Introduction to Algorithms

A Brief Introduction to C++

Control Statements

All control statements are similar

```
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

```
#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 performed very basic text-based (or *lexical*) substitutions
- The output is sent to the compiler

The C++ Preprocessor

The sequence is:

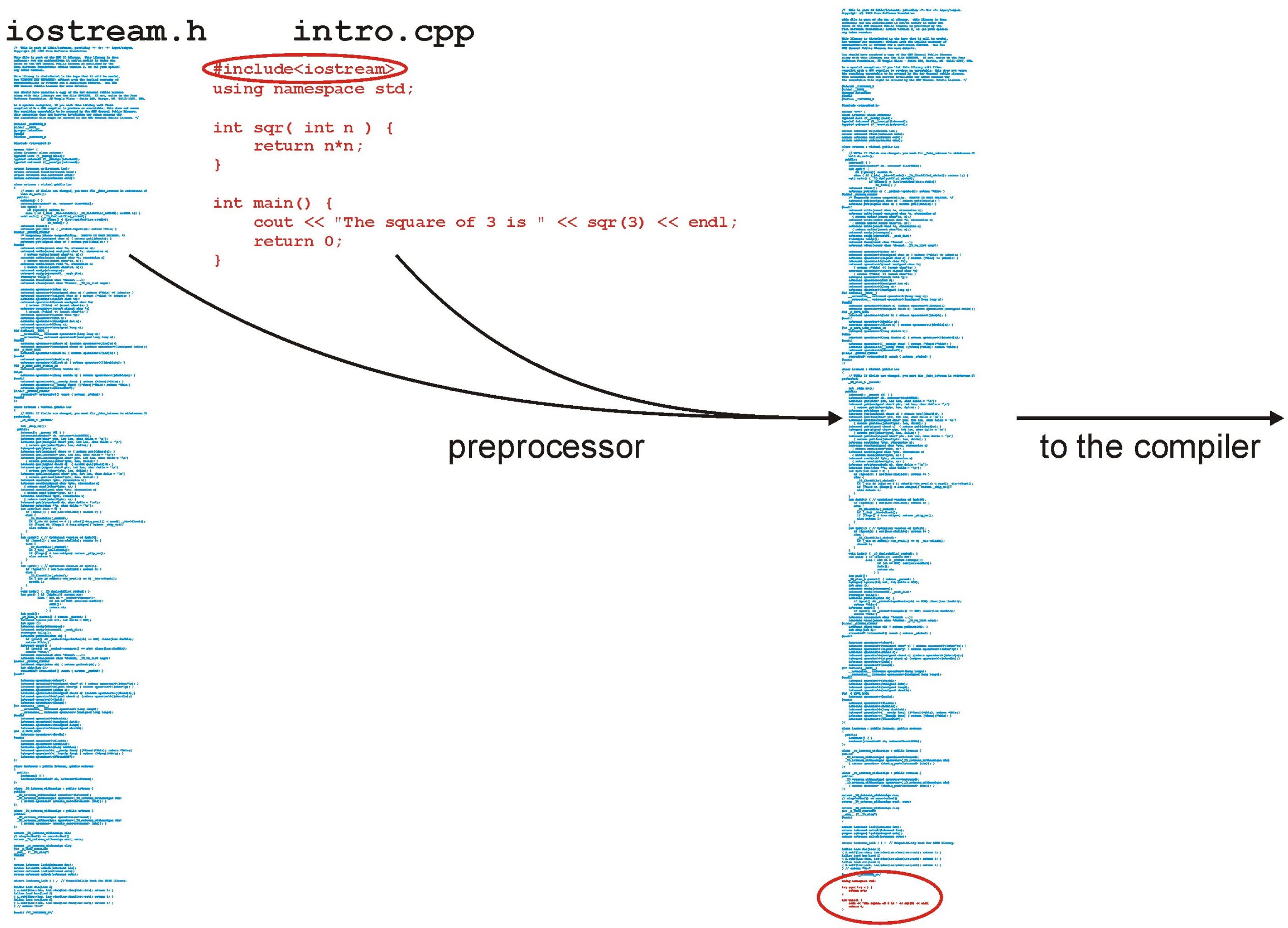
file (`filename.cpp`) → preprocessor → compiler (`g++`)

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



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

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
```

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/functions 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 cn_ustc {
    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: `cn_ustc::init()`
- The `using` statement:

```
using namespace cn_ustc;
```

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;
```

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();
};
```

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 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++, 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

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

Ouptut:

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

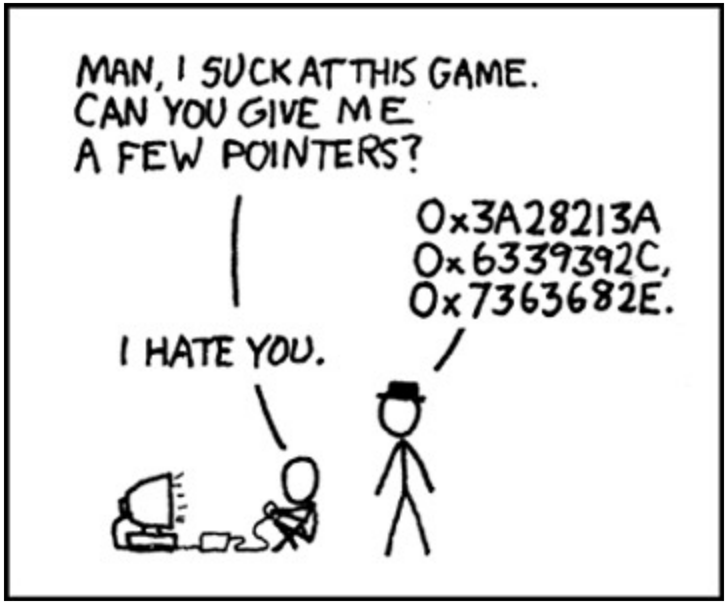
Example:

```
#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;
}
```

Pointers

One of the simplest ideas in C, but one which most students have a problem with 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
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

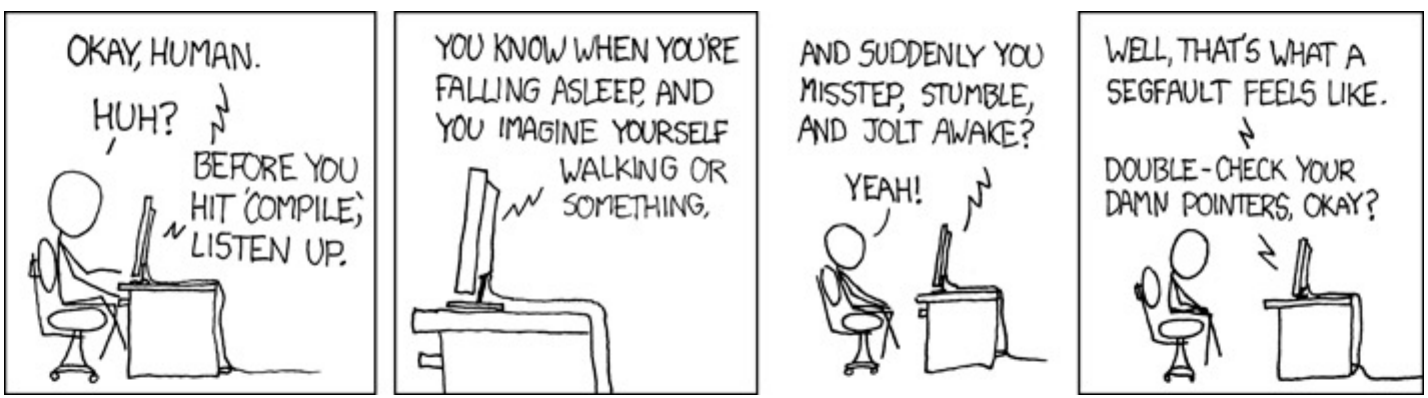
We can access/modify what is stored at that memory location by using the * operator (dereference)

```
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
```



http://xkcd.com/371/

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++

《C++ Primer》