CS 2420: C++ Crash Courses

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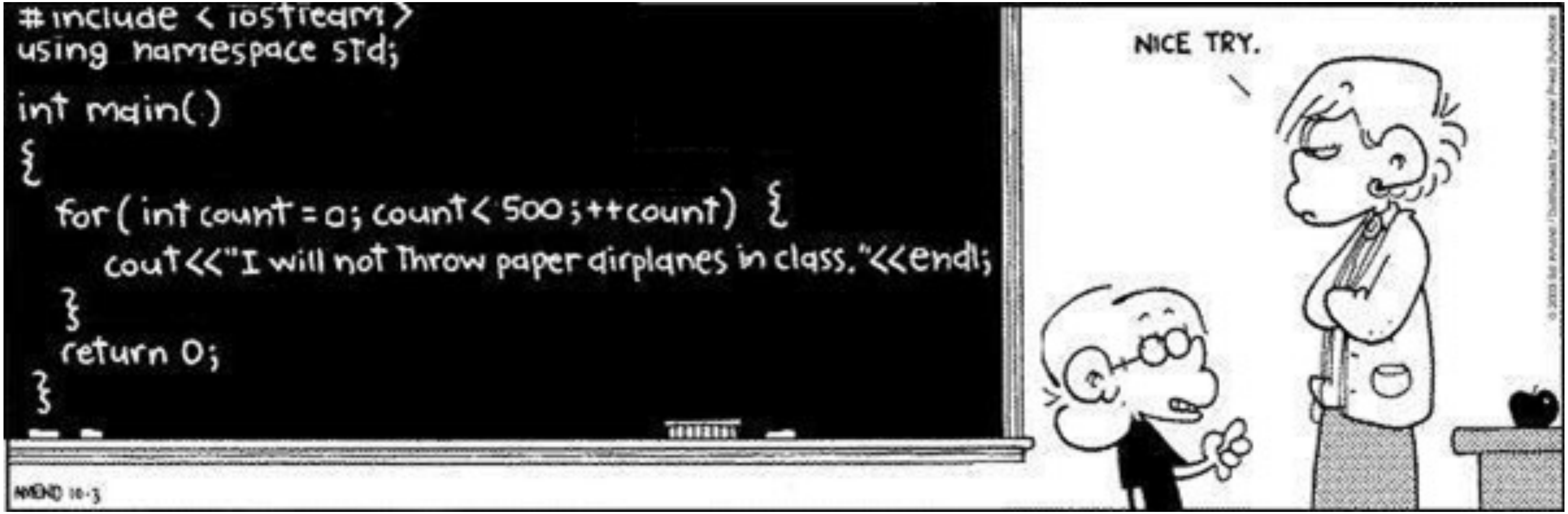
We Will Use C++ in this Course

- Online C++ editor: https://www.onlinegdb.com/



Control Statements

- All control statements are similar in all programming languages

```
if ( statement ) {
    // ...
} else if ( statement ) {
    // ...
} else {
    // ...
}
```

```
while ( statement ) {
    // ...
}
```

```
for ( int i = 0; i < N; ++i ) {
    // ...
}
```

```
do {
    // ...
} while ( statement );
```

Operators

- Operators have similar functionality for built-in datatypes:
  - Assignment `=`
  - Arithmetic `+` `-` `*` `/` `%`
    `+=` `-=` `*=` `/=` `%=`
  - Autoincrement `++`
  - Autodecrement `--`
  - Logical `&&` `||` `!`
  - Relational `==` `!=` `<` `<=` `>=` `>`
  - Comments `/*` `*/`
    `// to end of line`
  - Bitwise `&` `|` `^` `~`
    `&=` `|=` `^=`
  - Bit shifting `<<` `>>`
    `<<=` `>>=`

Arrays

- Accessing arrays is similar:

```
const int ARRAY_CAPACITY = 10; // prevents reassignment
int array[ARRAY_CAPACITY];

array[0] = 1;
for ( int i = 1; i < ARRAY_CAPACITY; ++i ) {
    array[i] = 2*array[i – 1] + 1;
}
```

Recall that arrays go from **`0`** to **`ARRAY_CAPACITY – 1`**

Definition:

The *capacity* of an array is the entries it can hold

The *size* of an array is the number of useful entries

Functions

- Function calls are similar, however, the are not required to be part of a class:

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

// A function with a global name
int sqr( int n ) {
    return n*n;
}

int main() {
    cout << "The square of 3 is " << sqr(3) << endl;
    return 0;
}
```

C++/Java Differences

- We will look at categories of differences between C++ and Java
  - Including header files (the preprocessor)
  - The file is the base of compilation
  - Namespaces
  - Printing

The C++ Preprocessor

- C++ is based on C, which was written in the early 1970s

- Any command starting with a **#** in the first column is not a C/C++ statement, but rather a preprocessor statement
  - The preprocessor performed very basic text-based (or *lexical*) substitutions
  - The output is sent to the compiler

The C++ Preprocessor

- The sequence is:

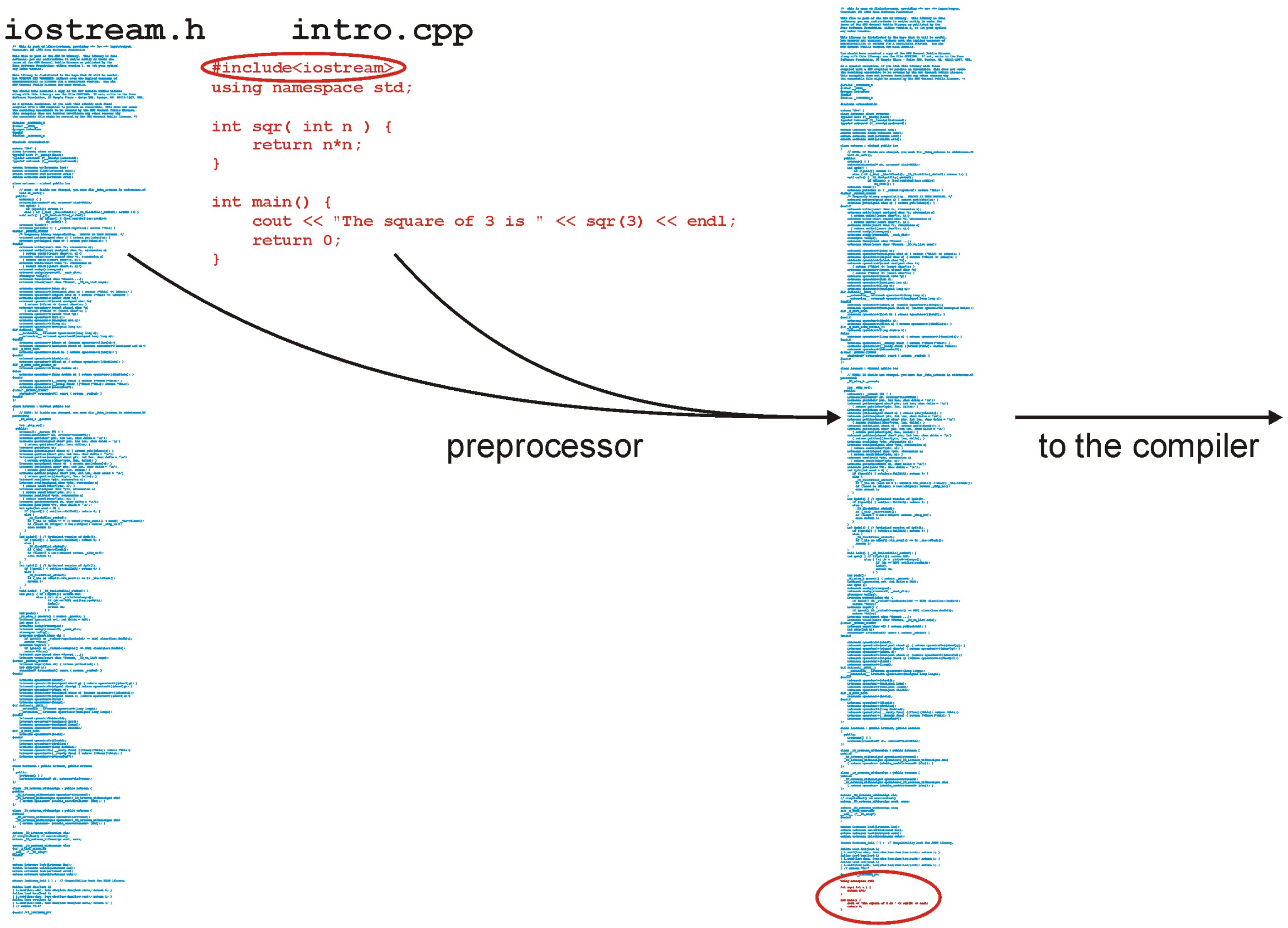
  file (`filename.cpp`) → preprocessor → compiler (g++)

- Note, this is done automatically by the compiler: no additional steps are necessary

- At the top of any C++ program, you will see one or more directives starting with a **#**, *e.g.*,

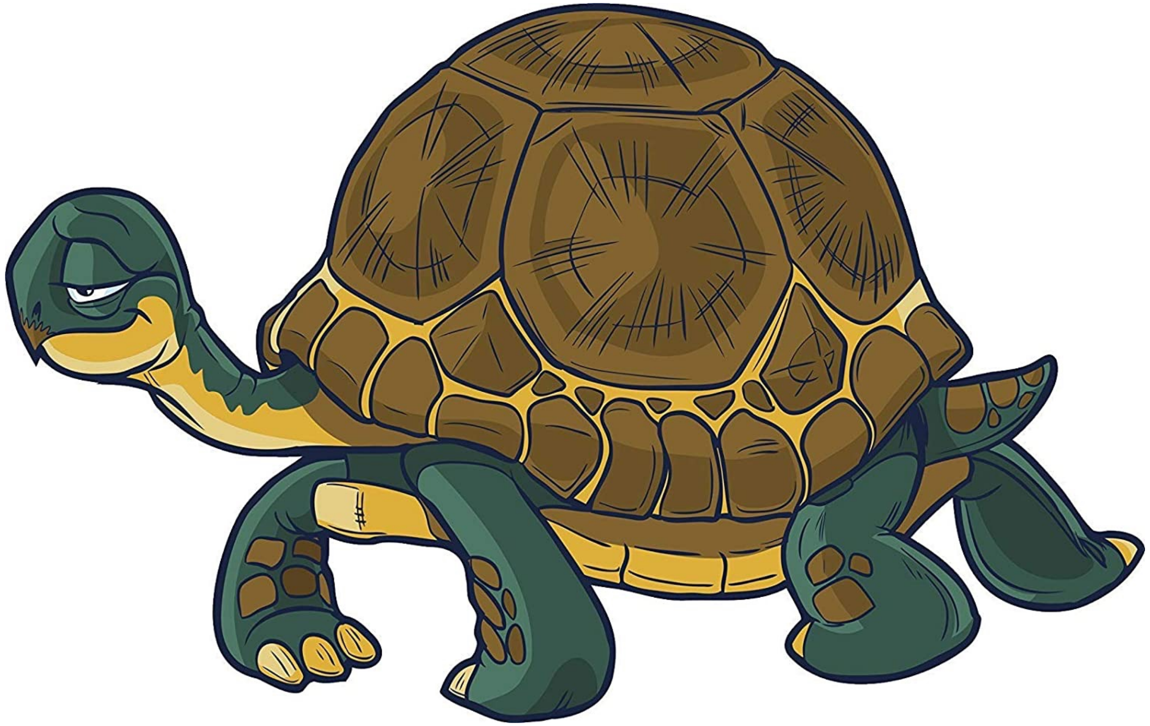
```
#include <iostream>
```

The C++ Preprocessor



What is the Problem of Preprocessor?

- The more headers you include, the longer the compile time …



Libraries

- You will write your code in a file such as `Single_list.h` where you will implement a data structure

- This file will be included in our tester file `Single_list_tester.h` with a statement such as:

```
#include "Single_list.h"
```

- The file `Single_list_int_driver.cpp` then includes the tester file:

```
#include "Single_list_tester.h"
```

Libraries

- You will note the difference:

```
#include <iostream>
#include "Single_list.h"
```

- The first looks for a file `iostream.h` which is shipped with the compiler (the standard library)

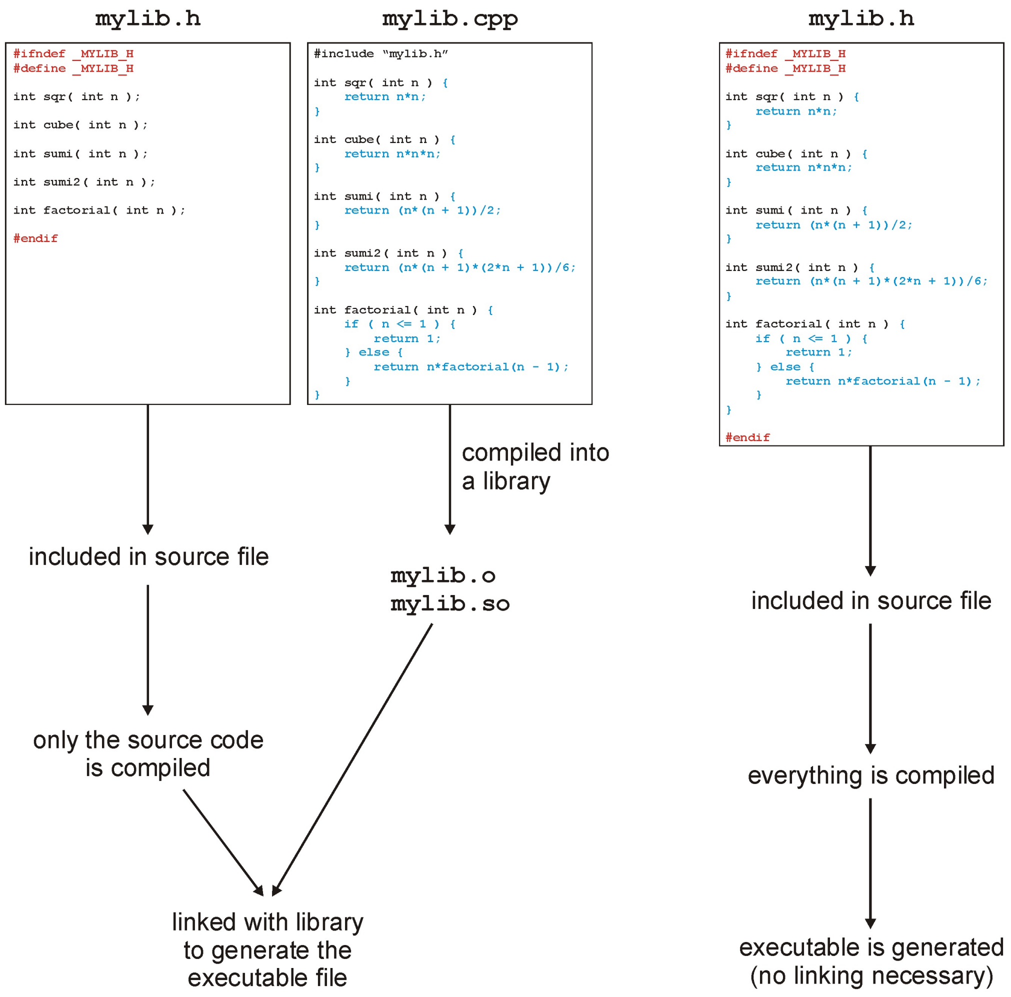
- The second looks in the current directory

Libraries

- In this class, you will put all code in the header file

- This is not normal practice:
  - Usually the header (`.h`) file only contains declarations
  - The definitions (the actual implementations) are stored in a related file and compiled into an object file

The C++ Preprocessor



The C++ Preprocessor

- With all these includes, it is always necessary to avoid the same file being included twice, otherwise you have duplicate definitions

- This is done with guard statements:

```
#ifndef SINGLE_LIST_H
#define SINGLE_LIST_H

template <typename Type>
class Single_list {
  ///...
};

#endif
```

The C++ Preprocessor

- This class definition contains only the signatures (or *prototypes*) of the operations

- The actual member function definitions may be defined elsewhere, either in:
  - The same file, or
  - Another file which is compiled into an object file

- We will use the first method

The File as the Unit of Compilation

- Another difference is the unit of compilation

- In C#, the class was the basis of compiling executable code:

```
class TestProgram {
    public static void Main() {
        System.Console.WriteLine( "Hello World" );
    }
}
```

- The existence of a function with the signature

```
public static void Main();
```

determines whether or not a class can be compiled into an executable

The File as the Unit of Compilation

- In C/C++, the file is the base unit of compilation:
  - Any `.cpp` file may be compiled into object code
  - Only files containing an `int main()` function can be compiled into an executable

- The signature of main is:

```
int main () {
    // does some stuff
    return 0;
}
```

- The operating system is expecting a return value
  - Usually 0

The File as the Unit of Compilation

- This file (`example.cpp`) contains two functions

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

int sqr( int n ) {      // Function declaration and definition
    return n*n;
}

int main() {
    cout << "The square of 3 is " << sqr(3) << endl;
    return 0;
}
```

The File as the Unit of Compilation

- To compile this file, we execute on the command line:

```
{ecelinux:1} g++ example.cpp
{ecelinux:2} ls
a.out       example.cpp
{ecelinux:3} ./a.out
The square of 3 is 9
{ecelinux:4}
```

The File as the Unit of Compilation

- This is an alternate form:

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

int sqr( int );                 // Function declaration

int main() {
    cout << "The square of 3 is " << sqr(3) << endl;
    return 0;
}

int sqr( int n ) {              // Function definition
    return n*n;                 // The definition can be in another file
}
```

Namespaces

- Variables defined:
  - In functions are *local variables*
  - In classes are *member variables*
  - Elsewhere are *global variables*

- Functions defined:
  - In classes are *member functions*
  - Elsewhere are *global functions*

- In all these cases, the keyword `static` can modify the scope

Namespaces

- Global variables/variables cause problems, especially in large projects
  - Hundreds of employees
  - Dozens of projects
  - Everyone wanting a function `init()`
- In C++ (and XML), this is solved using namespaces

Namespaces

- A namespace adds an extra disambiguation between similar names

```
namespace ca_uwaterloo_dwharder {
    int n = 4;
    double mean = 2.34567;

    void init() {
        // Does something...
    }
}
```

- There are two means of accessing these global variables and functions outside of this namespace:
  - The namespace as a prefix: `ca_uwaterloo_dwharder::init()`
  - The `using` statement: `using namespace ca_uwaterloo_dwharder;`

Namespaces

- You will only need this for the standard name space
  - All variables and functions in the standard library are in the **`std`** namespace

```
#include <iostream>
std::cout << "Hello world!" << std::endl;
```

```
#include <iostream>
using namespace std;            // never used in production code

cout << "Hello world!" << endl;
```

Printing

- Printing in C++ is done through overloading the **<<** operator:

  ```
  cout << 3;
  ```

  If the left-hand argument of **<<** is an object of type **`ostream`** (output *stream*) and the right-hand argument is a **`double`**, **`int`**, **`string`**, etc., an appropriate function which prints the object is called

Printing

- The format is suggestive of what is happening:
  - The objects are being *sent* to the **`cout`** (*console output*) object to be printed

```
cout << "The square of 3 is " << sqr(3) << endl;
```

- The objects being printed are:
  - a **`string`**
  - an **`int`**
  - a platform-independent end-of-line identifier

Printing

- How does

```
cout << "The square of 3 is " << sqr(3) << endl;
```

work?

- This is equivalent to

```
((cout << "The square of 3 is ") << sqr(3)) << endl;
```

where **<<** is an operation (like **+**) which prints the object and returns the `cout` object

Printing

- Visually:

```
((cout << "The square of 3 is ") << sqr(3)) << endl;
```

print `"The square of 3 is "` and return `cout`

```
(               cout               << sqr(3)) << endl;
```

print the result of `sqr(3)` and return `cout`

```
                      cout                    << endl;
```

print an end-of-line character (and return `cout`)

```
cout;
```

Printing

Another way to look at this is that

```
cout << "The square of 3 is " << sqr(3) << endl;
```

is the same as:

```
operator<<( operator<<( operator<<( cout, "The square of 3 is " ), sqr(3) ), endl );
```

This is how C++ treats these anyway...

Introduction to C++

- The next five topics in C++ will be:
  - Classes
  - Templates
  - Pointers
  - Memory allocation
  - Operator overloading

- With these, you will have (more than) enough information to start programming data structures and algorithms

Classes

- To begin, we will create a complex number class

- To describe this class, we could use the following words:
  - Store the real and imaginary components
  - Allow the user to:
    - Create a complex number
    - Retrieve the real and imaginary parts
    - Find the absolute value and the exponential value
    - Normalize a non-zero complex number

Classes

- An example of a C++ class declaration is:

```
class Complex {
    private:
        double re, im;

    public:
        Complex( double = 0.0, double = 0.0 );

        double real() const;
        double imag() const;
        double abs() const;
        Complex exp() const;

        void normalize();
};
```

Classes

- This only declares the class structure
  - It does not provide an implementation

- We could, like Java, include the implementation in the class declaration, however, this is not, for numerous reasons, standard practice

The Complex Class

- The next slide gives both the declaration of the `Complex` class as well as the associated definitions
  - The assumption is that this is within a single file

The Complex Class

```
#ifndef _COMPLEX_H
#define _COMPLEX_H
#include <cmath>
class Complex {
    private:
        double re, im;

    public:
        Complex( double = 0.0, double = 0.0 );

        // Accessors
        double real() const;
        double imag() const;
        double abs() const;
        Complex exp() const;

        // Mutators
        void normalize();
};
```

The Complex Class

Associates functions back to the class

```
// Constructor
Complex::Complex( double r, double i ):
re( r ),
im( i ) {
    // empty constructor
}
```

Each member variable should be assigned

The order must be the same as the order in which the member variables are defined in the class

For built-in datatypes, this is a simple assignment. For member variables that are objects, this is a call to a constructor.

For built-in datatypes, the above is equivalent to:

```
// Constructor
Complex::Complex( double r, double i ):re( 0 ), im( 0 ) {
    re = r;
    im = i;
}
```

The Complex Class

```
// Return the exponential of the complex value
Complex Complex::exp() const {
    double exp_re = std::exp( re );

    return Complex( exp_re*std::cos(im), exp_re*std::sin(im) );
}
```

The Complex Class

```
// Normalize the complex number (giving it unit absolute value, |z| = 1)
void Complex::normalize() {
    if ( re == 0 && im == 0 ) {
        return;
    }

    double absval = abs();
    re /= absval;
    im /= absval;
}

#endif
```

This calls the member function `double abs() const` from the `Complex` class on the object on which `void normalize()` was called

Visibility

- Visibility in C# and Java is described by placing public/private/protected in front of each class member or member function

- In C++, this is described by a block prefixed by one of

```
private:
protected:
public:
```

Visibility

```
class Complex {
    private:
        double re, im;

    public:
        Complex( double, double );

        double real() const;
        double imag() const;
        double abs() const;
        Complex exp() const;

        void normalize();
};
```

Visibility

- The reason for the change in Java/C# was that the C++ version has been noted to be a source of errors

- Code could be cut-and-paste from one location to another, and a poorly placed paste could change the visibility of some code:

  `public → private` automatically caught

  `private → public` difficult to catch and dangerous

Visibility

- It is possible for a class to indicate that another class is allowed to access its **private** members

- If class `ClassX` declares class `ClassY` to be a friend, then class `ClassY` can access (and modify) the private members of `ClassX`

Visibility

```
class ClassY;                   // declare that ClassY is a class

class ClassX {
    private:
        int privy;              // the variable privy is private

    friend class ClassY;        // ClassY is a "friend" of ClassX
};

class ClassY {                  // define ClassY
    private:
        ClassX value;           // Y stores one instance of X
    public:
        void set_x() {
            value.privy = 42;   // a member function of ClassY can
        }                       // access and modify the private
};                              // member privy of "value"
```

Accessors and Mutators

- We can classify member functions into two categories:
  - Those leaving the object unchanged
  - Those modifying the member variables of the object

- Respectively, these are referred to as:
  - **Accessors:** we are accessing and using the class members
  - **Mutators:** we are changing—mutating—the class members

Accessors and Mutators

- Good programming practice is to enforce that a routine specified to be an accessor cannot be accidentally changed to a mutator

- This is done with the const keyword after the parameter list

```
double abs() const;
```

Accessors and Mutators

- If a junior programmer were to try change

```
double Complex::abs() const {
  return std::sqrt( re*re + im*im );
}
```

  to

```
double Complex::abs() const {
    re = 1.0;                // modifying (mutating) 're'
    return std::sqrt( re*re + im*im );
}
```

  the compiler would signal an error

Accessors and Mutators

- As an example from a previous project, a student did this:

```
template <typename Type>
int Double_sentinel_list<Type>::count( Type const &obj ) const {
   for ( Double_node<Type> *temp = head(); temp != nullptr; temp = temp->next() ) {
            if ( temp->retrieve() == obj ) {
                        ++list_size;
            }
   }

   return list_size;
}
```

- Here, `list_size` was a member variable of the class
  - This code did not compile: the compiler issued a warning that a member variable was being modified in a read-only member function

Accessors and Mutators

- What the student wanted was a local variable:

```
template <typename Type>
int Double_sentinel_list<Type>::count( Type const &obj ) const {
    int obj_count = 0;

    for ( Double_node<Type> *temp = head(); temp != nullptr; temp = temp->next() ) {
        if ( temp->retrieve() == obj ) {
            ++obj_count;
        }
    }

    return obj_count;
}
```

Templates

- Now that we have seen an introduction to classes, the next generalization is templates

Templates

- In Java you will recall that all classes descend from the **`Object`** class

- Thus, it is possible to create an array which can hold instances of any class:

```
Object [] array = new Object[10];
```

Templates

- Suppose you want to build a general linked list which could hold anything
  - In Java you could have it store instance of the class `Object`

- Because there is no ultimate `Object` class, to avoid re-implementing each class for each class we are interested in storing, we must have a different mechanism

Templates

- This mechanism uses a tool called templates
  - A function has parameters which are of a specific type
  - A template is like a function, however, the parameters themselves are types

Templates

- That mechanism is called a template:

```
template <typename Type>
Type sqr( Type x ) {
    return x*x;
}
```

- This creates a function which returns something of the same type as the argument

Templates

- To tell the compiler what that type is, we must suffix the function:

```
int n = sqr<int>( 3 );
double x = sqr<double>( 3.141592653589793 );
```

- Usually, the compiler can determine the appropriate template without it being explicitly stated

Templates

- Example:

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

template <typename Type>
Type sqr( Type x ) {
    return x*x;
}

int main() {
    cout << "3 squared is " << sqr<int>( 3 ) << endl;
    cout << "Pi squared is " << sqr<double>( 3.141592653589793 ) << endl;

    return 0;
}
```

Output:

```
3 squared is 9
Pi squared is 9.8696
```

Templates

- Thus, calling `sqr<int>( 3 )` is equivalent to calling a function defined as:

```
int sqr( int x ) {
    return x*x;
}
```

```
template <typename Type>
Type sqr( Type x ) {
    return x*x;
}
```

- The compiler replaces the symbol **`Type`** with **`int`**

Templates

- Our complex number class uses double-precision floating-point numbers
- What if we don't require the precision and want to save memory with floating-point numbers
  - Do we write the entire class twice?
  - How about templates?

Templates

```
#ifndef _COMPLEX_H
#define _COMPLEX_H
#include <cmath>
template <typename Type>
class Complex {
    private:
        Type re, im;

    public:
        Complex( Type const & = Type(), Type const & = Type() );

        // Accessors
        Type real() const;
        Type imag() const;
        Type abs() const;
        Complex exp() const;

        // Mutators
        void normalize();
};
```

Templates

- The modifier `template <typename Type>` applies only to the following statement, so each time we define a function, we must restate that `Type` is a templated symbol:

```
// Constructor
template <typename Type>
Complex<Type>::Complex( Type const &r, Type const &i ):re(r), im(i) {
    // empty constructor
}
```

Templates

```
// return the real component
template <typename Type>
Type Complex<Type>::real() const {
    return re;
}

// return the imaginary component
template <typename Type>
Type Complex<Type>::imag() const {
    return im;
}

// return the absolute value
template <typename Type>
Type Complex<Type>::abs() const {
    return std::sqrt( re*re + im*im );
}
```

Templates

```
// Return the exponential of the complex value
template <typename Type>
Complex<Type> Complex<Type>::exp() const {
    Type exp_re = std::exp( re );

    return Complex<Type>( exp_re*std::cos(im), exp_re*std::sin(im) );
}

// Normalize the complex number (giving it unit norm, |z| = 1)
template <typename Type>
void Complex<Type>:noramlize() {
    if ( re == 0 && im == 0 ) {
        return;
    }

    Type absval = abs();
    re /= absval;
    im /= absval;
}

#endif
```

Templates

Example:

```
#include <iostream>
#include "Complex.h"
using namespace std;

int main() {
    Complex<double> z( 3.7, 4.2 );
    Complex<float>  w( 3.7, 4.2 );
    cout.precision( 20 ); // Print up to 20 digits

    cout << "|z| = " << z.abs() << endl;
    cout << "|w| = " << w.abs() << endl;

    z.normalize();
    w.normalize();

    cout << "After normalization, |z| = " << z.abs() << endl;
    cout << "After normalization, |w| = " << w.abs() << endl;

    return 0;
}
```

Ouptut:

```
|z| = 5.5973207876626123181
|w| = 5.597320556640625
After normalization, |z| =
1.0000000412736744781
After normalization, |w| = 1
```

Pointers

- One of the simplest ideas in C, but one which most students have a problem with is a pointer
  - Every variable (barring optimization) is stored somewhere in memory
  - That address is an integer, so why can't we store an address in a variable?

Pointers

- We could simply have an 'address' type:

```
address ptr;    // store an address
                // THIS IS WRONG
```

- However, the compiler does not know what it is an address of (is it the address of an int, a double, etc.)

- Instead, we have to indicate what it is pointing to:

```
int *ptr;   // a pointer to an integer
            // the address of the integer variable 'ptr'
```

Pointers

- First we must get the address of a variable
  This is done with the **&** operator

  (***a***mpersand/***a***ddress of)

- For example,

```
int m = 5;      // m is an int storing 5
int *ptr;       // a pointer to an int
ptr = &m;       // assign to ptr the
                // address of m
```

Pointers

- We can even print the addresses:

```
int m = 5;      // m is an int storing 5
int *ptr;       // a pointer to an int
ptr = &m;       // assign to ptr the
                // address of m
cout << ptr << endl;
```

- prints `0xffffd352`, a 32-bit number
  - The computer uses 32-bit addresses

Pointers

- We have pointers: we would now like to manipulate what is stored at that address

- We can access/modify what is stored at that memory location by using the * operator (dereference)

```
int m = 5;
int *ptr;
ptr = &m;
cout << *ptr << endl;  // prints 5
```

Pointers

- Similarly, we can modify values stored at an address:

```
int m = 5;
int *ptr;
ptr = &m;
*ptr = 3;    // store 3 at that memory location
cout << m << endl;  // prints 3
```

Pointers

- Pointers to objects must, similarly be dereferenced:

```
Complex z( 3, 4 );
Complex *pz;
pz = &z;
cout << z.abs() << endl;
cout << (*pz).abs() << endl;
```

Pointers

- One short hand for this is to replace

```
(*pz).abs();
```

  with

```
pz->abs();
```

Memory Allocation

- Memory allocation in C++ and C# is done through the **`new`** operator
- This is an explicit request to the operating system for memory
  - This is a very expensive operation
  - The OS must:
    - Find the appropriate amount of memory,
    - Indicate that it has been allocated, and
    - Return the address of the first memory location

Memory Allocation

- Memory deallocation differs, however:
  - C# uses automatic garbage collection
  - C++ requires the user to explicitly deallocate memory

- Note however, that:
  - *managed C*++ has garbage collection
  - other tools are also available for C++ to perform automatic garbage collection

Memory Allocation

- Inside a function, memory allocation of declared variables is dealt with by the compiler

```
int my_func() {
    Complex<double> z(3, 4);  // calls constructor with 3, 4
                              // creates 3 + 4j
                        // 16 bytes are allocated by the compiler

    double r = z.abs(); // 8 bytes are allocated by the compiler

    return 0;           // The compiler reclaims the 24 bytes
}
```

Memory Allocation

- Memory for a single instance of a class (one object) is allocated using the new operator, *e.g.*,

```
Complex<double> *pz = new Complex<double>( 3, 4 );
```

- The new operator returns the address of the first byte of the memory allocated

Memory Allocation

- We can even print the address to the screen

  If we were to execute

```
cout << "The address pz is " << pz << endl;
```

  we would see output like:

- `The address pz is 0x00ef3b40`

Memory Allocation

- Next, to deallocate the memory (once we're finished with it) we must explicitly tell the operating system using the delete operator:

```
delete pz;
```

Memory Allocation

- Consider a linked list where each node is allocated:

```
new Node<Type>( obj )
```

- Such a call will be made each time a new element is added to the linked list

- For each `new`, there must be a corresponding `delete`:
  - Each removal of an object requires a call to `delete`
  - If a non-empty list is itself being deleted, the destructor must call `delete` on all remaining nodes

A Quick Introduction to C++

- To summarize:
  - we have seen some of the similarities and differences between C# and C++
  - these slides touch on all of the topics which you will need to know to implement all of your projects

A Quick Introduction to C++

- There is a full C++ course this semester on CS 1420 starting from scratch
- The tutorial does not even assume you know what a variable is
- There are exercises and example code which you can run yourself