

## Lesson 4: C++ 101



*C with classes, new, overloading, templates*

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## 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

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## 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

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## 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 if 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

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



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## 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;
}
```

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## 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?

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## 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
```

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## 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);
}
```

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## 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"

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## 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;
}
```

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## 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

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## 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)

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## 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;

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## Outline

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



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## 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
```

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## 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  
}
```

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## 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;`

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## 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

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## 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

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## 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

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## 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

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## 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;`  
}

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- 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;
}
```

## 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

## 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 value.
```

- C++ allows us to define a template class

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

## 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>

- 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;
```

## Outline

- C with Classes
- New
- Overloading
- Templates



## 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

## 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++