

### Lesson 4: C++ 101



C with classes, new, overloading, templates

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



## 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;
}
```

- 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

## 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

## 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

## 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 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);  
}
```

## 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"

## 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;

- 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

## 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  
}
```

## 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]` (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
```

- 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

## 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;  
}
```

- 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;
}
```

- 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—I use them a lot, you might want to keep them around

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## Outline

## 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;
}
```

## 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>`

## 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++