CSE 1325: Object-Oriented Programming

Lecture 05 – Chapter 8

Eclectic Topics

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Based on material by Bjarne Stroustrup

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ERB 402

Office Hours:

Tuesday Thursday 11 - 12

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Lecture #4
Quick Review

- Common types of errors include which of the following: **b, c, d, and e**

  (a) Edit-time errors **(b) Compile-time errors**
  (c) Link-time errors **(d) Run-time errors**
  (e) Logic errors (f) Math errors

- To handle bad assumptions, a method should usually **c**

  (a) Document the assumptions and expect callers to comply

  (b) Force compliant types on parameters so the compiler can detect

  (c) Detect the invalid input and throw an exception

- What are the pros and cons of each strategy for handling errors?

  (a) Return an error code Easy to implement – **hard to manage unique error codes, caller may not check, checking return code obscures the program's logic**
  (b) Set a global error variable **Can check after several operations, but otherwise same cons as (a)**
  (c) Throw an exception **Handler code can be centralized, if not handled exception propagates, fits well in the object-oriented paradigm**

Lecture #4

Quick Review

- Why should error messages be printed to cerr instead of cout?
  They will be mixed with data if sent to cout
- When should assert be used instead of throwing an exception?
  Use assert for interface errors, and exceptions for potentially recoverable errors.
- Match the name to the associated type of testing
  - Interactive testing **(c)**
  - Regression testing **(a)**
  - Test-driven development **(b)**

  (a) Write numerous automated unit tests

  (b) Write the test before writing the code

  (c) Run the program like a “nightmare user”
- What are some common useful debugger capabilities?
  Breakpoints and watchpoints, single step over or into method calls, view (and change) variable values and raw memory, view the assembly code

Overview

- Declarations
  - Definitions
  - Headers and the preprocessor
  - Scope
- Functions
  - Declarations and definitions
  - Arguments
  - Call by value, reference, and **const** reference
- Namespaces
  - “Using” declarations
- Makefiles

Pre-C++ 11 Initialization

- Prior to C++ 11, 4 different initializers were used
  - int n=0; // but not for fields! Only direct init for those
  - int n(0); // equivalent to =, but parentheses were confusing
  - class1 c(“hello”, 3); // call a constructor
  - Int m[2] = {0, 42}; // for aggregates only
    // NOT classes or primitives
- Some initializations weren't possible w/o executing code
  - class C {int x[100]; public: C( ); /* can't directly initialize x */ };
  - char *buff=new char[1024]; // can't directly initialize the buffer
  - vector <string> v; // can't directly initialize the vector

C++ 11 Initialization

- With C++ 11, all initialization (not assignment) can be accomplished consistently with { }
  - int a{0};
  - string s{"hello"};
  - string s2{s}; //copy constructor – s2 contains a copy of s
  - vector <string> vs{"alpha", "beta", "gamma"};
  - map<string, string> stars

    { {"Superman", "+1 (212) 545-7890"},
    {"Batman", "+1 (212) 545-0987"}};
  - double *pd= new double [3] {0.5, 1.2, 12.99};
  - class C {int x[4]; C( ): x{0,1,2,3} { }};

C++ 11 Initialization

- With { } initialization, you can now implement default field values without deferred constructors
  - class C {public: int x=42; C( ) { }; C(int p_x) : x(p_x) { } };
  - C c; // c.x is 42
  - C c{17}; // c.x is 17
- An empty { } explicitly assigns default values (same as no { })
  - 0 and 0.0 for int, bool, and double
  - '\0' for strings
  - Default constructor for classes

In CSE1325, <u>always</u> use C++ 11 style initialization

C++ Declarations

- A declaration introduces a name into a scope.
- A declaration also specifies a type for the named object.
- Sometimes a declaration includes an initializer.
- **A name must be declared before it can be used.**

```
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)
```

Declaration – A statement that introduces a name with an associated type into a scope

C++ Declarations

- Declarations are frequently introduced into a C++ (and C) program through “headers”
  - A header is a file containing declarations providing an **interface** to other parts of a program
- This allows for **abstraction** – you don’t have to know the details of a function you (or someone else) wrote in order to use it. When you add

```
#include "my_header.h"
```

to your code, the declarations in the file **my_header.h** in the local directory become available

  - `#include "my_header.h"` checks the local directory first for my_header.h, then the system directories
  - `#include <my_header.h>` checks only the system directories

For example

- Define your own functions and variables

```
#include <iostream>           // We find the declaration of cout in here
using namespace std;          // Explanation coming shortly!

int f(int x);                 // This DECLARES f(int) - you can declare it as often
                              // as you like, but you must declare it before calling it

int main() {
     int i{7};                // This declares and defines i
     cout << f(i) << '\n';    // This INVOKES (calls) f(int)
}

int f(int x) {return x*x;}    // This DEFINES f(int) - you must define it exactly once
```

```
ricegf@pluto:~/dev/cpp/07$ g++ -w decl_correct.cpp
ricegf@pluto:~/dev/cpp/07$ ./a.out
49
```

C++ Definitions

Definition – A declaration that (also) *fully* specifies the entity declared

- Examples of definitions

```
int a = 7;                          // an (initialized) int
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; }; // a struct
```

- Examples of declarations that are not definitions

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

Memory is allocated when a variable is **defined**,
not when it is **declared**!

C++ Declarations and Definitions

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

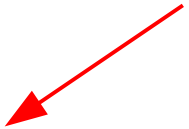
```
int a;          // definition
int a;          // error: double definition
double sqrt(double d) { … }   // definition
double sqrt(double d) { … }   // error: double definition
```

- You can *declare* something twice
  - A declaration says how something can be used
  - That is, its interface – perfect for a header file!

```
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
    - Preferably written by someone else
- Declarations are used to specify interfaces
  - To your own code
  - To libraries: Libraries are key!
    - We can’t write everything ourselves
    - We don't want to write everything ourselves!
- 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)

Classes

- A class encapsulates data and associated code
  - A class directly represents a concept in a program
    - If you can think of “it” as a separate entity, it is plausible that it could be a class or an object of a class
    - Examples: vector, matrix, input stream, string, FFT, valve controller, robot arm, device driver, picture on screen, dialog box, graph, window, temperature reading, clock
  - A class is a (user-defined) type that specifies how objects of its type can be created and used
  - In C++ (as in most modern languages), a class is the key building block for large programs
    - And very useful for small ones also
  - The concept was originally introduced in Simula67
  - **The classes public methods and variables are it's *interface***

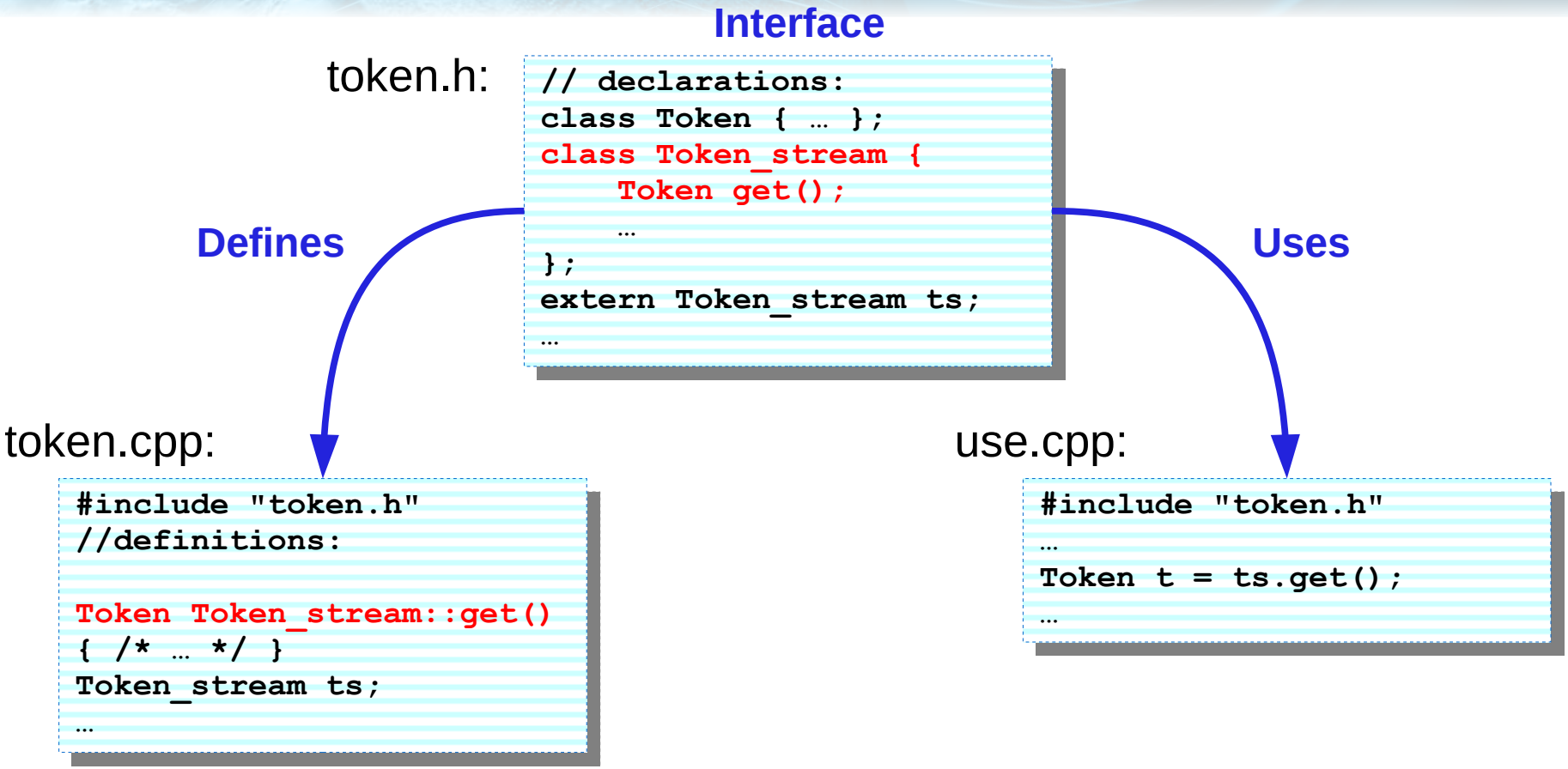
Class Interfaces

- What makes a good class interface?
  - Minimal
    - As small as possible
    - Simple and easy to use – or better, hard to **mis**use!
  - Complete
    - And no smaller
  - Type safe
    - Beware of confusing argument orders
    - Beware of over-general types (e.g., int to represent a month)

Header Files as Class Interface Definitions

- Until now, we have simply included (#include) the .cpp files that we need
- This is a Very Bad Idea
  - Your implementation is compiled as part of a different file
  - If a .cpp file is included twice, you'll get redefinition errors – making it difficult to determine a valid compilation order
- All the including file needs is the interface definition
  - The header file is that interface definition!

Source files



- A header file (here, **token.h**) defines an interface between user code and implementation code (usually in a library)
- We also declare a pre-instanced object of type Token_stream, ts, using extern
- The same **#include** declarations in both **.cpp** files (definitions and uses) ease consistency checking

Header Files

- An interface can be specified in a header file
  - The header file / interface

Specify the function's interface, but not it's implementation

```
#include "elevator.h"

int select_floor(Elevator elevator, Vector<int> request);
```

  - The cpp file / implementation

```
#include "select_floor.h"
#include "globals.h"
#include "elevator.h"

int select_floor(Elevator elevator, Vector<int> request) {
  int direction = elevator.is_going_up() ? 1 : -1;
  int floor = elevator.get_current_floor();
  for (int floors = 0; floors < max_floor; ++floors) {
    floor += direction;
    if (floor < 0 || floor > max_floor) {
       direction = -direction;
       floor = elevator.get_current_floor() + direction;
    }
    if (request[floor] == TRUE) {
       return floor;
```

Include the associated header so the compiler can verify consistency

Repeating an include from the header isn't *required*, but is *allowed*

Class Header Files

- Class methods are specified w/o implementation

elevator.h

```
#ifndef __ELEVATOR_H
#define __ELEVATOR_H 2017
class Elevator {
  public:
    Elevator() : top_floor{9} {}
    Elevator(int max_floors) : top_floor{max_floors} {}

    class Invalid_floor: global exception {}; // Exception
    void goto_floor(int floor);
    void move();

    int get_current_floor();
    int get_desired_floor();
    bool is_going_up();
    bool has_arrived();
    bool is_idle();

  private:
    int top_floor;
    int current_floor = 1;
    int desired_floor = 1;
    bool going_up = true;
    bool idle = false;
};
#endif
```

These statements ensure we don't redefine anything if the header file is included in more than one file*

The constructors – one default and one non-default

The methods declared here must be defined *somewhere* – typically in the associated implementation (.cpp) file

The private data for this class

Including a header is exactly equivalent to including the text of the header file into the file that includes it, at the point of the #include

* "#pragma once" is also often used for this purpose, but it is NOT part of the C++ standard

Class Implementation Files

- If methods are define in a header, the method bodies are implemented separately in the .cpp

elevator.cpp

```
#include "elevator.h"

void Elevator::goto_floor(int floor) {
   // Your code here
}

void Elevator::move() {
  // Your code here
}

int Elevator::get_current_floor() {
   // Your code here
}

int Elevator::get_desired_floor() {
   // Your code here
}

bool Elevator::is_going_up() {
   // Your code here
}

bool Elevator::has_arrived() {
```

Include the associated header so the compiler can verify consistency

Elevator::goto_floor means the method goto_floor in the class Elevator

This file is compiled separately into a .o file for linking (use g++ -c to avoid an error for a missing main())

Constructors

- A constructor is a special kind of member function that initializes an instance of its class
  - Initialize private variables, allocate memory, update static variables, etc.
- A constructor has the same name as the class and no return value
  - Constructors are usually the first methods in the public section
- A constructor can have any number of parameters
  - The default constructor has zero parameters
  - If no constructor is specified, the compiler defines the default constructor that just initializes the object based on the class definition
  - **If only non-default constructors are specified, the compiler will NOT provide a default constructor**
- A class may have any number of constructors
  - Each must have a unique parameter signature – the number of parameters, and the type of each

Direct Initialization

- C++ allows specification of private variable values as part of the constructor declaration
  - This is more efficient than a direct assignment, such as is done in Java or Python

```
class Elevator {
  public:
    Elevator() : top_floor{9} {}
    Elevator(int max_floors) : top_floor{max_floors} {}

  private:
    int top_floor;
};
```

Directly initialize top_floor to 9

Directly initialize top_floor to the parameter value

Note the curly braces (not parentheses)

Delegated Constructors

- Sometimes called “constructor chaining”, a similar syntax permits one constructor to rely on another in the same class
  - This avoids code duplication

```
class Elevator {
  public:
    Elevator() : Elevator(9) {}
    Elevator(int max_floors) : top_floor{max_floors} {}

  private:
    int top_floor;
};
```

Delegate to the 1 int parameter constructor

Directly initialize top_floor to the parameter value

Static Class Members

- A static method or variable exists as part of the class, shared among all objects
  - A static method may be called without instancing an object
  - A static variable must be defined outside the class

```
class Elevator {
  public:
    static int floors_traversed;  // declaration only
    static void moved() {++floors_traversed;}
    static int get_floors_traversed() {return floors_traversed;}

    void move(); // Unique to each object (other methods omitted)

  private:
    int top_floor;
};

int Elevator::floors_traversed; // definition (globally scoped)
void Elevator::move() {moved(); … }
```

Scope

- A **scope** is a region of program text
  - Global scope (outside any language construct)
  - Class scope (within a class)
  - Local scope (between any { … } braces)
  - Statement scope (unique to the 3-term for statement)

- A name in a scope can be seen from within its scope and within scopes nested within that scope
  - Only <u>after</u> the declaration of the name (“can’t look ahead” rule)
  - However, class members can be used *within the class* before they are declared
- A scope keeps “things” local
  - Prevents my variables, functions, etc., from interfering with yours
  - Remember: real programs have **many** thousands of entities
  - Locality is good!

Keep names as local as possible

Scope Example

```
// 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
```

Nested Scopes

```
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!
```

The code attached to these slides prints the various x values throughout the program

Shadowing – A variable declared in a narrower scope than that of a variable of the same name declared in a broader scope

Functions: Call by Value

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

// call-by-value (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;
    cout << yy << '\n';      // writes 7; f() doesn't change yy
}
```

```
ricegf@pluto:~/dev/cpp/201701/05$ g++ -std=c++11 call_by_value.cpp
ricegf@pluto:~/dev/cpp/201701/05$ ./a.out
1
0
8
7
ricegf@pluto:~/dev/cpp/201701/05$
```

Functions: Call by Reference

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

// call-by-value (send the function a reference to 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() changes xx
    int yy = 7;
    cout << f(yy) << '\n';   // writes 8;
    cout << yy << '\n';      // writes 7; f() changes yy
}
```

```
ricegf@pluto:~/dev/cpp/201701/05$ g++ -std=c++11 call_by_reference.cpp
ricegf@pluto:~/dev/cpp/201701/05$ ./a.out
1
1
8
8
ricegf@pluto:~/dev/cpp/201701/05$
```

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
```

Functions

- Avoid (non-const) reference arguments if possible
  - 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 large containers (*e.g.*, vector)
  - **const** reference arguments are very often useful

References

- “Reference” is a general concept
  - Not just for call-by-reference

```
int i = 7;
int& r = i;           // r and i point to the same memory address!
r = 9;                // i also 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 now 8)
```

- You can think of a reference as an alternative name for an object
- You can’t modify an object through a const reference
- You can't make a reference refer to another object after the reference variable is initialized (unlike pointers)
  - Thus, references are never “dangling”

Copy vs Reference

- We said earlier that a For Each loop can be very inefficient for vectors of large objects
  - Because it copies each object to the loop variable
  - Now we see how to access very large vector members efficiently – using references!

```
// Range-for (for each) loops
for (string s : v) cout << s << "\n";          // s is a copy of some v[i]
for (string& s : v) cout << s << "\n";         // s is literally v[i]
for (const string& s : v) cout << s << "\n";  // same but we can't modify v
```

Compile-time functions

- You can define functions that *can be* evaluated at compile time: **constexpr** functions
  - A definition usually results in memory allocation
  - A constexpr does not – the compiler simply substitutes the value of the expression as a constant wherever referenced

```
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 a variable argument
    Point x2 = scale(p);             // OK: run-time evaluation
}
```

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 *absolutely necessary*
- Return a result rather than modify an object through a reference argument if practical – experience will help
- 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)
```

Namespaces

- Consider this code from two programmers Jack and Jill

jack.h

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

jill.h

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

awesome_app.h

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

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:

jack.h

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

jill.h

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

awesome_app.h

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

void my_func(Jack::Widget p) {   // No collision!
    // …
}
```

:: means *membership* – Jack's Widget!

Namespaces

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

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

- In fact, you would have to if you didn't specify that you are “using namespace std;”!

Namespace – a named scope

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";       // std::cout is also fine
cin >> x;                               // error: cin not in scope
```

- or you could write a “using directive”

```
using namespace std;                    // “make all names from std available”
cout << "Please enter stuff… \n";       // std::cout is also fine
cin >> x;                               // std::cin is also fine
```

Using *Using* Well

- “using namespace std;” puts EVERYTHING from std into our current namespace
  - This is a lot of declarations, which may collide with our own declarations accidentally (remember std::to_string for double?)
  - This is sometimes called “namespace pollution”
- You can “using namespace” for multiple namespaces, but that increases the chances for collisions
  - This is (ahem) namespace mega-pollution!*
- But it's better to “using namespace::member” rather than the entire namespace
  - Explicit *using* places only the specific members you want into your namespace, and also makes clear to which namespace member belongs
  - But you're still permitted to “using namespace std;” as you like

* Yes, I just made that one up

More on Makefiles

http://www.cprogramming.com/tutorial/makefiles.html

- Maintaining an accurate Makefile is critical during development

```
# Makefile for Elevators
CC=g++
main: multicontroller.o view.o elevator.o select_floor.o
    $(CC) multicontroller.o view.o elevator.o select_floor.o
multicontroller.o: multicontroller.cpp globals.h view.h elevator.h
std_lib_facilities.h
    $(CC) -w -c multicontroller.cpp
view.o: view.cpp view.h globals.h view.h elevator.h std_lib_facilities.h
    $(CC) -w -c view.cpp
elevator.o: elevator.cpp elevator.h std_lib_facilities.h
    $(CC) -w -c elevator.cpp
select_floor.o: select_floor.cpp select_floor.h std_lib_facilities.h
    $(CC) -w -c select_floor.cpp
clean:
    -rm *.o a.out
```

Text macro

Default rule is the first one
Choose wisely

CC is often pre-defined in the bash environment for the default compiler.
Check before you redefine it.

Maintaining a Makefile

- Your program drives your Makefile
  - Adding a .cpp usually requires a new rule
  - Adding a new #include “...” usually requires a new *dependency* on the rule that compiles that file
  - Changes in compiler or linker options may require changes to the bash commands defined for one or more rules
- Your Makefile must be managed in git!
  - It evolves along with your program code

Quick Review

- A statement that introduces a name with an associated type into a scope is a _____.

  A statement that also fully specifies that entity is a _____.
- Why should programs #include header files instead of cpp files?
- True or False: Memory is allocated for a variable when it is declared.
- True or False: It is an error to include the same file in both the header and the body of a class file.
- What is the purpose of “#ifndef __FILE_H” and “#define __FILE_H 2016” at the top of a header file?

Quick Review

- A special kind of member function that initializes an instance of its class is a _____.
  _____ _____ is a shortcut to assign a value to a class's private variables in a constructor.
  _____ _____ implements one constructor by calling another.
- True or False: A default constructor with no parameters is always provided.
- To modify a parameter, the parameter must be passed by _____ - otherwise, the method only has a copy of the parameter.
  A _____ reference cannot modify the parameter even though it references to the original data.
- Constexpr specifies that a variable can be evaluated at _____ _____.
- A _____ is a named scope, which can be accessed via the _____ keyword or the ____ operator.
- A _____ builds a C++ program optimally with a simple “make” command.

For Next Class

- Review chapter 8 (some of today's material is found there)
  - Do the drills!
- Skim chapters 6 and 7
  - We won't use this (functional decomposition) example, but it's useful to understand
- Over the next two classes, we will design and implement a somewhat larger multi-file object-oriented program

Homework #3

This assignment involves writing a word / phrase guessing game (always a good way to learn a new language and new technology). We'll utilize a Makefile, use either the ddd or gdb debugger, employ git (of course!), and use Umbrello to design our class and use case diagrams.

Due Thursday, September 14 at 8 am.