

DM560

Introduction to Programming in C++

Functions

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[Based on slides by Bjarne Stroustrup]

Outline

1. Declarations and Definitions
2. Scopes
3. Functions
4. Namespaces

C++ Users: CERN's Higgs Boson Hunt

(2012) Higgs boson found! In email from CERN:

"all related computing done in C++."

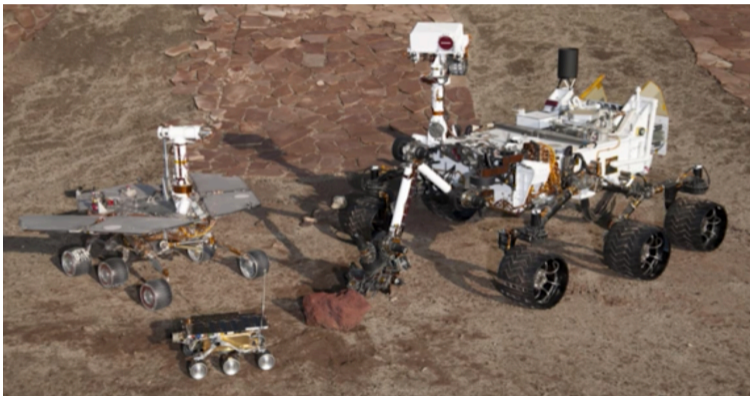
and a follow-up from Fermilab:

"The reports are correct, almost all significant computing done for high energy physics (and not only the LHC) is done in C++. And many (though not all) experiments are now in the process of migrating to the use of C++11."

Sources:

- The Big Data Software Problem Behind CERN's Higgs Boson Hunt
- Root a data analysis framework based on C++ <https://root.cern.ch//>

C++ Users: Mars Rover



<https://www.youtube.com/watch?v=3SdSKZFoUa8>

Overview

Goals:

- broaden the view of C++'s basic facilities (types, functions, and initialization)
- provide a more systematic view of those facilities.

Contents:

- Language Technicalities
- Declarations
 - Definitions
 - Headers and the preprocessor
 - Scope
- Functions
 - Declarations and definitions
 - Arguments
 - Call by value, reference, and const reference
- Namespaces
 - `using` declarations

Language Technicalities

- They are like the vocabulary and the grammar in a foreign language
- In a formal language the rules governing the composition of well-formed expressions are referred to as [syntax](#)
- We need to learn them because programs must be precisely and completely specified
 - A computer is a very stupid (though very fast) machine
 - A computer can't guess what you "really meant to say" (and shouldn't try to)
- However, here, we will look at only some of the C++ rules:
(the C++14 standard is 1,358 pages)

Language Technicalities

But! Don't spend your time on minor syntax and semantic issues

↪ Remember: we study [programming concepts](#), the programming language is only a tool.

- Most design and programming concepts are universal, or at least very widely supported by popular programming languages
So what you learn using C++ you can use with many other languages
- Language technicalities are specific to a given language
But many of the technicalities from C++ presented here have obvious counterparts in C, Java, C#, etc.
- Moreover, there is more than one way to say everything

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Declarations

A name must be declared before it can be used in a C++ program.

- A **declaration** introduces a **name** into a scope.
- A declaration also specifies a **type** for the named object.
- Sometimes a declaration includes an **initializer**.

Examples:

```
int a = 7;           // an int variable named 'a' is declared
const double cd = 8.7; // a double-precision floating-point constant
double sqrt(double); // a function taking a double argument and
                    // returning a double result
vector<Token> v;     // a vector variable of Tokens (variable)
```

Declarations

A **header** is a file containing **declarations** providing an **interface** to other parts of a program

- Declarations are frequently introduced into a program through **headers**
- This allows for **abstraction**—you don't have to know the details of a function like `cout` in order to use it.

When you add:

```
#include "std_lib_facilities.h"
```

to your code, the declarations in the file `std_lib_facilities.h` become available (including `cout`, etc.).

Examples

At least three errors:

```
int main()
{
    cout << f(i) << '\n';
}
```

Add declarations:

```
#include "std_lib_facilities.h" // we find the declaration of cout in here

int main()
{
    cout << f(i) << '\n';
}
```

Examples

Define your own functions and variables:

```
#include "std_lib_facilities.h"      // we find the declaration of cout in here

int f(int x ) { /* ... */ }        // declaration of f

int main()
{
    int i = 7;      // declaration of i
    cout << f(i) << '\n';
}
```

Definitions

A [definition](#) is a declaration that (also) fully specifies the entity declared

Examples:

```
int a = 7;
int b;           // an (uninitialized) int
vector<double> v; // an empty vector of doubles
double sqrt(double) { ... }; // a function with a body
struct Point { int x; int y; };
```

Examples of declarations that are not definitions

```
double sqrt(double); // function body missing
struct Point;        // class members specified elsewhere
extern int a;        // extern means "not definition"
                    // "extern" is archaic; we will hardly use it
```

Declarations and Definitions

- You *can't* **define** something twice
A definition says what something is

Examples

```
int a;           // definition
int a;           // error: double definition
double sqrt(double d) { ... } // definition
double sqrt(double d) { ... } // error: double definition
```

- You can **declare** something twice
A declaration says how something can be used

Example:

```
int a = 7;           // definition (also a declaration)
extern int a;        // declaration
double sqrt(double); // declaration
double sqrt(double d) { ... } // definition (also a declaration)
```

Why both Declarations and definitions?

- To refer to something, we need (only) its declaration
- Often we want the definition "elsewhere"
Later in a file, in another file possibly written by someone else
- Declarations are used to specify interfaces To your own code, To libraries
↪ Libraries are key: we can't write all ourselves, and wouldn't want to
- In larger programs, place all declarations in header files to ease sharing

Kinds of Declarations

The most interesting are

- Variables

```
int x;, vector<int> vi2 1,2,3,4;
```

- Constants

```
void f(const X&); constexpr int = isqrt(2);
```

- Functions (see §8.5)

```
double sqrt(double d) { /*... */}
```

- Namespaces (see §8.7)

- Types (classes and enumerations; see Chapter 9)

- Templates (see Chapter 19)

Header files and Preprocessor

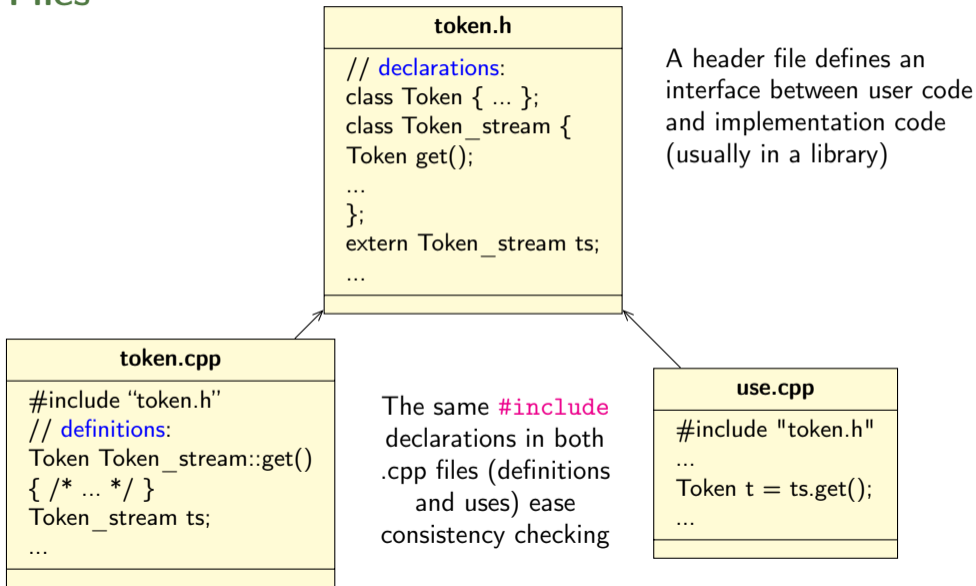
- A **header** is a file that holds declarations of functions, types, constants, and other program components.
- The construct

```
#include "std_lib_facilities.h"
```

is a **preprocessor directive** that adds declarations to your program
Typically, the header file is simply a text (source code) file

- A header gives you access to functions, types, etc. that you want to use in your programs.
 - Usually, you don't really care about how they are written.
 - The actual functions, types, etc. are defined in other source code files
 - Often as part of libraries

Source Files



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Scope

- A **scope** is a region of program text
 - **Global scope** (outside any language construct)
 - **Class scope** (within a class)
 - **Local scope** (between `{ ... }` braces)
 - **Statement scope** (e.g. in a for-statement)
- A **name** in a scope can be seen from within its scope and within scopes nested within that scope
 - Only after the declaration of the name (“can’t look ahead” rule)
 - Class members can be used within the class before they are declared
- A scope keeps “things” local
 - Prevents one’s variables, functions, etc., from interfering with others’
 - Remember: real programs have many thousands of entities
 - **Locality** is good! Keep names as local as possible

Scope

```
#include "std_lib_facilities.h"           // get max and abs from here
// no r, i, or v here
class My_vector {
    vector<int> v;                         // v is in class scope
public:
    int largest()                          // largest is in class scope
    {
        int r = 0;                         // r is local
        for (int i = 0; i<v.size(); ++i)    // i is in statement scope
            r = max(r,abs(v[i]));
        // no i here
        return r;
    }
    // no r here
};
// no v here
```

Scopes Nest

```
int x; // global variable - avoid those where you can
int y; // another global variable

int f()
{
    int x; // local variable (Note - now there are two x's)
    x = 7; // local x, not the global x
    {
        int x = y; // another local x, initialized by the global y
                // (Now there are three x's)
        ++x; // increment the local x in this scope
    }
}
```

Avoid such complicated nesting and hiding: keep it simple!

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Recap: Why Functions?

- Chop a program into manageable pieces
“divide and conquer”
- Match our understanding of the problem domain
 - Name logical operations
 - A function should do one thing well
- Functions make the program easier to read
- A function can be useful in many places in a program
- Ease testing, distribution of labor, and maintenance
- Keep functions small
Easier to understand, specify, and debug

Functions

- General form:

```
return_type name (formal arguments);           // a declaration  
return_type name (formal arguments) body      // a definition
```

For example:

```
double f(int a, double d) { return a*d; }
```

- Formal **arguments** are often called **parameters**
- If you don't want to return a value give **void** as the return type

```
void increase_power_to(int level);
```

Here, void means “doesn't return a value”

- A **body** is a block or a try block For example

```
{ /* code */ } // a block  
try { /* code */ } catch(exception& e) { /* code */ } // a try block
```

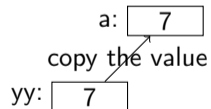
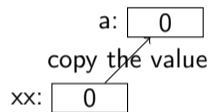
- Functions represent/implement computations/calculations

Functions: Call by Value

call-by-value \equiv send the function a copy of the argument's value

```
int f(int a) { a = a+1; return a; }

int main()
{
    int xx = 0;
    cout << f(xx) << '\n';           // writes 1
    cout << xx << '\n';           // writes 0; f() doesn't change xx
    int yy = 7;
    cout << f(yy) << '\n';       // writes 8; f() doesn't change yy
    cout << yy << '\n';           // writes 7
}
```

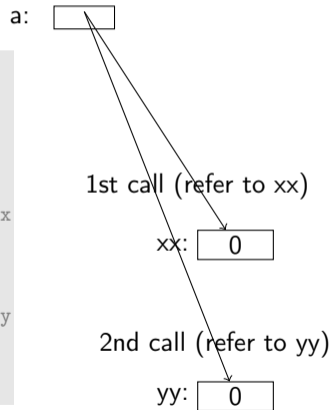


Functions: Call by Reference

call-by-reference \equiv pass a reference to the argument

```
int f(int& a) { a = a+1; return a; }

int main()
{
    int xx = 0;
    cout << f(xx) << '\n'; // writes 1
                                // f() changed the value of xx
    cout << xx << '\n'; // writes 1
    int yy = 7;
    cout << f(yy) << '\n'; // writes 8
                                // f() changes the value of yy
    cout << yy << '\n'; // writes 8
}
```



Functions

- Avoid (non-const) reference arguments when you can
They can lead to obscure bugs when you forget which arguments can be changed

```
int incr1(int a) { return a+1; }  
void incr2(int& a) { ++a; }  
int x = 7;  
x = incr1(x);    // pretty obvious  
incr2(x);        // pretty obscure
```

- So why have reference arguments?
 - Occasionally, they are essential
E.g., for changing several values
For manipulating containers (e.g., vector)
 - `const` reference arguments are very often useful

Call by Value/by Reference/by Const-Reference

```
void f(int a, int& r, const int& cr) { ++a; ++r; ++cr; } // error: cr is const
void g(int a, int& r, const int& cr) { ++a; ++r; int x = cr; ++x; } // ok

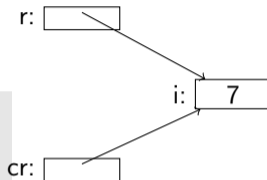
int main()
{
    int x = 0;
    int y = 0;
    int z = 0;
    g(x,y,z);           // x==0; y==1; z==0
    g(1,2,3);          // error: reference argument r needs a variable to refer to
    g(1,y,3);          // ok: since cr is const we can pass 'a temporary'
}
```

const references are very useful for passing large objects

References

- **reference** is a general concept
Not just for call-by-reference

```
int i = 7;  
int& r = i;  
r = 9; // i becomes 9  
const int& cr = i;  
// cr = 7; // error: cr refers to const  
i = 8;  
cout << cr << endl; // write out the value of i (that's 8)
```



- You can think of a reference as an alternative name for an object
- You can't modify an object through a **const** reference
make a reference refer to another object after initialization

Example

A range-for loop:

```
for (string s : v) cout << s << '\n';           // s is a copy of some v[i]
for (string& s : v) cout << s << '\n';         // no copy
for (const string& s : v) cout << s << '\n';   // and we don't modify v
```

Compile-time Functions

You can define functions that can be evaluated at compile time: `constexpr` functions

```
constexpr double xscale = 10;    // scaling factors
constexpr double yscale = .8;

constexpr Point scale(Point p) { return {xscale*p.x,yscale*p.y}; };

constexpr Point x = scale({123,456});    // evaluated at compile time

void use(Point p)
{
    constexpr Point x1 = scale(p);    // error: compile-time evaluation
                                       // requested for variable argument
    Point x2 = scale(p);              // OK: run-time evaluation
}
```

Note: these functions must be very simple, just a return statement.

Guidance for Passing Variables

- Use call-by-value for very small objects
- Use call-by-const-reference for large objects
- Use call-by-reference only when you have to
- Return a result rather than modify an object through a reference argument

For example:

```
class Image { /* objects are potentially huge */ };  
void f(Image i); ... f(my_image); // oops: this could be s-l-o-o-o-w  
void f(Image& i); ... f(my_image); // no copy, but f() can modify my_image  
void f(const Image&); ... f(my_image); // f() won't mess with my_image  
Image make_image(); // most likely fast! (''move semantics'' - later)
```

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Namespaces

Consider this code from two programmers Jack and Jill

```
class Glob { /*...*/ };           // in Jack's header file jack.h
class Widget { /*...*/ };        // also in jack.h

class Blob { /*...*/ };          // in Jill's header file jill.h
class Widget { /*...*/ };        // also in jill.h

#include "jack.h";                // this is in your code
#include "jill.h";                // so is this

void my_func(Widget p) // oops! - error: multiple definitions of Widget
{
    // ...
}
```

Namespaces

- The compiler will not compile multiple definitions; such clashes can occur from multiple headers.
- One way to prevent this problem is with namespaces:

```
namespace Jack {                                // in Jack's header file
    class Glob{ /*...*/ };
    class Widget{ /*...*/ };
}

#include "jack.h";          // this is in your code
#include "jill.h";         // so is this

void my_func(Jack::Widget p)    // OK, Jack's Widget class will not
{                                // clash with a different Widget
    // ...
}
```

Namespaces

- A namespace is a named scope
- The `::` syntax is used to specify which namespace we are using and which (of many possible) objects of the same name we are referring to
- For example, `cout` is in namespace `std`, we could write:

```
std::cout << "Please enter stuff... \n";
```

using Declarations and Directives

- To avoid the tedium of

```
std::cout << "Please enter stuff... \n";
```

- you could write a “using declaration”

```
using std::cout;           // when I say cout, I mean std::cout
cout << "Please enter stuff... \n"; // ok: std::cout
cin >> x;                  // error: cin not in scope
```

- or you could write a “using directive”

```
using namespace std; // ‘‘make all names from namespace std available’’
cout << "Please enter stuff... \n"; // ok: std::cout
cin >> x;                  // ok: std::cin
```

- More about header files in chapter 12

Summary

1. Declarations and Definitions
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