `temp`. This is better style because it doesn't confuse the concept of a parameter or input variable, with that of a local variable used for the function output. In this case, if the loop had used `n` then the last output statement would have been incorrect.*

More Loop Plans

Here are the plans that I created for each of the remaining two functions. Using limit loops, you should be able to complete these on your own.

Here is `firstDigit()`

```
// result <- |n|
// while result greater or equal to 10
//      result <- result / 10
// return result;
```

And, here is `numberOfDigits`

```
// Assume that 0 is a digit
// result <- |n|
// counter <- 1
// while result is greater or equal to 10
//     result <- result / 10
//     counter <- counter + 1
// return counter
```

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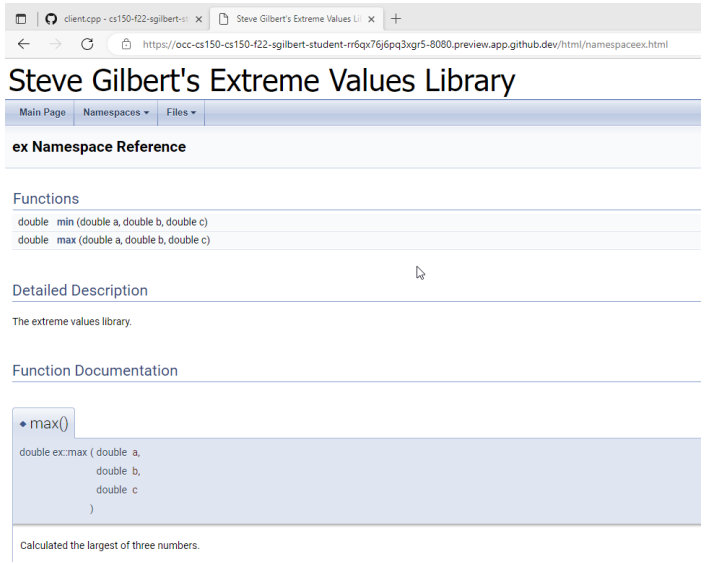

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