Scientific Computing: Objects

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Today's class

Today we will discuss the following topics:

- Object-oriented programming.
- Classes and objects in C++.
- Class inheritance, functional polymorphism.
- Assignment 2.

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Limits to structured programming

Structured programming is the methodology of breaking up a given programming task into smaller bits using subroutines which access other subroutines, until one has simple tasks to implement. This is a good approach to solving one particular programming task.

Problems arise with this approach when there are multiple different tasks being applied to the same data:

- Each separate code needs to know about the data structure.
- Leads to reinventing the wheel.

In these situations one would instead like to build 'components' with known properties and known interfaces to allow them to easily plug into your program.

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Object-oriented programming

What is object-oriented programming (OOP)?

- Structured programming: functions and data are accessible from everywhere and by everyone.
- OOP: functions and data are bundled together into a 'class'. The implementation details are hidden.

OOP has a number of advantages:

- Complexity can be hidden inside each class.
- Separates the interface from the implementation.
- Good reuse of components.

But be sure you know:

- the computational cost of the operations.
- what temporary variables are created.

At a low level, OOP may need to be broken for best performance.

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C++ class syntax

How is OOP accomplished in C++? Classes and objects!

- Define a class, with its own internal variables and functions.
- Declare variables (objects) to be of this class.

In this sense a class is like a customized variable, a self-contained package that includes all the bits that you need to work on your data.

```
class classname {
 private:   // Things that can't be accessed from outside the object.
   int var1;
   float var2;

 public:   // The things that can be accessed from outside.
   void func1();
   int func2(int x, int y);
};
```

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Data hiding

- Good implementations hide the data details.
- Each function or variable is one of three types:
  1. private: only functions of the class have access.
  2. public: accessible when using the class.
  3. protected: accessible only to this class and derived classes.
- These are specified as sections within the class.

```
class classname {
  // Things that can't be accessed from
  // outside the object.
  private:
    int var1;
    float var2;

  // The things that can be accessed from
  // outside the object.
  public:
    void func1();
    int func2(int x, int y);
    float ReturnVar2() {
      return var2;
    };

};
```

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The StoneWt class

```
// MyStoneWt.cpp
#include <iostream>
class StoneWt {
  private:
    int stone; // whole stones
    float lbs_left; // fractional pounds
  public:
    void set_stn(int stn, float lbs) {stone = stn; lbs_left = lbs;};
    void show_stn() {std::cout << "The weight is " << stone
      << " stone and " << lbs_left << " pounds." << std::endl;};
};
```

The StoneWt class

```
// MyStoneWt.cpp
#include <iostream>
class StoneWt {
  private:
    int stone; // whole stones
    float lbs_left; // fractional pounds
  public:
    void set_stn(int stn, float lbs) {stone = stn; lbs_left = lbs;};
    void show_stn() {std::cout << "The weight is " << stone
      << " stone and " << lbs_left << " pounds." << std::endl;};
};

int main() {
  StoneWt myweight;
  myweight.set_stn(10, 2.1);
  myweight.show_stn();}
```

The StoneWt class

```
// MyStoneWt.cpp
#include <iostream>
class StoneWt {
  private:
    int stone; // whole stones
    float lbs_left; // fractional pounds
  public:
    void set_stn(int stn, float lbs) {stone = stn; lbs_left = lbs;};
    void show_stn() {std::cout << "The weight is " << stone
      << " stone and " << lbs_left << " pounds." << std::endl;};
};

int main() {
  StoneWt myweight;
  myweight.set_stn(10, 2.1);
  myweight.show_stn();}
```

```
ejspence@mycomp ~> g++ MyStoneWt.cpp -o MyStoneWt
ejspence@mycomp ~> ./MyStoneWt
The weight is 10 stone and 2.1 pounds.
```

The StoneWt class, improved

```
// StoneWt.h
#ifndef STONEWT_H
#define STONEWT_H

class StoneWt {

  private:
    int stone; // whole stones
    float lbs_left; // frac. lbs

  public:
    // Set the weight, in stone.
    void set_stn(int stn,
                 float lbs);

    // Print the weight.
    void show_stn();
};
#endif
```

Stolen from C++ Primer Plus

```
// StoneWt.cpp
#include <iostream>
#include "StoneWt.h"
void StoneWt::set_stn(int stn, float lbs) {
  stone = stn; lbs_left = lbs;
};

void StoneWt::show_stn() {
  std::cout << "The weight is " <<
    stone << " stone and " << lbs_left << "
    pounds." << std::endl;
};
```

```
// MyStoneWt.cpp
#include "StoneWt.h"
int main {
  StoneWt myweight;
  myweight.set_stn(10, 2.1);
  myweight.show_stn();
}
```

Constructors

C++ allows the flexibility of instantiating your object in different ways. This is accomplished through a 'contructor':

- Constructors are functions that have the same name as the class.
- They perform whatever initialization of the object is necessary.
- By having different numbers or types of arguments you can have different constructors to do different initializations.
- The constructors are listed in the public part of the class definition.

```
class classname {
  ...
  public:
    // Two constructors.  Note that the constructors do not have return types.
    classname();       // Default contructor.
    classname(arguments);
    int func1(int a);
};
```

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Destructors

By default C++ will destroy a variable when it 'goes out of scope'. But some objects require special instructions to be deleted correctly. This function is called the 'destructor'.

- The destructor is a function that has the same name as the class, but begins with a ~.
- The destructor must perform the deletion of whatever variables were created with 'new'. Otherwise it needn't be specified.
- The destructor is listed in the public part of the class definition.

```
class classname {
  ...
  public:
    // Note that the destructor does not have a return type.
    ~classname();
};
```

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The StoneWt class

```cpp
// StoneWt.h
#ifndef STONEWT_H
#define STONEWT_H

class StoneWt {

  private:
    int stone; // whole stones
    float lbs_left; // frac. lbs

  public:
    StoneWt();
    StoneWt(int stn, float lbs);
    ~StoneWt();
    void set_stn(int stn,
                 float lbs);
    void show_stn();
};
#endif
```

```cpp
// StoneWt.cpp
#include <iostream>
#include "StoneWt.h"

void StoneWt::set_stn(int stn, float lbs)
{stone = stn; lbs_left = lbs;};

void StoneWt::show_stn() {
  std::cout << "The weight is " <<
    stone << " stone and " << lbs_left <<
    " pounds." << std::endl;
};

StoneWt::StoneWt() // Default constructor.
{stone = 0; lbs_left = 0.0;};

StoneWt::StoneWt(int stn, float lbs)
{stone = stn; lbs_left = lbs;};

StoneWt::~StoneWt() {}; // Destructor.
```

The StoneWt class, continued

```
// MyStoneWt.cpp
#include "StoneWt.h"
int main {
  StoneWt myweight;
  StoneWt *myweight2;

  myweight2 = new StoneWt(4, 0.2);
  myweight.show_stn();
  myweight.set_stn(10, 2.1);
  myweight.show_stn();
  myweight2 -> show_stn();
}
```

The StoneWt class, continued

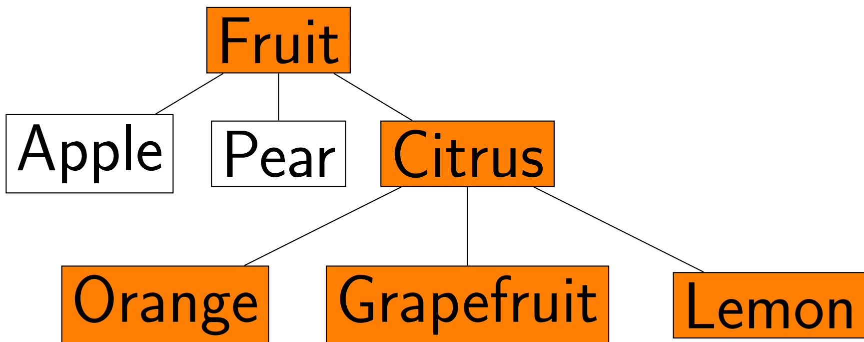
```
// MyStoneWt.cpp
#include "StoneWt.h"
int main {
  StoneWt myweight;
  StoneWt *myweight2;

  myweight2 = new StoneWt(4, 0.2);
  myweight.show_stn();
  myweight.set_stn(10, 2.1);
  myweight.show_stn();
  myweight2 -> show_stn();
}
```

```
ejspence@mycomp ~> g++ StoneWt.cpp -c -o StoneWt.o
ejspence@mycomp ~> g++ MyStoneWt.cpp -c -o MyStoneWt.o
ejspence@mycomp ~> g++ StoneWt.o MyStoneWt.o -o MyStoneWt
ejspence@mycomp ~> ./MyStoneWt
The weight is 0 stone and 0 pounds.
The weight is 10 stone and 2.1 pounds.
The weight is 4 stone and 0.2 pounds.
```

Class inheritance

Sometimes it makes sense to build classes that are based on the features of other classes (modular programming!), rather than starting a new class from scratch.



Class inheritance, continued

- Derived classes are derived from base classes.
- The derived classes automatically include the base class' public members.
- When the derived-class constructor is invoked, the base-class constructor is also invoked. Hence the option of specifying how the base-class constructor is to be invoked by the derived-class constructor.

```
// Base class
class baseclass {
  private:
    ...
  public:
    baseclass();
    baseclass(int a);
    ...
};
```

```
// Derived class
class derivedclass : public baseclass {
  private:
    ...
  public:
    derivedclass() : baseclass();
    derivedclass(int a) : baseclass(a);
    ...
};
```

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Class inheritance, example

```
// matrix.h
#ifndef MATRIX_H
#define MATRIX_H

class matrix {
  // 'protected' allows these
  // variables to be directly
  // accessed by derived classes.
  protected:
    int rows, cols;
    double *elements;
  public:
    matrix(int r, int c);
    ~matrix();
    int get_rows();
    int get_cols();
    void fill(double value);
};
#endif
```

```
// sqrmatrix.h
#ifndef SQRMATRIX_H
#define SQRMATRIX_H
#include <iostream>
#include "matrix.h"
class sqrmatrix : public matrix {
  public:
    sqrmatrix(int r,int c) : matrix(r,c) {
      if (r != c) {
        std::cerr<<"Not a square matrix.";
        exit(1);
      }};
    double trace() {
      double sum = 0.0;
      for(int i = 0; i < rows; i++)
        sum += elements[i * cols + i];
      return sum;
    };
};
#endif
```

Class inheritance, example

```
// Mysqrmatrix.cpp
#include <iostream>
#include "sqrmatrix.h"
int main {
  sqrmatrix Q(5,5);

  Q.fill(1.6); // Assume that this fills the matrix with elements.
  std::cout << "Trace = " << Q.trace() << std::endl;
}
```

```
ejspence@mycomp ~> g++ matrix.cpp -c -o matrix.o
ejspence@mycomp ~> g++ Mysqrmatrix.cpp -c -o Mysqrmatrix.o
ejspence@mycomp ~> g++ Mysqrmatrix.o matrix.o -o Mysqrmatrix
ejspence@mycomp ~> ./Mysqrmatrix
Trace = 8
```

Polymorphism

Polymorphism refers to the use of a standard set of properties and behaviours so that objects can be used interchangably. This is implemented by the overloading and overriding of previously-existing functionality.

Why bother?

- Avoid the duplication of code.
- Re-using function names for the same functionality allows a common interface, and consistency of design.
- This simplifies and structures the code.

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Polymorphism in class inheritance

Polymorphism naturally arises in class inheritance, since the derived class shares commonality with the base class. The idea is as follows:

- Use the base class as a framework for the derived class' usage.
- Override base class functions with new implementations of the functions in the derived class definitions.
- Simplifies and structures the code.

However, there is a twist, because baseclass pointers can point to derivedclass objects (think about it):

- However, which overloaded function will it run, the baseclass function or the derivedclass function?
- If you want it to run the derivedclass function, define the baseclass version of the function with the virtual keyword.

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Poymorphic class inheritance, example

```
// matrix.h
#ifndef MATRIX_H
#define MATRIX_H
#include <iostream>
class matrix {
  protected:
    int rows, cols;
    double *elements;
  public:
    matrix(int r, int c);
    ~matrix();
    int get_rows();
    int get_cols();
    virtual void printstats() {
      std::cout << "rows: " <<
      rows << ", cols: " << cols
      << std::endl;
    }
};
#endif
```

```
// sqrmatrix.h
#ifndef SQRMATRIX_H
#define SQRMATRIX_H

#include "matrix.h"
class sqrmatrix : public matrix {
  public:
    sqrmatrix(int r,int c) : matrix(r,c) {
      if (r != c) {
        std::cerr<<"Not a square matrix.";
        exit(1);
      }};
    double trace();
    void printstats() {
      std::cout << "rows: " << rows <<
      ", cols: " << cols <<
      ", trace: " << trace() << std::endl;
    }
};
#endif
```

Class inheritance, example

```
// Mysqrmatrix.cpp
#include "sqrmatrix.h"

int main {
  matrix Q(2,3);
  sqrmatrix R(5,5);
  matrix *S = new sqrmatrix(6,6);

  Q.fill(1.6); R.fill(1.6); S -> fill(1.6);
  Q.printstats(); R.printstats(); S -> printstats();
}
```

```
ejspence@mycomp ~> make
ejspence@mycomp ~> ./Mysqrmatrix
rows: 2, cols: 3
rows: 5, cols: 5, trace: 8
rows: 6, cols: 6, trace: 9.6
```

If the matrix class printstats function was not virtual then "S -> printstats()" would print the matrix class version.

Assignment 2

On the class website is a file called Diffuse.cpp. This program evolves a 1D density field, and outputs the results to a text file. Assignment: put this code under version control with git and modify it into a new, modularized version:

- Create a class for the field being evolved that contains the functionality to allocate the field, perform a single time step, constructor, destructor, etc.
- Create a Makefile to compile this project.
- Create a module containing the constants for the problem.
- Create a module for the file output functions.

The orginal file should become just a 'driver', containing main, that solves the same problem as the original code. Please submit:

- all source, header and make files for the new program.
- the output of 'git log' for your code development. We expect to see several commits, and meaningful comments.

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