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.

```
1 class Point {
2     /* stuff */
3 };
4 int main () {
5   Point p; /* stuff */
6 }
```

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:

```
1 // /functionality.cpp
2   Point p(1.,2.);
3   cout << "distance to origin "
4        << p.distance_to_origin()
5        << '\n';
6   p.scaleby(2.);
7   cout << "distance to origin "
8        << p.distance_to_origin()
9        << '\n'
10       << "and angle " << p.angle()
11       << '\n';
```

Output:

```
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. Construct an object

The declaration of an object `x` of class `Point`; the coordinates of the point are initially set to `1.5,2.5`.

```
Point x(1.5, 2.5);
```

```
1  class Point {
2  private: // data members
3    double x,y;
4  public: // function members
5    Point
6      (double x_in,double y_in){
7        x = x_in; y = y_in;
8    };
9    /* ... */
10 };
```

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

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.
- You can have multiple private/public sections, in any order.

Methods

7. Class methods

Definition and use of the *distance* function:

Code:

```
1 // /pointclass.cpp
2 class Point {
3 private:
4   float x,y;
5 public:
6   Point(float in_x,float in_y) {
7     x = in_x; y = in_y; };
8   float distance_to_origin() {
9     return sqrt( x*x + y*y );
10  };
11 };
12    /* ... */
13  Point p1(1.0,1.0);
14  float d = p1.distance_to_origin();
15  cout << "Distance to origin: "
16       << d << '\n';
```

Output:

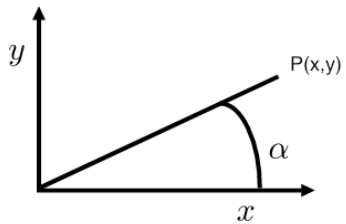
```
Distance to origin:
     1.41421
```

8. Class methods

- 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* for points that 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.

9. Food for thought: constructor vs data

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

Example: create a point in x,y Cartesian coordinates, but store $r,theta$ polar coordinates:

```
1 #include <cmath>
2 class Point {
3 private: // members
4   double r,theta;
5 public: // methods
6   Point( double x,double y ) {
7     r = sqrt(x*x+y*y);
8     theta = atan2(y/x);
9   }
```

Note: no change to outward API.

Exercise 5

Discuss the pros and cons of this design:

```
1  class Point {
2  private:
3    double x,y,r,theta;
4  public:
5    Point(double xx,double yy) {
6      x = xx; y = yy;
7      r = // sqrt something
8      theta = // something trig
9    };
10   double angle() { return alpha; };
11 };
```

10. Data access in methods

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

```
1  class Point {
2  private:
3    double x,y;
4  public:
5   void flip() {
6       Point flipped;
7       flipped.x = y; flipped.y = x;
8       // more
9    };
10 };
```

(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 determined 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"`

11. Methods that alter the object

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

Code:

```
1 // /pointscaleby.cpp
2 class Point {
3     /* ... */
4   void scaleby( double a ) {
5     x *= a; y *= a; };
6     /* ... */
7 };
8     /* ... */
9   Point p1(1.,2.);
10  cout << "p1 to origin "
11       << p1.length() << '\n';
12  p1.scaleby(2.);
13  cout << "p1 to origin "
14       << p1.length() << '\n';
```

Output:

```
p1 to origin 2.23607
p1 to origin 4.47214
```

Data initialization

12. 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.

13. Data initialization

The naive way:

```
1 class Point {
2 private:
3   double x,y;
4 public:
5   Point( double in_x,
6          double in_y ) {
7     x = in_x; y = in_y;
8   };
```

The preferred way:

```
1 // /pointinit.cpp
2 class Point {
3 private:
4   double x,y;
5 public:
6   Point( double in_x,
7          double in_y )
8     : x(in_x),y(in_y) {
9   }
```

Explanation later. It's technical.

Interaction between objects

14. Methods that create a new object

Code:

```
1 // /pointscale.cpp
2 class Point {
3     /* ... */
4   Point scale( double a ) {
5     auto scaledpoint =
6         Point( x*a, y*a );
7     return scaledpoint;
8   };
9     /* ... */
10  cout << "p1 to origin "
11       << p1.dist_to_origin()
12       << '\n';
13  Point p2 = p1.scale(2.);
14  cout << "p2 to origin "
15       << p2.dist_to_origin()
16       << '\n';
```

Output:

```
p1 to origin 2.23607
p2 to origin 4.47214
```

Note the 'anonymous *Point* object' in the *scale* method.

15. Anonymous objects

Create a point by scaling another point:

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

Two ways of handling the `return` statement:

Naive:

```
1 // /pointscale.cpp
2 Point Point::scale( double a )
      {
3   Point scaledpoint =
4     Point( x*a, y*a );
5   return scaledpoint;
6 };
```

Creates point, copies it to *new_point*

Better:

```
1 // /pointscale.cpp
2 Point Point::scale( double a )
      {
3   return Point( x*a, y*a );
4 };
```

Creates point, moves it directly to *new_point*

'move semantics' and 'copy elision':
compiler is pretty good at avoiding copies

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?

16. Constructor/destructor

Constructor: function that gets called when you create an object.

```
MyClass {
public:
  MyClass( /* args */ ) { /* construction */ }
  /* more */
};
```

If you don't define it, you get a default.

Destructor (rarely used):
function that gets called when the object goes away, for instance when you leave a scope.

17. Using the default constructor

No constructor explicitly defined;

You recognize the default constructor in the main by the fact that an object is defined without any parameters.

Code:

```
1  // /default.cpp
2  class IamOne {
3  private:
4    int i=1;
5  public:
6    void print() {
7      cout << i << '\n';
8    };
9  };
10     /* ... */
11   IamOne one;
12   one.print();
```

Output:

```
1
```

18. Default constructor

Refer to *Point* definition above.
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 an error (g++; different for intel):

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

19. Default constructor

The problem is with *p2*:

```
Point p1(1.5, 2.3);
Point p2;
```

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

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

- default constructor is there by default, unless you define another constructor.
- you can redefine the default constructor:

  ```
  // /pointdefault.cpp
    Point() {};
    Point( double x,double y )
      : x(x),y(y) {};
  ```

  (but often you can avoid needing 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;
```

20. Classes for abstract objects

Objects can model fairly abstract things:

Code:

```
1 // /stream.cpp
2 class Stream {
3 private:
4   int last_result{0};
5 public:
6   int next() {
7     return last_result++; };
8 };
9
10 int main() {
11   Stream ints;
12   cout << "Next: "
13        << ints.next() << '\n';
14   cout << "Next: "
15        << ints.next() << '\n';
16   cout << "Next: "
17        << ints.next() << '\n';
```

Output:

```
Next: 0
Next: 1
Next: 2
```

21. Preliminary to the following exercise

A prime number generator has:
an API of just one function: `nextprime`

To support this it needs to store:
an integer `last_prime_found`

Programming 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:

```
// /6primesbyclass.cpp
  cin >> nprimes;
  primegenerator sequence;
  while (sequence.number_of_primes_found()<nprimes) {
    int number = sequence.nextprime();
    cout << "Number " << number << " is prime" << '\n';
  }
```

Programming 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.

This is a great exercise for a top-down approach! First formulate the quantor structure of this statement, then translate that to code:

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.

22. 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:

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

In particular this holds for each prime number:

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

Programming 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.

Advanced stuff

23. Direct alteration of internals

Return a reference to a private member:

```
1 class Point {
2 private:
3   double x,y;
4 public:
5   double &x_component() { return x; };
6 };
7 int main() {
8   Point v;
9   v.x_component() = 3.1;
10 }
```

Only define this if you need to be able to alter the internal entity.

24. Reference to internals

Returning a reference saves you on copying.
Prevent unwanted changes by using a 'const reference'.

```
1  class Grid {
2  private:
3    vector<Point> thepoints;
4  public:
5    const vector<Point> &points() const {
6      return thepoints; };
7  };
8  int main() {
9    Grid grid;
10   cout << grid.points()[0];
11   // grid.points()[0] = whatever ILLEGAL
12 }
```

25. Access gone wrong

We make a class for points on the unit circle

```
1  // /unit.cpp
2  class UnitCirclePoint {
3  private:
4    float x,y;
5  public:
6    UnitCirclePoint(float x) {
7      setx(x); };
8    void setx(float newx) {
9      x = newx; y = sqrt(1-x*x);
10   };
```

You don't want to be able to change just one of x, y!
In general: enforce invariants on the members.

26. Const functions

A function can be marked as const:
it does not alter class data,
only changes are through return and parameters

27. 'this' pointer to the current object

Inside an object, a pointer to the object is available as `this`:

```
1 class Myclass {
2 private:
3   int myint;
4 public:
5   Myclass(int myint) {
6     this->myint = myint; // `this' redundant!
7   };
8 };
```

28. 'this' use

You don't often need the `this` pointer. Example: you need to call a function inside a method that needs the object as argument)

```
1 /* forward definition: */ class someclass;
2 void somefunction(const someclass &c) {
3   /* ... */ }
4 class someclass {
5 // method:
6 void somemethod() {
7   somefunction(*this);
8 };
```

(Rare use of dereference star)

Operator overloading

29. Operator overloading

Syntax:

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

For instance:

Code:

```
1 // /pointscale.cpp
2 Point Point::operator*(double f) {
3     return Point(f*x,f*y);
4 };
5     /* ... */
6   cout << "p1 to origin "
7        << p1.dist_to_origin() <<
       '\n';
8   Point scale2r = p1*2.;
9   cout << "scaled right: "
10       << scale2r.dist_to_origin()
       << '\n';
11  // ILLEGAL Point scale2l = 2.*p1;
```

Output:

```
p1 to origin 2.23607
scaled right: 4.47214
```

Can also:

Exercise 12

Revisit exercise 7 and replace the *add* and *scale* functions by overloaded operators.

Hint: for the *add* function you may need '`this`'.

30. Constructors and contained classes

Finally, if a class contains objects of another class,

```
1 class Inner {
2 public:
3   Inner(int i) { /* ... */ }
4 };
5 class Outer {
6 private:
7   Inner contained;
8 public:
9 };
```

31. 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.

32. 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.

```
1  // /copyscalar.cpp
2  class has_int {
3  private:
4    int mine{1};
5  public:
6    has_int(int v) {
7      cout << "set: " << v
8           << '\n';
9      mine = v; };
10   has_int( has_int &h ) {
11     auto v = h.mine;
12     cout << "copy: " << v
13          << '\n';
14     mine = v; };
15   void printme() {
16     cout << "I have: " << mine
17          << '\n'; };
18 };
```

33. Copy constructor in action

Code:

```
1 // /copyscalar.cpp
2   has_int an_int(5);
3   has_int other_int(an_int);
4   an_int.printme();
5   other_int.printme();
6   has_int yet_other = other_int;
7   yet_other.printme();
```

Output:

```
set: 5
copy: 5
I have: 5
I have: 5
copy: 5
I have: 5
```

34. Copying is recursive

Class with a vector:

```
1 // /copyvector.cpp
2 class has_vector {
3 private:
4   vector<int> myvector;
5 public:
6   has_vector(int v) { myvector.push_back(v); };
7   void set(int v) { myvector.at(0) = v; };
8   void printme() { cout
9       << "I have: " << myvector.at(0) << '\n'; };
10 };
```

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

Code:

```
1 // /copyvector.cpp
2   has_vector a_vector(5);
3   has_vector other_vector(a_vector);
4   a_vector.set(3);
5   a_vector.printme();
    other_vector.printme();
```

Output:

```
I have: 3
I have: 5
```

35. 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.

36. Destructor example

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

```
1  // /destructor.cpp
2  class SomeObject {
3  public:
4    SomeObject() {
5      cout << "calling the constructor"
6           << '\n';
7    };
8    ~SomeObject() {
9      cout << "calling the destructor"
10          << '\n';
11   };
12 };
```

37. Destructor example

Destructor called implicitly:

Code:

```
1 // /destructor.cpp
2   cout << "Before the nested scope"
3        << '\n';
4   {
5     SomeObject obj;
6     cout << "Inside the nested
       scope"
7          << '\n';
8   }
9   cout << "After the nested scope"
10       << '\n';
```

Output:

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

Headers

38. C headers plusplus

You know how to use `.h` files in C.

Classes in C++ need some extra syntax.

39. Data members in proto

Data members, even private ones, need to be in the header file:

```
1 class something {
2 private:
3   int localvar;
4 public:
5   // declaration:
6   double somedo(vector);
7 };
```

Implementation file:

```
1 // definition
2 double something::somedo(vector v) {
3     .... something with v ....
4     .... something with localvar ....
5 };
```

40. Static class members

A static member acts as if it's shared between all objects.
(Note: C++17 syntax)

Code:

```
1  // /static17.cpp
2  class myclass {
3  private:
4    static inline int count=0;
5  public:
6    myclass() { ++count; };
7    int create_count() {
8      return count; };
9  };
10     /* ... */
11   myclass obj1,obj2;
12   cout << "I have defined "
13        << obj1.create_count()
14        << " objects" << '\n';
```

Output:

```
I have defined 2 objects
```

41. Static class members, C++11 syntax

```
1 // /static.cpp
2 class myclass {
3 private:
4   static int count;
5 public:
6   myclass() { ++count; };
7   int create_count() { return count; };
8 };
9     /* ... */
10 // in main program
11 int myclass::count=0;
```