

Objects and classes

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Classes

1. Definition of object/class

An object is an entity that you can request to do certain things. These actions are the *methods*, and to make these possible the object probably stores data, the *members*.

When designing a class, first ask yourself: 'what functionality should the objects support'.

A class is a user-defined type; an object is an instance of that type.

2. Running example

We are going to build classes for points/lines/shapes in the plane.

```
class Point {  
    /* stuff */  
};  
int main () {  
    Point p; /* stuff */  
}
```

Exercise 1

Thought exercise: what are some of the actions that a point object should be capable of?

3. Object functionality

Small illustration: point objects.

Code:

```
Point p(1.,2.); // make point (1,2)
cout << "distance to origin "
      << p.distance_to_origin() <<
      '\n';
p.scaleby(2.);
cout << "distance to origin "
      << p.distance_to_origin() << '\n'
      << "and angle " << p.angle()
      << '\n';
```

Output

[object] functionality:

```
distance to origin
    2.23607
distance to origin
    4.47214
and angle 1.10715
```

Note the 'dot' notation.

Exercise 2

Thought exercise:

What data does the object need to store to be able to calculate angle and distance to the origin?

Is there more than one possibility?

4. The object workflow

- First define the class, with data and function members:

```
class MyObject {  
    // define class members  
    // define class methods  
};
```

(details later) typically before the *main*.

- You create specific objects with a declaration

```
MyObject  
    object1( /* .. */ ),  
    object2( /* .. */ );
```

- You let the objects do things:

```
object1.do_this();  
x = object2.do_that( /* ... */ );
```


5. Constructor and data initialization

Use the constructor to create an object of a class:
function with same name as the class.
(but no return type!)

Constructors are typically used to initialize data members.

```
class Point {                                Point v(1.,2.);
private: // members
    double x,y;
public: // methods
    Point( double in_x,
           double in_y ) {
        x = in_x; y = in_y;
    };
};
```

6. Private and public

Best practice we will use:

```
class MyClass {  
private:  
    // data members  
public:  
    // methods  
}
```

- Data is private: not visible outside of the objects.
- Methods are public: can be used in the code that uses objects.

Methods

7. Class methods

Let's define method *distance*.

Definition in the class:

```
class Point {  
    /* stuff */  
    double distance_to_origin() {  
        return sqrt(x*x + y*y); };  
}
```

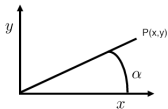
Use in the program:

```
Point pt(5,12);  
double  
    s = pt.distance_to_origin();
```

- Methods look like ordinary functions,
- except that they can use the data members of the class, for instance x, y ;
- Methods can only be used on an object with the 'dot' notation. They are not independently defined.

Exercise 3

Add a method *angle* to the *Point* class. How many parameters does it need?



Hint: use the function *atan* or *atan2*.

You can base this off the file `pointclass.cxx` in the repository

Exercise 4

Make a class *GridPoint* which can have only integer coordinates. Implement a function *manhattan_distance* which gives the distance to the origin counting how many steps horizontal plus vertical it takes to reach that point.

8. Food for thought: constructor vs data

The arguments of the constructor imply nothing about what data members are stored!

Example: create a vector from x,y cartesian coordinates, but store r, θ polar coordinates:

```
#include <cmath>
class Point {
private: // members
    double r, theta;
public: // methods
    Point( double x, double y ) {
        r = sqrt(x*x+y*y);
        theta = atan2(y/x);
    }
}
```

Note: no change to outward API.

Exercise 5

Discuss the pros and cons of this design:

```
class Point {  
private:  
    double x,y,r,theta;  
public:  
    Point(double xx,double yy) {  
        x = xx; y = yy;  
        r = // sqrt something  
        theta = // something trig  
    };  
    double angle() { return alpha; };  
};
```


9. Data access in methods

You can access data members of other objects of the same type:

```
class Point {  
private:  
    double x,y;  
public:  
    void flip() {  
        Point flipped;  
        flipped.x = y; flipped.y = x;  
        // more  
    };  
};
```

(Normally, data members should not be accessed directly from outside an object)

Exercise 6

Extend the `Point` class of the previous exercise with a method: `distance` that computes the distance between this point and another: if `p, q` are `Point` objects,

`p.distance(q)`

computes the distance between them.

Review quiz 1

T/F?

- A class is primarily determined by the data it stores.
`/poll "Class determined by its data" "T" "F"`
- A class is primarily determining by its methods.
`/poll "Class determined by its methods" "T" "F"`
- If you change the design of the class data, you need to change the constructor call.
`/poll "Change data, change constructor proto too" "T" "F"`

10. Methods that alter the object

For instance, you may want to scale a vector by some amount:

Code:

```
class Point {
    /* ... */
    void scaleby( double a ) {
        x *= a; y *= a; };
    /* ... */
};
/* ... */
Point p1(1.,2.);
cout << "p1 to origin "
      << p1.length() << '\n';
p1.scaleby(2.);
cout << "p1 to origin "
      << p1.length() << '\n';
```

Output

```
[geom] pointscaleby:

p1 to origin 2.23607
p1 to origin 4.47214
```

Data initialization

11. Member default values

Class members can have default values, just like ordinary variables:

```
class Point {  
private:  
    float x=3., y=.14;  
public:  
    // et cetera  
}
```

Each object will have its members initialized to these values.

12. Data initialization

The naive way:

```
class Point {  
private:  
    double x,y;  
public:  
    Point( double in_x,  
           double in_y ) {  
        x = in_x; y = in_y;  
    };  
};
```

The preferred way:

```
class Point {  
private:  
    double x,y;  
public:  
    Point( double userx,double  
           usery )  
        : x(userx),y(usery) {  
    }  
};
```

Interaction between objects

13. Methods that create a new object

Code:

```
class Point {  
    /* ... */  
    Point scale( double a ) {  
        auto scaledpoint =  
            Point( x*a, y*a );  
        return scaledpoint;  
    };  
    /* ... */  
    cout << "p1 to origin "  
        << p1.dist_to_origin() << '\n';  
    Point p2 = p1.scale(2.);  
    cout << "p2 to origin "  
        << p2.dist_to_origin() << '\n';  
};
```

Output

```
[geom] pointscale:  
  
p1 to origin 2.23607  
p2 to origin 4.47214
```

Note the 'anonymous object' in the assignment

14. Anonymous objects

Create a point by scaling another point:

```
new_point = old_point.scale(2.81);
```

Two ways of handling the `return` statement:

Naive:

```
Point Point::scale( double a )
{
    Point scaledpoint =
        Point( x*a, y*a );
    return scaledpoint;
};
```

Creates point, copies it to
new_point

Better:

```
Point Point::scale( double a )
{
    return Point( x*a, y*a );
};
```

Creates point, moves it directly
to *new_point*

'move semantics'

Optional exercise 7

Write a method *halfway* that, given two *Point* objects *p*, *q*, construct the *Point* halfway, that is, $(p + q)/2$:

```
Point p(1,2.2), q(3.4,5.6);  
Point h = p.halfway(q);
```

You can write this function directly, or you could write functions *Add* and *Scale* and combine these.

(Later you will learn about operator overloading.)

How would you print out a *Point* to make sure you compute the halfway point correctly?

15. Default constructor

Consider this code that looks like variable declaration, but for objects:

```
Point p1(1.5, 2.3);  
Point p2;  
p2 = p1.scaleby(3.1);
```

Compiling gives (g++; different for intel):

```
pointdefault.cxx: In function 'int main()':  
pointdefault.cxx:32:21: error: no matching function for call to  
      'Point::Point()'
```

16. Default constructor

The problem is with *p2*:

```
Point p1(1.5, 2.3);
```

```
Point p2;
```

- *p1* is created with the constructor;
- *p2* uses the default constructor:

```
Point() {};
```

- as soon as you define a constructor, the default constructor goes away;
- you need to redefine the default constructor:

```
Point() {};
```

```
Point( double x, double y )
```

```
    : x(x), y(y) {};
```

(but only if you really need it.)

Exercise 8

Make a class `LinearFunction` with a constructor:

```
LinearFunction( Point input_p1,Point input_p2 );
```

and a member function

```
float evaluate_at( float x );
```

which you can use as:

```
LinearFunction line(p1,p2);  
cout << "Value at 4.0: " << line.evaluate_at(4.0) << endl;
```

17. Classes for abstract objects

Objects can model fairly abstract things:

Code:

```
class Stream {
private:
    int last_result{0};
public:
    int next() {
        return last_result++; };
};

int main() {
    Stream ints;
    cout << "Next: "
         << ints.next() << '\n';
    cout << "Next: "
         << ints.next() << '\n';
    cout << "Next: "
         << ints.next() << '\n';
}
```

Output

```
[object] stream:
Next: 0
Next: 1
Next: 2
```

Project Exercise 9

Write a class `primegenerator` that contains:

- Methods `number_of_primes_found` and `nextprime`;
- Also write a function `isprime` that does not need to be in the class.

Your main program should look as follows:

```
cin >> nprimes;
primegenerator sequence;
while (sequence.number_of_primes_found()<nprimes) {
    int number = sequence.nextprime();
    cout << "Number " << number << " is prime" << '\n';
}
```


Turn it in!

- If you have compiled your program, do:
`coe_primes yourprogram.cc`
where 'yourprogram.cc' stands for the name of your source file.
- Is it reporting that your program is correct? If so, do:
`coe_primes -s yourprogram.cc`
where the `-s` flag stands for 'submit'.
- If you don't manage to get your code working correctly, you can submit as incomplete with
`coe_primes -i yourprogram.cc`
- If you don't understand what the script is telling you, try the debug flag:
`coe_primes -d yourprogram.cc`

Project Exercise 10

The Goldbach conjecture says that every even number, from 4 on, is the sum of two primes $p + q$. Write a program to test this for the even numbers up to a bound that you read in. Use the `primegenerator` class you developed in exercise 32.

This is a great exercise for a top-down approach!

1. Make an outer loop over the even numbers e .
2. For each e , generate all primes p .
3. From $p + q = e$, it follows that $q = e - p$ is prime: test if that q is prime.

For each even number e then print e, p, q , for instance:

The number 10 is 3+7

If multiple possibilities exist, only print the first one you find.

Turn it in!

- If you have compiled your program, do:

```
coe_goldbach yourprogram.cc
```

where 'yourprogram.cc' stands for the name of your source file.

- Is it reporting that your program is correct? If so, do:

```
coe_goldbach -s yourprogram.cc
```

where the `-s` flag stands for 'submit'.

- If you don't manage to get your code working correctly, you can submit as incomplete with

```
coe_goldbach -i yourprogram.cc
```

18. A Goldbach corollary

The Goldbach conjecture says that every even number $2n$ (starting at 4), is the sum of two primes $p + q$:

$$2n = p + q.$$

Equivalently, every number n is equidistant from two primes:

$$n = \frac{p + q}{2} \quad \text{or} \quad q - n = n - p.$$

In particular this holds for each prime number:

$$\forall r \text{ prime} \exists p, q \text{ prime} : r = (p + q)/2 \text{ is prime.}$$

Project Exercise 11

Write a program that tests this. You need at least one loop that tests all primes r ; for each r you then need to find the primes p, q that are equidistant to it. Do you use two generators for this, or is one enough? Do you need three, for p, q, r ?

For each r value, when the program finds the p, q values, print the p, q, r triple and move on to the next r .

Turn it in!

- If you have compiled your program, do:

```
coe_pqr yourprogram.cc
```

where 'yourprogram.cc' stands for the name of your source file.

- Is it reporting that your program is correct? If so, do:

```
coe_pqr -s yourprogram.cc
```

where the `-s` flag stands for 'submit'.

- If you don't manage to get your code working correctly, you can submit as incomplete with

```
coe_pqr -i yourprogram.cc
```

Advanced stuff about constructors

19. Advantage of initializer list

Allows for reuse of names:

Code:

```
class Point {
private:
    double x,y;
public:
    Point( double x,double y )
        : x(x),y(y) {
    }
    /* ... */
    Point p1(1.,2.);
    cout << "p1 = "
         << p1.getx() << "," <<
         p1.gety()
         << '\n';
```

Output

[geom] pointinityxy:

p1 = 1,2

20. Constructors and contained classes

Finally, if a class contains objects of another class,

```
class Inner {  
public:  
    Inner(int i) { /* ... */ }  
};  
class Outer {  
private:  
    Inner contained;  
public:  
};
```

21. When are contained objects created?

```
Outer( int n ) {  
    contained = Inner(n);  
};
```

1. This first calls the default constructor
2. then calls the *Inner(n)* constructor,
3. then copies the result over the *contained* member.

```
Outer( int n )  
    : contained(Inner(n)) {  
    /* ... */  
};
```

1. This creates the *Inner(n)* object,
2. placed it in the *contained* member,
3. does the rest of the constructor, if any.

22. Copy constructor

- Default defined copy and 'copy assignment' constructors:

```
some_object x(data);  
some_object y = x;  
some_object z(x);
```

- They copy an object:
 - simple data, including pointers
 - included objects recursively.
- You can redefine them as needed.

```
class has_int {  
private:  
    int mine{1};  
public:  
    has_int(int v) {  
        cout << "set: " << v <<  
            '\n';  
        mine = v; };  
    has_int( has_int &h ) {  
        auto v = h.mine;  
        cout << "copy: " << v <<  
            '\n';  
        mine = v; };  
    void printme() {  
        cout << "I have: " << mine  
            << '\n'; };  
};
```

23. Copy constructor in action

Code:

```
has_int an_int(5);  
has_int other_int(an_int);  
an_int.printme();  
other_int.printme();
```

Output

[object] copyscalar:

set: 5

copy: 5

I have: 5

I have: 5

24. Copying is recursive

Class with a vector:

```
class has_vector {  
private:  
    vector<int> myvector;  
public:  
    has_vector(int v) { myvector.push_back(v); };  
    void set(int v) { myvector.at(0) = v; };  
    void printme() { cout  
        << "I have: " << myvector.at(0) << '\n'; };  
};
```

Copying is recursive, so the copy has its own vector:

Code:

```
has_vector a_vector(5);  
has_vector other_vector(a_vector);  
a_vector.set(3);  
a_vector.printme();  
other_vector.printme();
```

Output

[object] copyvector:

I have: 3

I have: 5

25. Destructor

- Every class *myclass* has a *destructor* `~myclass` defined by default.

- The default destructor does nothing:

```
~myclass() {};
```

- A destructor is called when the object goes out of scope. Great way to prevent memory leaks: dynamic data can be released in the destructor. Also: closing files.

26. Destructor example

Just for tracing, constructor and destructor do `cout`:

```
class SomeObject {
public:
    SomeObject() {
        cout << "calling the constructor"
              << '\n';
    };
    ~SomeObject() {
        cout << "calling the destructor"
              << '\n';
    };
};
```

27. Destructor example

Destructor called implicitly:

Code:

```
cout << "Before the nested scope"
      << '\n';
{
    SomeObject obj;
    cout << "Inside the nested scope"
          << '\n';
}
cout << "After the nested scope"
      << '\n';
```

Output

[object] destructor:

```
Before the nested
  scope
calling the
  constructor
Inside the nested
  scope
calling the
  destructor
After the nested
  scope
```


Operator overloading

28. Operator overloading

Syntax:

```
<returntype> operator<op>( <argument> ) { <definition> }
```

For instance:

Code:

```
Point Point::operator*(double factor)
{
    return Point(factor*x,factor*y);
};
/* ... */
cout << "p1 to origin "
      << p1.dist_to_origin() << '\n';
Point scale2r = p1*2.;
cout << "scaled right: "
      << scale2r.dist_to_origin() <<
      '\n';
// ILLEGAL Point scale2l = 2.*p1;
```

Output

```
[geom] pointmult:
p1 to origin 2.23607
scaled right: 4.47214
```

Can also:

```
Point Point::operator*=(double factor);
```

Exercise 12: Adding points

Define addition on your point class.

Other object stuff

29. String an object

1. Define a function that yields a string representing the object, and
2. redefine the less-less operator to use this.

```
#include <sstream>  
using std::stringstream;
```

```
#include <string>  
using std::string;
```

30. Class declarations

Header file:

```
class something {  
private:  
    int i;  
public:  
    double dosomething( int i, char c );  
};
```

Implementation file:

```
double something::dosomething( int i, char c ) {  
    // do something with i,c  
};
```