C and C++

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A Brief Introduction to C++

- In this topic we will see:
  - Functions
  - The preprocessor, compilation, namespaces
  - Printing
  - Classes, templates
  - Pointers
  - Memory allocation and deallocation

Control Statements

```
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 `==` `!=` `<` `<=` `>=` `>`
  - Bitwise `&` `|` `^` `~`
    `&=` `|=` `^=`
  - Bit shifting `<<` `>>`
    `<<=` `>>=`

https://en.wikipedia.org/wiki/Operators_in_C_and_C%2B%2B

Arrays

- Accessing arrays:

```
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`**

Functions

- Function calls:

```
#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;
}
```

The C++ Preprocessor

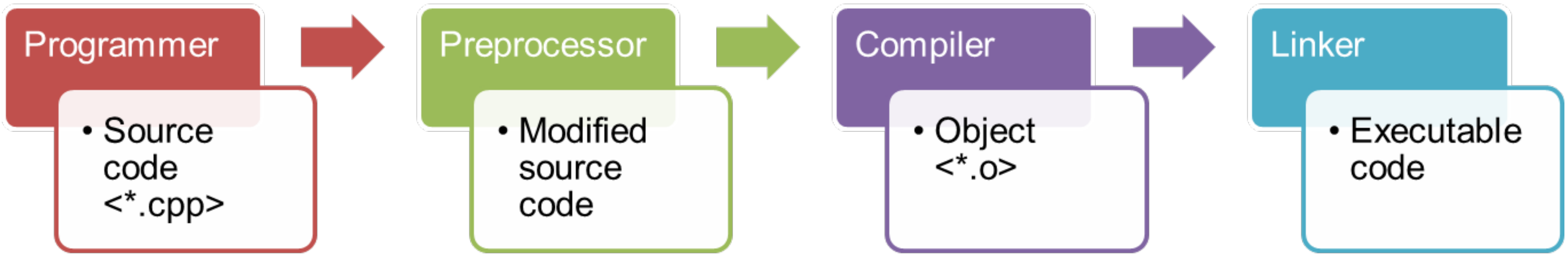
- C++ is based on C, which was written in the early 1970s

- Any command starting with a **#** in the first column is not a C/C++ statement, but rather a preprocessor statement
  - The preprocessor performs 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++)



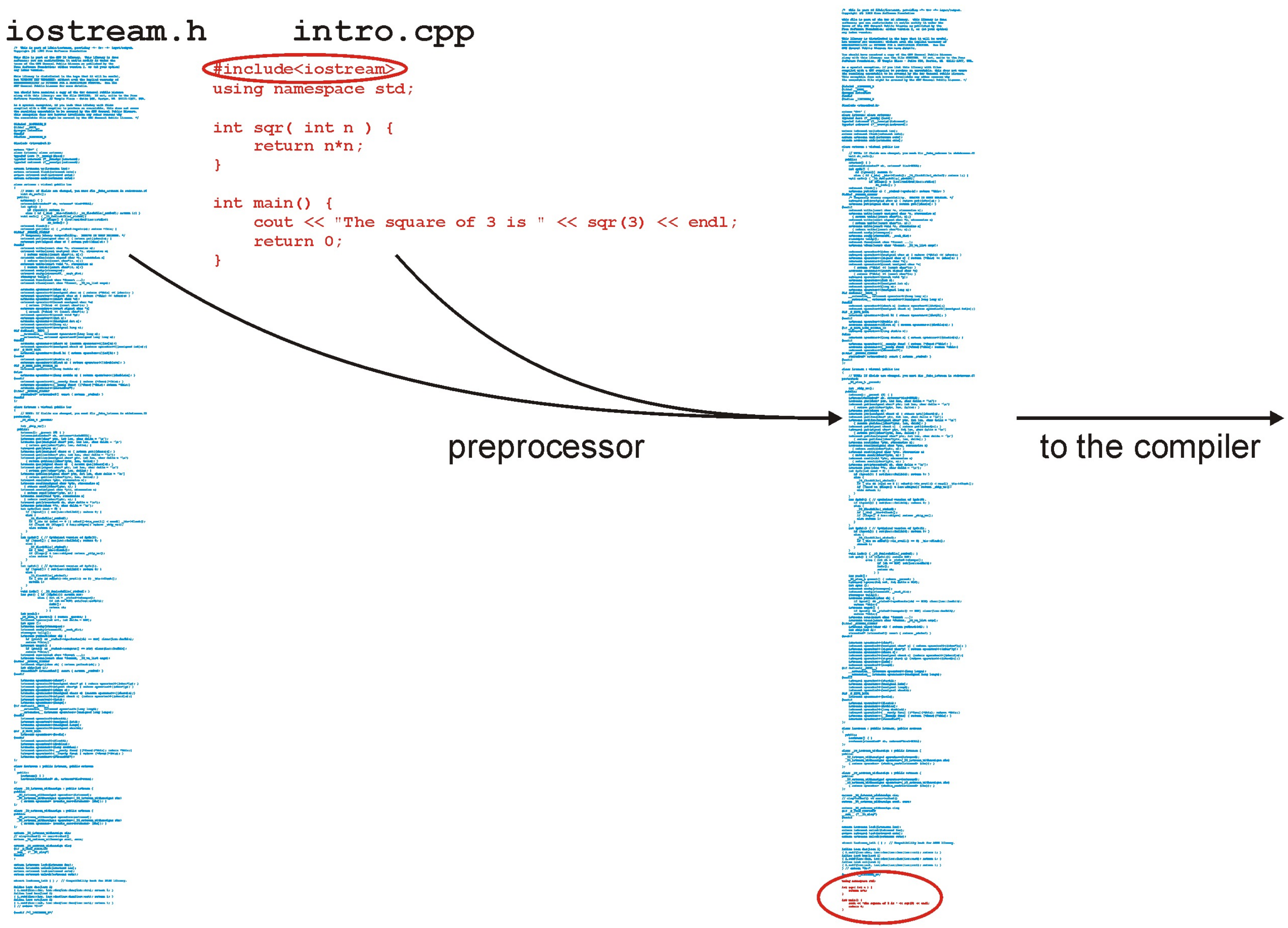
- Note, this is done automatically by the compiler:

  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



Libraries

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

- 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 up in the current directory

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 (preprocessor conditions):

```
#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

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 (this signal is given back to OS)

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:

```
$ g++ example.cpp
$ ls
a.out       example.cpp
$ ./a.out
The square of 3 is 9
```

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
  - Static local variables retain their contents between function calls

Namespaces

- Global variables/variables cause problems, especially in large projects
  - Hundreds of employees
  - Dozens of projects
  - Everyone wanting a function `init()`

- In C++, this is solved using namespaces.

Namespaces

- A namespace adds an extra disambiguation between similar names

```
namespace snu_ece {
    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:

    `snu_ece::init()`

    (note that :: is scope resolution operator)
  - The using statement:

    `using namespace snu_ece;`

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;

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

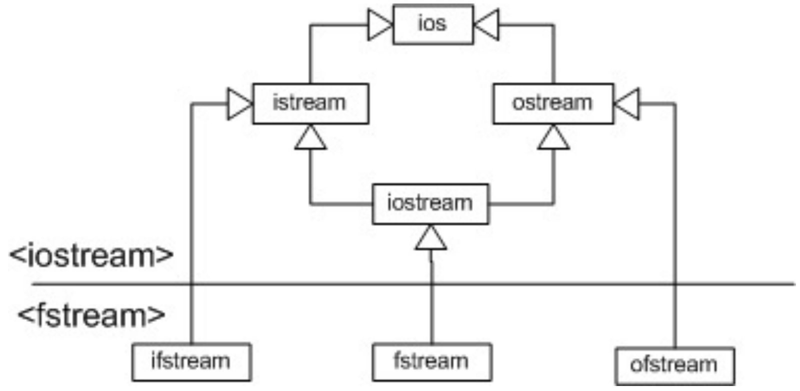
Printing

- 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.

  ➔ called operator overloading



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 operator (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…

std::**ostream::operator<<** <ostream> <iostream>

C++98 C++11

arithmetic types (1)	ostream& operator<< (bool val); ostream& operator<< (short val); ostream& operator<< (unsigned short val); ostream& operator<< (int val); ostream& operator<< (unsigned int val); ostream& operator<< (long val); ostream& operator<< (unsigned long val); ostream& operator<< (long long val); ostream& operator<< (unsigned long long val); ostream& operator<< (float val); ostream& operator<< (double val); ostream& operator<< (long double val); ostream& operator<< (void* val);
stream buffers (2)	ostream& operator<< (streambuf* sb);
manipulators (3)	ostream& operator<< (ostream& (*pf)(ostream&)); ostream& operator<< (ios& (*pf)(ios&)); ostream& operator<< (ios_base& (*pf)(ios_base&));

http://www.cplusplus.com/reference/ostream/ostream/operator%3C%3C/

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Introduction to C++

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

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 include the implementation in the class declaration, however, this is not, for numerous reasons, standard practice

- 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

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

Associates functions back to the class

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.

The Complex Class

```
// return the real component
double Complex::real() const {
    return re;
}

// return the imaginary component
double Complex::imag() const {
    return im;
}

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

Refers to the member variables re and im of this class

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

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

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

private: only accessible from the member functions of the class

protected: additionally accessible from the member functions of derived classes

```
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

- It is possible for a class to indicate that another class is allowed to access its <u>private</u> 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"
```

Visibility (Inheritance)

- Base and Member access specification:

```
class Child : public Parent
{
  protected:
     int a;
  public:
     Child();
};
```

base access specifier

member access specifier

Base class members		How base class members appear in derived class

`private: x`
`protected: y`
`public: z`
	`private` base class	`x` inaccessible
		`private: y`
		`private: z`

	`protected` base class	`x` inaccessible
		`protected: y`
		`protected: z`

	`public` base class	`x` inaccessible
		`protected: y`
		`public: z`

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;
```

- `const` member function:
  - Is prevented from modifying its calling object

- When **const** is in the parameter list

```
int setNum(const int num)
```

  - the function is prevented from modifying the parameter.

Accessors and Mutators

- If a junior programmer were to try changing

```
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

  (the compiler issues a warning that a member variable was being modified in a read-only member function)

Templates

- A function has parameters which are of a specific type
- A template is like a function, however, the parameters themselves are types

- This 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 to use 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 using 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 its following statement, so each time we define a function, we must restate that `Type` is a templated symbol (by using **`template <typename Type>`**):

```
// 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:

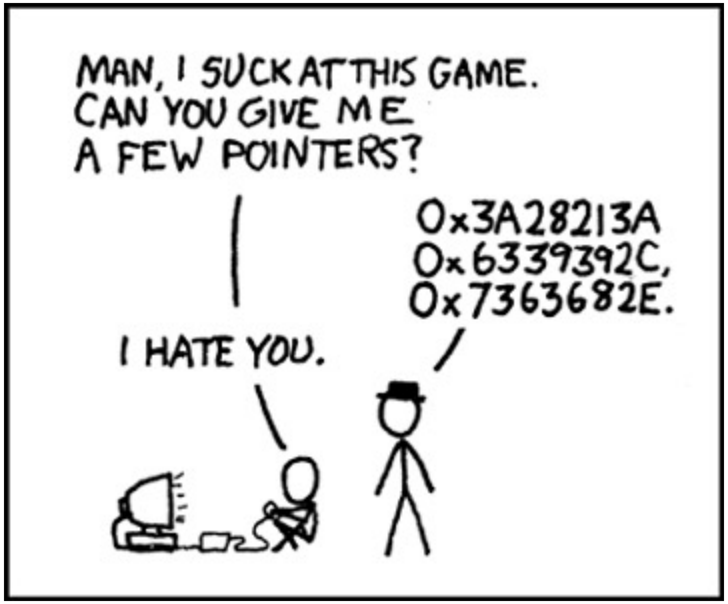
```
#include <iostream>
#include "Complex.h"
using namespace std;

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;
}
```

- Ouput:

```
|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 is stored somewhere in memory
  - That address is an integer, so why can't we store an address in a variable?



http://xkcd.com/138/

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  (What does this mean?)
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

- In case of a computer using 32-bit addresses
- This can point byte-addresses of up to 2^32 ~ 4 x 10^9 = 4GB

Pointers

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

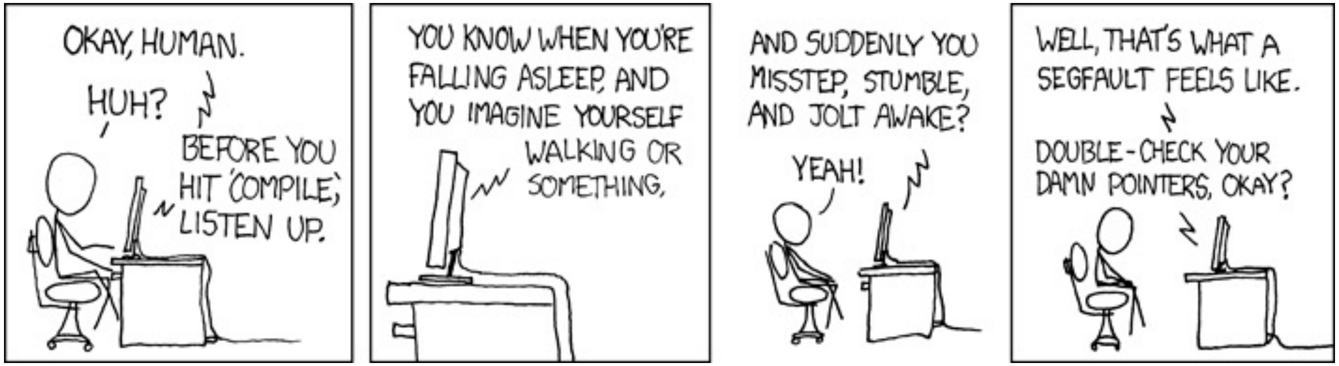
- We can access/modify what is stored at that memory location by using the * operator (dereference)

```
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
```



http://xkcd.com/371/

```
int* arr = new int[10];
…
delete[] arr;
cout << arr[10] << endl;
```

← Segmentation Fault

Pointers

- Pointers to objects must, similarly be dereferenced:

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

- One short hand for this is to replace

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

with

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

Memory Allocation

- Memory allocation in 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 deallocation differs, however:
  - C++ requires the user to explicitly deallocate memory

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 this:

```
The address pz is 0x00ef3b40
```

- 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

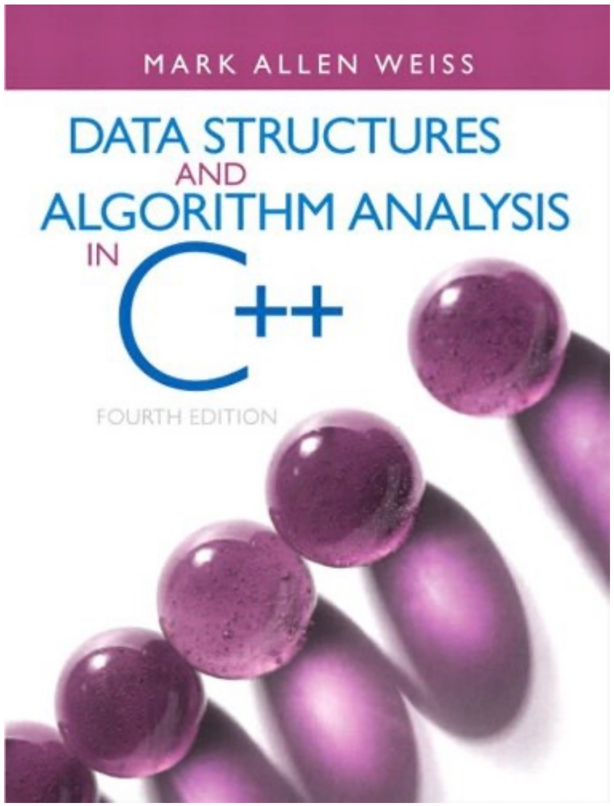
- For each **`new`**, there must be a corresponding **`delete`**:
  - Each removal of an object requires a call to **`delete`**
  - If a non-empty list is itself being deleted, the destructor must call delete on all remaining nodes

A Quick Introduction to C++

- To summarize:
  - These are very basic C++ things and may not be enough to complete the assignments!
  - You will need to self-study if you are not familiar/comfortable with theses!
  - Online tutorials
    - http://www.cplusplus.com/doc/tutorial/
    - https://www.w3schools.com/cpp/
    - https://www.learncpp.com/

Reading Assignment #2 – Chapter 2

Quiz #1: 9/30 (covering chapters 1 and 2, 4-5 questions, 40 mins, Lecture will follow)



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