

Objects and classes

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Class basics

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:

```
1 // object/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);
```

```
class Point {  
private: // data members  
    double x,y;  
public: // function members  
    Point  
        (double x_in,double  
         y_in){  
        x = x_in; y = y_in;  
    };  
    /* ... */  
};
```

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 // geom/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:

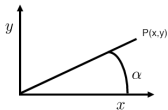
Distance to origin:
↪1.41421

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.cpp` 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, 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 theta; };  
};
```

10. 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.

Quiz 1

T/F?

- A class is primarily determined by the data it stores. Class determined by its data+
- A class is primarily determined by its methods. Class determined by its methods+
- If you change the design of the class data, you need to change the constructor call. Change data, change constructor proto too+

11. Methods that alter the object

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

Code:

```
1 // geom/pointscaleby.cpp
2 class Point {
3     /* ... */
4     void scaleby( float a ) {
5         x *= a; y *= a; };
6     /* ... */
7 };
8     /* ... */
9     Point p1(1.,2.);
10    cout << "p1 to origin "
11          << p1.distance_to_origin()
12          << '\n';
13    p1.scaleby(2.);
14    cout << "p1 to origin "
15          << p1.distance_to_origin()
16          << '\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:

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

The preferred way:

```
1 // geom/pointinit.cpp  
2 class Point {  
3 private:  
4     float x,y;  
5 public:  
6     Point( float in_x,  
7           float 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 // geom/pointscale.cpp
2 class Point {
3     /* ... */
4     Point scale( float a ) {
5         Point scaledpoint( x*a, y*a );
6         return scaledpoint;
7     };
8     /* ... */
9     cout << "p1 to origin "
10         << p1.dist_to_origin()
11         << '\n';
12     Point p2 = p1.scale(2.);
13     cout << "p2 to origin "
14         << p2.dist_to_origin()
15         << '\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 of the `scale` method:

Naive:

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

Creates point, copies it to *new_point*

Better:

```
1 // geom/pointscale.cpp
2 Point Point::scale( float 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 *translated* that, given a *Point* and two *floats*, returns the point translated by those amounts:

Code:

```
1 // geom/halfway.cpp
2 Point p1( 1.5,2.5 );
3 cout << p1.stringified() << '\n';
4 float x=.2, y=.3;
5 auto p2 = p1.translated(x,y);
6 cout << "by: " << x << ", " << y <<
    '\n';
7 cout << p2.stringified() << '\n';
```

Output:

```
(1.5,2.5)
by: 0.2,0.3
(1.7,2.8)
```

Optional exercise 8

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 // object/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:

```
1 // geom/pointdefault.cpp  
2 Point() {};  
3 Point( float x, float y )  
4   : x(x), y(y) {};
```

(but often you can avoid needing it)

Exercise 9

Make a class *LinearFunction* with constructor:

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

where the first stands for a line through the origin.
Implement again the *evaluate* function so that

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

Exercise 10

Can you extend the previous exercise to let

LinearFunction line(p1)

mean a line through the origin?

20. String an object, 1

Define a function that yields a string representing the object:

```
1 // geom/pointfunc.cpp
2 string as_string() {
3     stringstream ss;
4     ss << "(" << x << ", " << y << ")";
5     return ss.str();
6 };
```

```
1 // geom/pointfunc.cpp
2 string as_fmt_string() {
3     auto ss = format("{}{}", x, y);
4     return ss;
5 };
```

21. 'this' pointer to the current object

A pointer to the object itself is available as `this`. Variables of the current object can be accessed this way:

```
class MyClass {  
private:  
    int myint;  
public:  
    MyClass(int myint) {  
        this->myint = myint;    // option 1  
        (*this).myint = myint; // option 2  
    };  
};
```

22. '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)

```
/* forward definition: */ class someclass;
void somefunction(const someclass &c) {
    /* ... */ }
class someclass {
// method:
void somemethod() {
    somefunction(*this);
};
```

(Rare use of dereference star)

23. Classes for abstract objects

Objects can model fairly abstract things:

Code:

```
1 // object/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
```


24. 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 11

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:

```
1 // primes/6primesbyclass.cpp
2 cin >> nprimes;
3 primegenerator sequence;
4 while (sequence.number_of_primes_found()<nprimes) {
5     int number = sequence.nextprime();
6     cout << "Number " << number << " is prime" << '\n';
7 }
```

Programming Project Exercise 12

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.

First formulate the quantor structure of this statement, then translate that top-down to code, using the generator you developed above.

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.

25. 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:

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

We now have the statement that each prime number is the average of two other prime numbers.

Programming Project Exercise 13

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.

Use your prime generator. 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 .

Class inclusion: has-a

26. Has-a relationship

A class usually contains data members. These can be simple types or other classes. This allows you to reflect relations between things you are modeling.

```
class Person {  
    string name;  
    ....  
};  
class Course {  
private:  
    Person the_instructor;  
    int year;  
};`
```

This is called the has-a relation:

Course has-a Person

27. Literal and figurative has-a

A line segment has a starting point and an end point. *LineSegment* code design:

Store both points:

```
class Segment {  
private:  
    Point p_start,p_end;  
public:  
    Point end_point() {  
        return p_end; };  
}  
int main() {  
    Segment seg;  
    Point somepoint =  
        seg.end_point();  
}
```

or store one and derive the other:

```
class Segment {  
private:  
    Point starting_point;  
    float length,angle;  
public:  
    Point end_point() {  
        /* some computation  
        from the  
        starting point */ };  
}
```

Implementation vs API: implementation can be very different from user interface.

28. Constructors in has-a case

Class for a person:

```
class Person {  
private:  
    string name;  
public:  
    Person( string name ) {  
        /* ... */  
    };  
};
```

Class for a course, which contains a person:

```
class Course {  
private:  
    Person instructor;  
    int enrollment;  
public:  
    Course( string instr,int n  
        ) {  
        /* ??? */  
    };  
};
```

Declare a *Course* variable as: `Course("Eijkhout",65);`

29. Constructors in the has-a case

Possible constructor:

```
Course( string teachername, int nstudents ) {  
    instructor = Person(teachername);  
    enrollment = nstudents;  
};
```

Preferred:

```
Course( string teachername, int nstudents )  
    : instructor(Person(teachername)),  
      enrollment(nstudents) {  
};
```

30. Rectangle class

To implement a rectangle with sides parallel to the x/y axes, two designs are possible. For the function:

```
float Rectangle::area();
```

it is most convenient to store width and height.

For inclusion testing:

```
bool Rectangle::contains(Point);
```

it would be convenient to store bottomleft/topright points.

Exercise 14

Make a class *Rectangle* (sides parallel to axes) with a constructor:

```
Rectangle(Point botleft, float width, float height);
```

Can you figure out how to use member initializer lists for the constructors?

Implement methods:

```
float area(); float rightedge_x(); float topedge_y();
```

and write a main program to test these.

Exercise 15

Add a second constructor

```
Rectangle(Point botleft,Point topright);
```

Can you find a way to combine the constructors through constructor delegating? This can be done two ways!

Optional exercise 16

Make a copy of your solution of the previous exercise, and redesign your class so that it stores two *Point* objects. Your main program should not change.

Class inheritance: is-a

31. Hierarchical object relations

Hierarchical relations between classes:

- each object in class A is also in class B.
but not conversely
- Example: each manager is an employee
- Example: each square is a rectangle

32. Example of class hierarchy

- Class *Employee*:

```
class Employee {  
    private:  
        int number,salary;  
    /* ... */  
};
```

- class *Manager* is subclass of *Employee*
(every manager is an employee, with number and salary)
- Manager has extra field *n_minions*

How do we implement this?

33. Another example: multiple subclasses

- Example: both triangle and square are polygons.
- You can implement a method draw for both triangle/square
- ... or write it once for polygon, and then use that.

34. Terminology

Derived classes *inherit* data and methods from the base class: base class data and methods are accessible in objects of the derived class.

- Example: *Polygon* is the *base class*
Triangle is a *derived class*
Triangle has *corners* because Polygon has
- *Employee* is the *base class*.
Manager is a *derived class*
Manager has *employee_number* because Employee has

35. Base/Derived example

```
class Polygon {  
protected:  
    vector<Point> corners;  
public:  
    int ncorners() { return corners.size(); };  
};  
class Triangle : public Polygon {  
    /* constructor omitted */  
};  
int main () {  
    Triangle t;  
    cout << t.ncorners(); // prints 3, we hope
```

36. Examples for base and derived cases

General *FunctionInterpolator* class with method *value_at*. Derived classes:

- *LagrangeInterpolator* with *add_point_and_value*;
- *HermiteInterpolator* with *add_point_and_derivative*;
- *SplineInterpolator* with *set_degree*.

37. General case, special case

You can have classes where an object of one class is a special case of the other class. You declare that as

```
class General {  
protected: // note!  
    int g;  
public:  
    void general_method() {};  
};  
  
class Special : public General {  
public:  
    void special_method() { g = ... };  
};
```

38. Inheritance: derived classes

Derived class *Special* inherits methods and data from base class *General*:

```
int main() {  
    Special special_object;  
    special_object.general_method();  
    special_object.special_method();  
}
```

Members of the base class need to be **protected**, not **private**, to be inheritable.

39. Constructors

When you run the special case constructor, usually the general constructor needs to run too. Here we invoke it explicitly:

```
class General {  
public:  
    General( double x,double y ) {};  
};  
class Special : public General {  
public:  
    Special( double x ) : General(x,x+1) {};  
};
```


40. Access levels

Methods and data can be

- `private`, because they are only used internally;
- `public`, because they should be usable from outside a class object, for instance in the main program;
- `protected`, because they should be usable in derived classes.

Exercise 17

Take your code where a *Rectangle* was defined from one point, width, and height.

Make a class *Square* that inherits from *Rectangle*. It should have the function *area* defined, inherited from *Rectangle*.

First ask yourself: what should the constructor of a *Square* look like?

Exercise 18

Revisit the *LinearFunction* class. Add methods *slope* and *intercept*.

Now generalize *LinearFunction* to *StraightLine* class. These two are almost the same except for vertical lines. The *slope* and *intercept* do not apply to vertical lines, so design *StraightLine* so that it stores the defining points internally. Let *LinearFunction* inherit.

41. Overriding methods

- A derived class can inherit a method from the base class.
- A derived class can define a method that the base class does not have.
- A derived class can *override* a base class method:

```
class Base {  
public:  
    virtual f() { ... };  
};  
class Deriv : public Base {  
public:  
    virtual f() override { ... };  
};
```

42. More

- Multiple inheritance: an X is-a A, but also is-a B.
This mechanism is somewhat dangerous.
- Virtual base class: you don't actually define a function in the base class, you only say 'any derived class has to define this function'.

Advanced topics

Operator overloading

43. Better syntax

Operations that ‘feel like arithmetic’

So far:

```
Point p3 = p1.add(p2);  
Point p4 = p3.scale(2.5);
```

Improved:

```
Point p3 = p1+p2;  
Point p4 = p3*2.5;
```

This is possible because you can *overload* the *operators*. For instance,

```
1 // geom/overload.cpp  
2 Point operator*( float f ) {  
3     return Point( x*f,y*f );  
4 }
```


44. Operator overloading

Syntax:

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

For instance:

Code:

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

Output:

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

Exercise 19

Define the plus operator between *Point* objects. The declaration is:

```
Point operator+(Point q);
```

You can base this off the file `overload.cpp` in the repository

Exercise 20

Rewrite the *halfway* method of exercise 8 and replace the *add* and *scale* functions by overloaded operators.

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

45. Functor example

Simple example of overloading parentheses:

Code:

```
1 // object/functor.cpp
2 class IntPrintFunctor {
3 public:
4     void operator()(int x) {
5         cout << x << '\n';
6     }
7 };
8     /* ... */
9     IntPrintFunctor intprint;
10    intprint(5);
```

Output:

5

Exercise 21

Evaluate a linear function:

Using method:

```
1 // geom/overload.cpp
2 LinearFunction line(p1,p2);
3 cout << "Value at 4.0: "
4     << line.evaluate_at(4.0)
5     << '\n';
```

using operator:

```
1 // geom/overload.cpp
2 float y = line(4.0);
3 cout << y << '\n';
```

Write the appropriate overloaded operator.

You can base this off the file `overload.cpp` in the repository

The this pointer

46. 'this' pointer to the current object

A pointer to the object itself is available as `this`. Variables of the current object can be accessed this way:

```
class MyClass {  
private:  
    int myint;  
public:  
    MyClass(int myint) {  
        this->myint = myint;    // option 1  
        (*this).myint = myint; // option 2  
    };  
};
```

47. '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)

```
/* forward definition: */ class someclass;
void somefunction(const someclass &c) {
    /* ... */ }
class someclass {
// method:
void somemethod() {
    somefunction(*this);
};
```

(Rare use of dereference star)

Internal access

48. Direct alteration of internals

Return a reference to a private member:

```
class Point {  
private:  
    double x,y;  
public:  
    double &x_component() { return x; };  
};  
int main() {  
    Point v;  
    v.x_component() = 3.1;  
}
```

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

49. Reference to internals

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

```
class Grid {  
private:  
    vector<Point> thepoints;  
public:  
    const vector<Point> &points() const {  
        return thepoints; };  
};  
int main() {  
    Grid grid;  
    cout << grid.points()[0];  
    // grid.points()[0] = whatever ILLEGAL  
}
```

50. Access gone wrong

We make a class for points on the unit circle

```
1 // object/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.

51. Const functions

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

Headers

52. C headers plusplus

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

Classes in C++ need some extra syntax.

53. Data members in proto

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

```
class something {  
private:  
    int localvar;  
public:  
    // declaration:  
    double somedo(vector);  
};
```

Implementation file:

```
// definition  
double something::somedo(vector v) {  
    .... something with v ....  
    .... something with localvar ....  
};
```


54. Static class members

A static member acts as if it's shared between all objects.

(Note: C++17 syntax)

Code:

```
1 // link/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*

55. Static class members, C++11 syntax

```
1 // link/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;
```