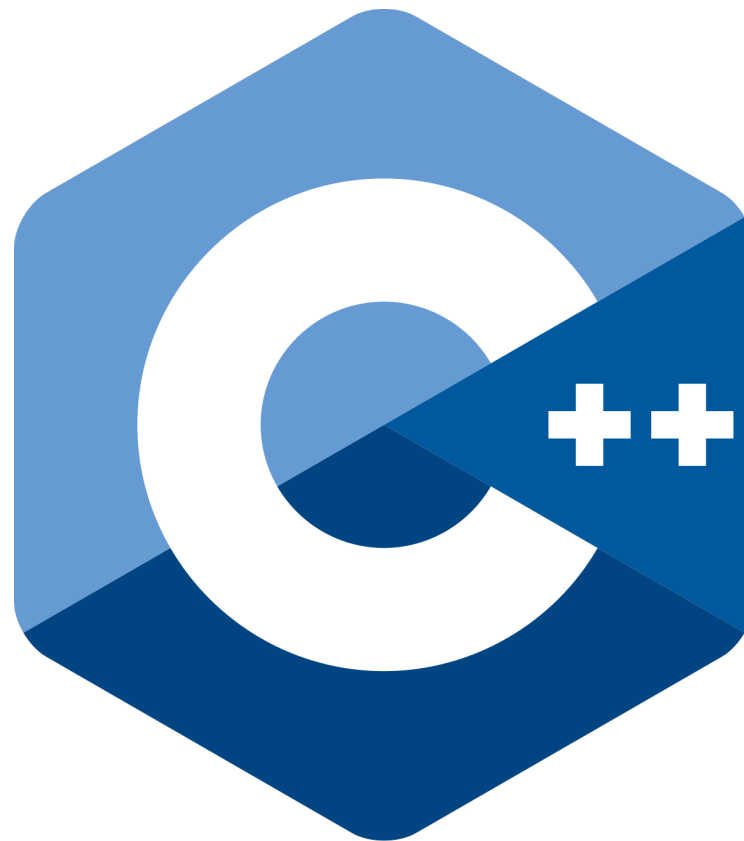


Algorithms and Analysis

Lesson 4: *C++ 101*



C with classes, new, overloading, templates

Outline

1. **C with Classes**
2. New
3. Overloading
4. Templates



C

- C was developed in the 1970s by Dennis Ritchie for writing UNIX tools
- It supported structural programming through functions
- It allowed run-time allocation of memory (through `malloc` and `free`)
- It allowed manipulation of memory through pointers
- This made it efficient

C

- C was developed in the 1970s by Dennis Ritchie for writing UNIX tools
- It supported structural programming through functions
- It allowed run-time allocation of memory (through `malloc` and `free`)
- It allowed manipulation of memory through pointers
- This made it efficient

C

- C was developed in the 1970s by Dennis Ritchie for writing UNIX tools
- It supported structural programming through functions
- It allowed run-time allocation of memory (through `malloc` and `free`)
- It allowed manipulation of memory through pointers
- This made it efficient

C

- C was developed in the 1970s by Dennis Ritchie for writing UNIX tools
- It supported structural programming through functions
- It allowed run-time allocation of memory (through `malloc` and `free`)
- It allowed manipulation of memory through pointers
- This made it efficient

C

- C was developed in the 1970s by Dennis Ritchie for writing UNIX tools
- It supported structural programming through functions
- It allowed run-time allocation of memory (through `malloc` and `free`)
- It allowed manipulation of memory through pointers
- This made it efficient

C

- C was developed in the 1970s by Dennis Ritchie for writing UNIX tools
- It supported structural programming through functions
- It allowed run-time allocation of memory (through `malloc` and `free`)
- It allowed manipulation of memory through pointers
- This made it efficient, but not safe

C

- C was developed in the 1970s by Dennis Ritchie for writing UNIX tools
- It supported structural programming through functions
- It allowed run-time allocation of memory (through `malloc` and `free`)
- It allowed manipulation of memory through pointers
- This made it efficient, but not safe or easy to use

Keeping Things Together

- As soon as you start programming bigger systems you want to keep information together
- C facilitated this through C structures `struct`

```
struct MyStructure {    // Structure declaration
    int myNum;           // Member (int variable)
    char myLetter;      // Member (char variable)
}; // End the structure with a semicolon
```

```
int main() {
    struct MyStructure s1;

    s1.myNum = 13;
    s1.myLetter = 'B';

    printf("My number: %d\n", s1.myNum);
    printf("My letter: %c\n", s1.myLetter);
    return 0;
}
```

Keeping Things Together

- As soon as you start programming bigger systems you want to keep information together
- C facilitated this through C structures `struct`

```
struct MyStructure {    // Structure declaration
    int myNum;           // Member (int variable)
    char myLetter;      // Member (char variable)
}; // End the structure with a semicolon
```

```
int main() {
    struct MyStructure s1;

    s1.myNum = 13;
    s1.myLetter = 'B';

    printf("My number: %d\n", s1.myNum);
    printf("My letter: %c\n", s1.myLetter);
    return 0;
}
```

Keeping Things Together

- As soon as you start programming bigger systems you want to keep information together
- C facilitated this through C structures `struct`

```
struct MyStructure {    // Structure declaration
    int myNum;           // Member (int variable)
    char myLetter;      // Member (char variable)
}; // End the structure with a semicolon
```

```
int main() {
    struct MyStructure s1;

    s1.myNum = 13;
    s1.myLetter = 'B';

    printf("My number: %d\n", s1.myNum);
    printf("My letter: %c\n", s1.myLetter);
    return 0;
}
```

Estimated Errors in the Mean

- When working with empirical data, $\{X_i, i = 1, 2, \dots, n\}$, we want to compute the *mean* and *variance* (from which we can estimate the error in the mean)
- We can do this on the fly by storing

$$n, \quad \hat{\mu}_n = \frac{1}{n} \sum_{i=1}^n X_i, \quad Q_n = \sum_{i=1}^n (X_i - \hat{\mu}_n)^2$$

- Given X_{n+1} we can update our data using: $\Delta = \frac{X_{n+1} - \hat{\mu}_n}{n+1}$

$$\hat{\mu}_{n+1} = \hat{\mu}_n + \Delta \quad Q_{n+1} = Q_n + n \Delta (X_{n+1} - \hat{\mu}_n)$$

Estimated Errors in the Mean

- When working with empirical data, $\{X_i, i = 1, 2, \dots, n\}$, we want to compute the *mean* and *variance* (from which we can estimate the error in the mean)
- We can do this on the fly by storing

$$n, \quad \hat{\mu}_n = \frac{1}{n} \sum_{i=1}^n X_i, \quad Q_n = \sum_{i=1}^n (X_i - \hat{\mu}_n)^2$$

- Given X_{n+1} we can update our data using: $\Delta = \frac{X_{n+1} - \hat{\mu}_n}{n+1}$

$$\hat{\mu}_{n+1} = \hat{\mu}_n + \Delta \quad Q_{n+1} = Q_n + n \Delta (X_{n+1} - \hat{\mu}_n)$$

Estimated Errors in the Mean

- When working with empirical data, $\{X_i, i = 1, 2, \dots, n\}$, we want to compute the *mean* and *variance* (from which we can estimate the error in the mean)
- We can do this on the fly by storing

$$n, \quad \hat{\mu}_n = \frac{1}{n} \sum_{i=1}^n X_i, \quad Q_n = \sum_{i=1}^n (X_i - \hat{\mu}_n)^2$$

- Given X_{n+1} we can update our data using: $\Delta = \frac{X_{n+1} - \hat{\mu}_n}{n+1}$

$$\hat{\mu}_{n+1} = \hat{\mu}_n + \Delta \quad Q_{n+1} = Q_n + n \Delta (X_{n+1} - \hat{\mu}_n)$$

Estimated Errors in the Mean

- When working with empirical data, $\{X_i, i = 1, 2, \dots, n\}$, we want to compute the *mean* and *variance* (from which we can estimate the error in the mean)
- We can do this on the fly by storing

$$n, \quad \hat{\mu}_n = \frac{1}{n} \sum_{i=1}^n X_i, \quad Q_n = \sum_{i=1}^n (X_i - \hat{\mu}_n)^2$$

- Given X_{n+1} we can update our data using: $\Delta = \frac{X_{n+1} - \hat{\mu}_n}{n+1}$

$$\hat{\mu}_{n+1} = \hat{\mu}_n + \Delta \quad Q_{n+1} = Q_n + n \Delta (X_{n+1} - \hat{\mu}_n)$$

this requires the back of an envelop to verify

Second Order Statistics in C

- In C we can use a struct to keep this data together

```
struct Sos {  
    unsigned n;  
    double mu;  
    double Q;  
};
```

- We can write functions that update the Sos structure

```
void add(struct Sos& sos, double x) {  
    double delta = (x - mu) / (n+1.0);  
    Q += n*delta*(x - mu);  
    mu += delta;  
    n++;  
}
```

- **structs** help keep information together, but can we do better?

Second Order Statistics in C

- In C we can use a `struct` to keep this data together

```
struct Sos {  
    unsigned n;  
    double mu;  
    double Q;  
};
```

- We can write functions that update the Sos structure

```
void add(struct Sos& sos, double x) {  
    double delta = (x - mu) / (n+1.0);  
    Q += n*delta*(x - mu);  
    mu += delta;  
    n++;  
}
```

- **structs** help keep information together, but can we do better?

Second Order Statistics in C

- In C we can use a `struct` to keep this data together

```
struct Sos {  
    unsigned n;  
    double mu;  
    double Q;  
};
```

- We can write functions that update the Sos structure

```
void add(struct Sos& sos, double x) {  
    double delta = (x - mu) / (n+1.0);  
    Q += n*delta*(x - mu);  
    mu += delta;  
    n++;  
}
```

- **structs** help keep information together, but can we do better?

Classes

- Classes are richer user defined datatype than structs
- C++ was developed by Bjarne Stroustrup and released in 1985 as “C with classes”
- It was syntactic sugar that compiled down to C (as such it was intended to be as fast as C)
- You are familiar with classes from python and they are very much the same thing

Classes

- Classes are richer user defined datatype than structs
- C++ was developed by Bjarne Stroustrup and released in 1985 as “C with classes”
- It was syntactic sugar that compiled down to C (as such it was intended to be as fast as C)
- You are familiar with classes from python and they are very much the same thing

Classes

- Classes are richer user defined datatype than structs
- C++ was developed by Bjarne Stroustrup and released in 1985 as “C with classes”
- It was syntactic sugar that compiled down to C (as such it was intended to be as fast as C)
- You are familiar with classes from python and they are very much the same thing

Classes

- Classes are richer user defined datatype than structs
- C++ was developed by Bjarne Stroustrup and released in 1985 as “C with classes”
- It was syntactic sugar that compiled down to C (as such it was intended to be as fast as C)
- You are familiar with classes from python and they are very much the same thing

Classes

- Classes are richer user defined datatype than structs
- C++ was developed by Bjarne Stroustrup and released in 1985 as “C with classes”
- It was syntactic sugar that compiled down to C (as such it was intended to be as fast as C)
- You are familiar with classes from python and they are very much the same thing

Classes

- Classes are richer user defined datatype than structs
- C++ was developed by Bjarne Stroustrup and released in 1985 as “C with classes”
- It was syntactic sugar that compiled down to C (as such it was intended to be as fast as C)
- You are familiar with classes from python and they are very much the same thing, except C++ is a lot more elegant than python

Classes

- Classes are richer user defined datatype than structs
- C++ was developed by Bjarne Stroustrup and released in 1985 as “C with classes”
- It was syntactic sugar that compiled down to C (as such it was intended to be as fast as C)
- You are familiar with classes from python and they are very much the same thing, except C++ is a lot more elegant than python
- C++ has grown since 1985, adding templates and a lot of nice functionality

Classes by Example

- Define interface in header file `sos.h`

```
#ifndef __SOS_H__
#define __SOS_H__

class Sos {
private:                // encapsulate
    int n;
    double mu;
    double Q;

public:                // interface
    Sos();             // constructor
    void add(double x); // add data
    double mean();      // return mean
    double var();       // unbiased estimate of variance
    double error();     // estimated error in mean
}

#endif
```

Classes by Example

- Define interface in header file `sos.h`

```
#ifndef __SOS_H__
#define __SOS_H__

class Sos {
private:                // encapsulate
    int n;
    double mu;
    double Q;

public:                 // interface
    Sos();              // constructor
    void add(double x); // add data
    double mean();      // return mean
    double var();       // unbiased estimate of variance
    double error();     // estimated error in mean
}

#endif
```

Classes by Example

- Define interface in header file `sos.h`

```
#ifndef __SOS_H__
#define __SOS_H__

class Sos {
private:                                // encapsulate
    int n;
    double mu;
    double Q;

public:                                  // interface
    Sos();                               // constructor
    void add(double x);                  // add data
    double mean();                       // return mean
    double var();                        // unbiased estimate of variance
    double error();                      // estimated error in mean
}

#endif
```

Classes by Example

- Define interface in header file `sos.h`

```
#ifndef __SOS_H__
#define __SOS_H__

class Sos {
private:                // encapsulate
    int n;
    double mu;
    double Q;

public:                // interface
    Sos();             // constructor
    void add(double x); // add data
    double mean();      // return mean
    double var();       // unbiased estimate of variance
    double error();     // estimated error in mean
}

#endif
```

Classes by Example

- Define interface in header file `sos.h`

```
#ifndef __SOS_H__
#define __SOS_H__

class Sos {
private:                // encapsulate
    int n;
    double mu;
    double Q;

public:                 // interface
    Sos();              // constructor
    void add(double x); // add data
    double mean();      // return mean
    double var();       // unbiased estimate of variance
    double error();     // estimated error in mean
}

#endif
```

Classes by Example

- Define interface in header file `sos.h`

```
#ifndef __SOS_H__
#define __SOS_H__

class Sos {
private:                // encapsulate
    int n;
    double mu;
    double Q;

public:                 // interface
    Sos();              // constructor
    void add(double x); // add data
    double mean();      // return mean
    double var();       // unbiased estimate of variance
    double error();     // estimated error in mean
}

#endif
```


Classes by Example

- Define interface in header file `sos.h`

```
#ifndef __SOS_H__
#define __SOS_H__

class Sos {
private:                // encapsulate
    int n;
    double mu;
    double Q;

public:                 // interface
    Sos();              // constructor
    void add(double x); // add data
    double mean();      // return mean
    double var();       // unbiased estimate of variance
    double error();     // estimated error in mean
}

#endif
```

Classes by Example

- Define interface in header file `sos.h`

```
#ifndef __SOS_H__
#define __SOS_H__

class Sos {
private:                // encapsulate
    int n;
    double mu;
    double Q;

public:                 // interface
    Sos();              // constructor
    void add(double x); // add data
    double mean();      // return mean
    double var();       // unbiased estimate of variance
    double error();     // estimated error in mean
}

#endif
```

Implementation of sos.cc

```
Sos::Sos() {n=0; mu=0.0; Q=0.0;}

void Sos::add(double x) {
    double delta = (x - mu)/(n+1.0);
    Q += n*delta*(x - mu);
    mu += delta;
    n++;
}

double Sos::mean() const {return mu;}

double Sos::var() const
{
    assert(n>1.0);
    return Q/(n-1.0);
}

double error() const
{
    return sqrt(var()/n);
}
```

Implementation of sos.cc

```
Sos::Sos() {n=0; mu=0.0; Q=0.0;}

void Sos::add(double x) {
    double delta = (x - mu)/(n+1.0);
    Q += n*delta*(x - mu);
    mu += delta;
    n++;
}

double Sos::mean() const {return mu;}

double Sos::var() const
{
    assert(n>1.0);
    return Q/(n-1.0);
}

double error() const
{
    return sqrt(var()/n);
}
```

Implementation of sos.cc

```
Sos::Sos() {n=0; mu=0.0; Q=0.0;}

void Sos::add(double x) {
    double delta = (x - mu)/(n+1.0);
    Q += n*delta*(x - mu);
    mu += delta;
    n++;
}

double Sos::mean() const {return mu;}

double Sos::var() const
{
    assert(n>1.0);
    return Q/(n-1.0);
}

double error() const
{
    return sqrt(var()/n);
}
```

Implementation of sos.cc

```
Sos::Sos() {n=0; mu=0.0; Q=0.0;}

void Sos::add(double x) {
    double delta = (x - mu)/(n+1.0);
    Q += n*delta*(x - mu);
    mu += delta;
    n++;
}

double Sos::mean() const {return mu;}

double Sos::var() const
{
    assert(n>1.0);
    return Q/(n-1.0);
}

double error() const
{
    return sqrt(var()/n);
}
```

Implementation of sos.cc

```
Sos::Sos() {n=0; mu=0.0; Q=0.0;}

void Sos::add(double x) {
    double delta = (x - mu)/(n+1.0);
    Q += n*delta*(x - mu);
    mu += delta;
    n++;
}

double Sos::mean() const {return mu;}

double Sos::var() const
{
    assert(n>1.0);
    return Q/(n-1.0);
}

double error() const
{
    return sqrt(var()/n);
}
```

Using Classes

- Classes are easy to use

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

void main() {
    Sos mean;
    for(int i=0; i<n; ++i) {
        // compute X
        mean.add(X);
    }
    cout << mean.mean() << ' ' << mean.error() << endl;
}
```

- Sos is the class that I use most (both in C++ and python)

Using Classes

- Classes are easy to use

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

void main() {
    Sos mean;
    for(int i=0; i<n; ++i) {
        // compute X
        mean.add(X);
    }
    cout << mean.mean() << ' ' << mean.error() << endl;
}
```

- Sos is the class that I use most (both in C++ and python)

Using Classes

- Classes are easy to use

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

void main() {
    Sos mean;
    for(int i=0; i<n; ++i) {
        // compute X
        mean.add(X);
    }
    cout << mean.mean() << ' ' << mean.error() << endl;
}
```

- Sos is the class that I use most (both in C++ and python)

Using Classes

- Classes are easy to use

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

void main() {
    Sos mean;
    for(int i=0; i<n; ++i) {
        // compute X
        mean.add(X);
    }
    cout << mean.mean() << ' ' << mean.error() << endl;
}
```

- Sos is the class that I use most (both in C++ and python)

Using Classes

- Classes are easy to use

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

void main() {
    Sos mean;
    for(int i=0; i<n; ++i) {
        // compute X
        mean.add(X);
    }
    cout << mean.mean() << ' ' << mean.error() << endl;
}
```

- Sos is the class that I use most (both in C++ and python)

Using Classes

- Classes are easy to use

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

void main() {
    Sos mean;
    for(int i=0; i<n; ++i) {
        // compute X
        mean.add(X);
    }
    cout << mean.mean() << ' ' << mean.error() << endl;
}
```

- Sos is the class that I use most (both in C++ and python)

Libraries

- C++ comes with a lot of in built libraries
- You include libraries using include statements

```
#include <iostream>
#include <vector>
```
- Same as C, but the C++ built in libraries don't have ".h"
- These are known as the standard library or the standard template library (STL)
- There is a naming convention, that libraries built into the system are called `<library>` while libraries you write are called `"library.h"`

Libraries

- C++ comes with a lot of in built libraries
- You include libraries using include statements

```
#include <iostream>  
#include <vector>
```

- Same as C, but the C++ built in libraries don't have ".h"
- These are known as the standard library or the standard template library (STL)
- There is a naming convention, that libraries built into the system are called `<library>` while libraries you write are called `"library.h"`

Libraries

- C++ comes with a lot of in built libraries
- You include libraries using include statements

```
#include <iostream>
#include <vector>
```
- Same as C, but the C++ built in libraries don't have ".h"
- These are known as the standard library or the standard template library (STL)
- There is a naming convention, that libraries built into the system are called `<library>` while libraries you write are called `"library.h"`

Libraries

- C++ comes with a lot of in built libraries
- You include libraries using include statements

```
#include <iostream>
#include <vector>
```
- Same as C, but the C++ built in libraries don't have ".h"
- These are known as the standard library or the standard template library (STL)
- There is a naming convention, that libraries built into the system are called `<library>` while libraries you write are called `"library.h"`

Libraries

- C++ comes with a lot of in built libraries
- You include libraries using include statements

```
#include <iostream>
#include <vector>
```
- Same as C, but the C++ built in libraries don't have ".h"
- These are known as the standard library or the standard template library (STL)
- There is a naming convention, that libraries built into the system are called `<library>` while libraries you write are called `"library.h"`

Namespaces

- When you are writing very large programmes (possibly involving other peoples code) you might accidentally use the same name for a class, function or variable used elsewhere
- If you are lucky this won't compile, or crash. If you are unlucky you will have a weird bug that will be very difficult to find
- To prevent this, C++ invented a new scope called **namespaces**
- By default all the standard library classes and functions are in namespace `std`
- To call the library we write `std::vector<double>`
- We can be lazy and write **`using namespace std;`**

Namespaces

- When you are writing very large programmes (possibly involving other peoples code) you might accidentally use the same name for a class, function or variable used elsewhere
- If you are luck this won't compile, or crash. If you are unlucky you will have a weird bug that will be very difficult to find
- To prevent this, C++ invented a new scope called **namespaces**
- By default all the standard library classes and functions are in namespace `std`
- To call the library we write `std::vector<double>`
- We can be lazy and write `using namespace std;`

Namespaces

- When you are writing very large programmes (possibly involving other peoples code) you might accidentally use the same name for a class, function or variable used elsewhere
- If you are lucky this won't compile, or crash. If you are unlucky you will have a weird bug that will be very difficult to find
- To prevent this, C++ invented a new scope called **namespaces**
- By default all the standard library classes and functions are in namespace `std`
- To call the library we write `std::vector<double>`
- We can be lazy and write `using namespace std;`

Namespaces

- When you are writing very large programmes (possibly involving other peoples code) you might accidentally use the same name for a class, function or variable used elsewhere
- If you are luck this won't compile, or crash. If you are unlucky you will have a weird bug that will be very difficult to find
- To prevent this, C++ invented a new scope called **namespaces**
- By default all the standard library classes and functions are in namespace `std`
- To call the library we write `std::vector<double>`
- We can be lazy and write **`using namespace std;`**

Namespaces

- When you are writing very large programmes (possibly involving other peoples code) you might accidentally use the same name for a class, function or variable used elsewhere
- If you are lucky this won't compile, or crash. If you are unlucky you will have a weird bug that will be very difficult to find
- To prevent this, C++ invented a new scope called **namespaces**
- By default all the standard library classes and functions are in namespace `std`
- To call the library we write `std::vector<double>`
- We can be lazy and write `using namespace std;`

Namespaces

- When you are writing very large programmes (possibly involving other peoples code) you might accidentally use the same name for a class, function or variable used elsewhere
- If you are lucky this won't compile, or crash. If you are unlucky you will have a weird bug that will be very difficult to find
- To prevent this, C++ invented a new scope called **namespaces**
- By default all the standard library classes and functions are in namespace `std`
- To call the library we write `std::vector<double>`
- We can be lazy and write `using namespace std;`

Namespaces

- When you are writing very large programmes (possibly involving other peoples code) you might accidentally use the same name for a class, function or variable used elsewhere
- If you are luck this won't compile, or crash. If you are unlucky you will have a weird bug that will be very difficult to find
- To prevent this, C++ invented a new scope called **namespaces**
- By default all the standard library classes and functions are in namespace `std`
- To call the library we write `std::vector<double>`
- We can be lazy and write `using namespace std;`

Print

- Rather than pesky `printf` statements C++ allows us to use the operator `<<`
- When you get used to it, you will love it

```
#include <iostream>          // header file the defines library
using namespace std;

void main() {
    int i = 5;
    double x = 3.3;

    cout << "hello there" << i << ' ' << x << endl;
}
```

Print

- Rather than pesky `printf` statements C++ allows us to use the operator `<<`
- When you get used to it, you will love it

```
#include <iostream>           // header file the defines library
using namespace std;

void main() {
    int i = 5;
    double x = 3.3;

    cout << "hello there" << i << ' ' << x << endl;
}
```

Print

- Rather than pesky `printf` statements C++ allows us to use the operator `<<`
- When you get used to it, you will love it

```
#include <iostream>          // header file the defines library
using namespace std;

void main() {
    int i = 5;
    double x = 3.3;

    cout << "hello there" << i << ' ' << x << endl;
}
```

Outline

1. C with Classes
2. **New**
3. Overloading
4. Templates



Pointers

- In C and C++ we can access an object through its memory address

```
int a = 5;    // creates an object a with value 5
int* b = &a;  // b is the memory address of object a
*b = 6        // *b is now a pseudonym for a
```

- `b` is called a pointer
- The *dereferencing* operator `*` turns the pointer back into the object

Pointers

- In C and C++ we can access an object through its memory address

```
int a = 5;    // creates an object a with value 5
int* b = &a;  // b is the memory address of object a
*b = 6        // *b is now a pseudonym for a
```

- `b` is called a pointer
- The *dereferencing* operator `*` turns the pointer back into the object

Pointers

- In C and C++ we can access an object through its memory address

```
int a = 5;    // creates an object a with value 5
int* b = &a;  // b is the memory address of object a
*b = 6        // *b is now a pseudonym for a
```

- `b` is called a pointer
- The *dereferencing* operator `*` turns the pointer back into the object

Pointers

- In C and C++ we can access an object through its memory address

```
int a = 5;    // creates an object a with value 5
int* b = &a;  // b is the memory address of object a
*b = 6        // *b is now a pseudonym for a
```

- **b** is called a pointer
- The *dereferencing* operator ***** turns the pointer back into the object

Pointers

- In C and C++ we can access an object through its memory address

```
int a = 5;    // creates an object a with value 5
int* b = &a;  // b is the memory address of object a
*b = 6        // *b is now a pseudonym for a
```

- `b` is called a pointer
- The *dereferencing* operator `*` turns the pointer back into the object

New Object

- The operator **new** will create an object and return a reference

```
Widget w(arg); // w is an instance of class Widget
Widget* wpt = new Widget(args); // pointer to instance of class Widget
```

- To call a member function, `func()`, of class `w` you use

```
w.func()
```

- To call a member function of `wpt` use either

```
(*wpt).func(); // dereference object and call member function
```

New Object

- The operator **new** will create an object and return a reference

```
Widget w(arg); // w is an instance of class Widget  
Widget* wpt = new Widget(args); // pointer to instance of class Widget
```

- To call a member function, `func()`, of class `w` you use

```
w.func()
```

- To call a member function of `wpt` use either

```
(*wpt).func(); // dereference object and call member function
```

New Object

- The operator **new** will create an object and return a reference

```
Widget w(arg); // w is an instance of class Widget  
Widget* wpt = new Widget(args); // pointer to instance of class Widget
```

- To call a member function, `func()`, of class `w` you use

```
w.func()
```

- To call a member function of `wpt` use either

```
(*wpt).func(); // dereference object and call member function
```

New Object

- The operator **new** will create an object and return a reference

```
Widget w(arg); // w is an instance of class Widget  
Widget* wpt = new Widget(args); // pointer to instance of class Widget
```

- To call a member function, `func()`, of class `w` you use

```
w.func()
```

- To call a member function of `wpt` use either

```
(*wpt).func(); // dereference object and call member function
```

New Object

- The operator **new** will create an object and return a reference

```
Widget w(arg); // w is an instance of class Widget
Widget* wpt = new Widget(args); // pointer to instance of class Widget
```

- To call a member function, `func()`, of class `w` you use

```
w.func()
```

- To call a member function of `wpt` use either

```
(*wpt).func(); // dereference object and call member function
wpt->func();    // easy to type
```

Inheritance

- C++ allows classes to inherit from other classes
- Suppose `Square` and `Circle` inherits from `Shape`
- If `Shape` has a (virtual) member function `area` then `Square` and `Circle` can redefine this

```
class Square: public Shape {  
    private:  
        double l;  
  
    public:  
        Square(double len) {l=len;}    // constructor  
        double area() {return l*l;}    // define area  
}
```


Inheritance

- C++ allows classes to inherit from other classes
- Suppose Square and Circle inherits from Shape
- If Shape has a (virtual) member function area then Square and Circle can redefine this

```
class Square: public Shape {  
    private:  
        double l;  
  
    public:  
        Square(double len) {l=len;} // constructor  
        double area() {return l*l;} // define area  
}
```

Inheritance

- C++ allows classes to inherit from other classes
- Suppose `Square` and `Circle` inherits from `Shape`
- If `Shape` has a (virtual) member function `area` then `Square` and `Circle` can redefine this

```
class Square: public Shape {  
    private:  
        double l;  
  
    public:  
        Square(double len) {l=len;}    // constructor  
        double area() {return l*l;}    // define area  
}
```

Inheritance

- C++ allows classes to inherit from other classes
- Suppose `Square` and `Circle` inherits from `Shape`
- If `Shape` has a (virtual) member function `area` then `Square` and `Circle` can redefine this

```
class Square: public Shape {  
    private:  
        double l;  
  
    public:  
        Square(double len) {l=len;} // constructor  
        double area() {return l*l;} // define area  
}
```

Polymorphism

- Polymorphism is a way of using inheritance where we instantiate a parent pointer with a child class

```
Shape* shape = new Square(2.5);
```

```
cout << shape->area() << endl;
```

- This provides a clean way of choosing a behaviour depending on the object type
- It is used in *iterators* which we will come to later in the course

Polymorphism

- Polymorphism is a way of using inheritance where we instantiate a parent pointer with a child class

```
Shape* shape = new Square(2.5);
```

```
cout << shape->area() << endl;
```

- This provides a clean way of choosing a behaviour depending on the object type
- It is used in *iterators* which we will come to later in the course

Polymorphism

- Polymorphism is a way of using inheritance where we instantiate a parent pointer with a child class

```
Shape* shape = new Square(2.5);
```

```
cout << shape->area() << endl;
```

- This provides a clean way of choosing a behaviour depending on the object type
- It is used in *iterators* which we will come to later in the course

Polymorphism

- Polymorphism is a way of using inheritance where we instantiate a parent pointer with a child class

```
Shape* shape = new Square(2.5);
```

```
cout << shape->area() << endl;
```

- This provides a clean way of choosing a behaviour depending on the object type
- It is used in *iterators* which we will come to later in the course

Arrays

- C++ also uses **new** to return arrays (in place of malloc)

```
int* pt = new int[20];
```

creates a pointer to memory location where we can store 20 integers

- We can dereference the i^{th} element using `pt[i]`
- We can free this up with

```
delete[] pt;
```


Arrays

- C++ also uses **new** to return arrays (in place of malloc)

```
int* pt = new int[20];
```

creates a pointer to memory location where we can store 20 integers

- We can dereference the i^{th} element using `pt[i]`
- We can free this up with

```
delete[] pt;
```

Arrays

- C++ also uses **new** to return arrays (in place of malloc)

```
int* pt = new int[20];
```

creates a pointer to memory location where we can store 20 integers

- We can dereference the i^{th} element using `pt[i]` (which is equivalent to `*(pt+i)`)
- We can free this up with

```
delete[] pt;
```

Arrays

- C++ also uses **new** to return arrays (in place of malloc)

```
int* pt = new int[20];
```

creates a pointer to memory location where we can store 20 integers

- We can dereference the i^{th} element using `pt[i]` (which is equivalent to `*(pt+i)`)—this is the same as C
- We can free this up with

```
delete[] pt;
```

Arrays

- C++ also uses **new** to return arrays (in place of malloc)

```
int* pt = new int[20];
```

creates a pointer to memory location where we can store 20 integers

- We can dereference the i^{th} element using `pt[i]` (which is equivalent to `*(pt+i)`)—this is the same as C
- We can free this up with

```
delete[] pt;
```

References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6                // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a);                // does nothing a=5
g(a);                // now a=7
```

References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6;               // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a); // does nothing a=5
g(a); // now a=7
```

References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6;               // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a); // does nothing a=5
g(a); // now a=7
```

References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6                // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a);           // does nothing a=5
g(a);           // now a=7
```


References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6                // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a);           // does nothing a=5
g(a);           // now a=7
```

References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6                 // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a);                // does nothing a=5
g(a);                // now a=7
```

References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6                // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a);           // does nothing a=5
g(a);           // now a=7
```

References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6                 // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a); // does nothing a=5
g(a); // now a=7
```

References

- C and C++ also provides references

```
int a = 5;           // create a memory location called a
int& b = a;          // b is a pseudonym for a
b = 6                 // both b and a are now 6
```

- References are like dereferenced pointers
- There are many uses of references, one is so we can make functions change the value of their arguments

```
void f(int x) {x += 6;} // define function f

void g(int& x) {x += 2;} // define function g

int a = 5;

f(a);           // does nothing a=5
g(a);           // now a=7
```

Saving Copying

- When we declare a function `f (Widget w)` then widget `w` is copied to the function (this is known as passed by value)
- If widget is big, even if we don't want to change it we might **not** want to copy it

```
void f(const Widget& w);  
void g(Widget w);
```

- In both cases `w` is a `Widget`, but function `f` avoids copying its input

Saving Copying

- When we declare a function `f(Widget w)` then widget `w` is copied to the function (this is known as passed by value)
- If widget is big, even if we don't want to change it we might **not** want to copy it

```
void f(const Widget& w);  
void g(Widget w);
```

- In both cases `w` is a `Widget`, but function `f` avoids copying its input

Saving Copying

- When we declare a function `f (Widget w)` then widget `w` is copied to the function (this is known as passed by value)
- If widget is big, even if we don't want to change it we might **not** want to copy it

```
void f(const Widget& w);  
void g(Widget w);
```

- In both cases `w` is a Widget, but function `f` avoids copying its input

Saving Copying

- When we declare a function `f (Widget w)` then widget `w` is copied to the function (this is known as passed by value)
- If widget is big, even if we don't want to change it we might **not** want to copy it

```
void f(const Widget& w);  
void g(Widget w);
```

- In both cases `w` is a `Widget`, but function `f` avoids copying its input

Outline

1. C with Classes
2. New
3. **Overloading**
4. Templates



Overloading

- C and C++ allow you to define different functions with the same name but different arguments

```
void func(int a);    // called if argument is an int  
void func(double a); // called if argument is a double
```

- Needs to be used sensibly, but provides flexibility

Overloading

- C and C++ allow you to define different functions with the same name but different arguments

```
void func(int a);      // called if argument is an int  
void func(double a);  // called if argument is a double
```

- Needs to be used sensibly, but provides flexibility

Example

- In the second order statistics class we could define a member function

```
void add(const Sos& rhs);
```

- With an implementation

```
void Sos::add(const Sos& rhs)
{
    double total = n + rhs.n;
    double diff = rhs.mu-mu;
    mu += rhs.n*diff/total;
    Q += rhs.Q + n*rhs.n*diff*diff/total;
    n = total;

    return rhs;
}
```

Overloading Continued

- This allows us to add second order statistics

```
Sos total;
for(int i=0; i<10; ++i) {
    Sos local;
    for(int j=0; j<100; ++j) {
        // compute X
        cout << local.mean() << ',' << local.error() << endl;
        local.add()
    }
    total.add(local)
    cout << total.mean() << ',' << total.error() << endl;
}
```

Operator Overloading

- C++ like python allows us to overload operators
- Rather than using add I might prefer to use

```
class Sos {  
    ...  
    double operator+=(double x) { add(x); return(x); }  
}
```

- Then we can write

```
Sos sos;  
sos += X;
```

Operator Overloading

- C++ like python allows us to overload operators
- Rather than using add I might prefer to use

```
class Sos {  
    ...  
    double operator+=(double x) { add(x); return(x); }  
}
```

- Then we can write

```
Sos sos;  
sos += X;
```


Operator Overloading

- C++ like python allows us to overload operators
- Rather than using add I might prefer to use

```
class Sos {  
    ...  
    double operator+=(double x) { add(x); return(x); }  
}
```

- Then we can write

```
Sos sos;  
sos += X;
```

Overloading <<

- To print an object of type `Sos` we define

```
ostream& operator<<(ostream& out, const Sos& d)
{
    out << d.mean() << " " << d.error();
    return(out);
}
```

- We can then print

```
Sos sos;
...

cout << sos << endl;
```

- I've made `sos.h` and `sos.cc` available on the web site

Overloading <<

- To print an object of type `Sos` we define

```
ostream& operator<<(ostream& out, const Sos& d)
{
    out << d.mean() << " " << d.error();
    return(out);
}
```

- We can then print

```
Sos sos;
...

cout << sos << endl;
```

- I've made `sos.h` and `sos.cc` available on the web site

Overloading <<

- To print an object of type `Sos` we define

```
ostream& operator<<(ostream& out, const Sos& d)
{
    out << d.mean() << " " << d.error();
    return(out);
}
```

- We can then print

```
Sos sos;
...

cout << sos << endl;
```

- I've made `sos.h` and `sos.cc` available on the web site

Overloading <<

- To print an object of type `Sos` we define

```
ostream& operator<<(ostream& out, const Sos& d)
{
    out << d.mean() << " " << d.error();
    return(out);
}
```

- We can then print

```
Sos sos;
...

cout << sos << endl;
```

- I've made `sos.h` and `sos.cc` available on the web site—I use them a lot, you might want to keep them around

Outline

1. C with Classes
2. New
3. Overloading
4. **Templates**



Templates

- Many algorithms and data structures can be applied to a wide range of types

```
vector<double> double_vec; // resizable array of doubles
vector<int>    int_vec;    // resizable array of int
map<string, int> mymap     // map with string keys and int values
```

- C++ allows us to define a template class

```
template <typename T>
class myclass {
    private T data;
}
```

Templates

- Many algorithms and data structures can be applied to a wide range of types

```
vector<double> double_vec; // resizable array of doubles
vector<int>    int_vec;    // resizable array of int
map<string, int> mymap     // map with string keys and int values
```

- C++ allows us to define a template class

```
template <typename T>
class myclass {
    private T data;
}
```


Templates

- Many algorithms and data structures can be applied to a wide range of types

```
vector<double> double_vec; // resizable array of doubles
vector<int>    int_vec;    // resizable array of int
map<string, int> mymap     // map with string keys and int values
```

- C++ allows us to define a template class

```
template <typename T>
class myclass {
    private T data;
}
```

Templates

- Many algorithms and data structures can be applied to a wide range of types

```
vector<double> double_vec; // resizable array of doubles
vector<int>    int_vec;    // resizable array of int
map<string, int> mymap     // map with string keys and int values
```

- C++ allows us to define a template class

```
template <typename T>
class myclass {
    private T data;
}
```

Templates

- Many algorithms and data structures can be applied to a wide range of types

```
vector<double> double_vec; // resizable array of doubles  
vector<int>    int_vec;    // resizable array of int  
map<string, int> mymap    // map with string keys and int values
```

- C++ allows us to define a template class

```
template <typename T>  
class myclass {  
    private T data;  
}
```

Templates

- Templates work very simply
- They provide a template for same type (e.g. `T`)
- When you ask for an instance of that object

```
myclass<int> instance;
```

the C++ compiler takes your template and substitutes the `T` with `int`

- This is both simple and powerful

Templates

- Templates work very simply
- They provide a template for same type (e.g. `T`)
- When you ask for an instance of that object

```
myclass<int> instance;
```

the C++ compiler takes your template and substitutes the `T` with `int`

- This is both simple and powerful

Templates

- Templates work very simply
- They provide a template for same type (e.g. `T`)
- When you ask for an instance of that object

```
myclass<int> instance;
```

the C++ compiler takes your template and substitutes the `T` with `int`

- This is both simple and powerful

Templates

- Templates work very simply
- They provide a template for same type (e.g. `T`)
- When you ask for an instance of that object

```
myclass<int> instance;
```

the C++ compiler takes your template and substitutes the `T` with `int`

- This is both simple and powerful

Templates

- Templates work very simply
- They provide a template for same type (e.g. `T`)
- When you ask for an instance of that object

```
myclass<int> instance;
```

the C++ compiler takes your template and substitutes the `T` with `int`

- This is both simple and powerful

Template Functions

- As well as classes I can create template functions

```
template <typename T>
T accumulate(const vector<T>& vec) {
    T sum = 0;
    for(int i=0; i<vec.size(); ++i) {
        sum += vec[i];
    }
    return sum
}
```

- This will work with `vector<int>`, `vector<double>`

Template Functions

- As well as classes I can create template functions

```
template <typename T>
T accumulate(const vector<T>& vec) {
    T sum = 0;
    for(int i=0; i<vec.size(); ++i) {
        sum += vec[i];
    }
    return sum
}
```

- This will work with `vector<int>`, `vector<double>`

Summary

- C++ is a rich language
- You should learn some C++ in low-level programming
- There are a lot of resources
- I'm afraid you will only get good at it by writing programs
- The lab session are to help you learn C++

Summary

- C++ is a rich language
- You should learn some C++ in low-level programming
- There are a lot of resources
- I'm afraid you will only get good at it by writing programs
- The lab session are to help you learn C++

Summary

- C++ is a rich language
- You should learn some C++ in low-level programming
- There are a lot of resources
- I'm afraid you will only get good at it by writing programs
- The lab session are to help you learn C++

Summary

- C++ is a rich language
- You should learn some C++ in low-level programming
- There are a lot of resources
- I'm afraid you will only get good at it by writing programs
- The lab session are to help you learn C++

Summary

- C++ is a rich language
- You should learn some C++ in low-level programming
- There are a lot of resources
- I'm afraid you will only get good at it by writing programs
- The lab session are to help you learn C++