Pointers to base class

One of the key features of derived classes is that a pointer to a derived class is type-compatible with a pointer to its base class. Polymorphism is the art of taking advantage of this simple but powerful and versatile feature that brings Object Oriented Methodologies to its full potential.

We are going to start by rewriting our program about the rectangle and the triangle of the previous section taking into consideration this pointer compatibility property:

```
// pointers to base class
#include <iostream>
using namespace std;

class Polygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
  };

class Rectangle: public Polygon {
  public:
    int area ()
      { return (width * height); }
  };

class Triangle: public Polygon {
  public:
    int area ()
      { return (width * height / 2); }
  };

int main () {
  Rectangle rect;
  Triangle trgl;
  Polygon * ppoly1 = &rect;
  Polygon * ppoly2 = &trgl;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  cout << rect.area() << endl;
  cout << trgl.area() << endl;
  return 0;
}
```

```
20
10
```

In function main, we create two pointers that point to objects of class Polygon (ppoly1 and ppoly2). Then we assign references to rect and trgl to these pointers, and because both are objects of classes derived from Polygon, both are valid assignment operations.

The only limitation in using *ppoly1 and *ppoly2 instead of rect and trgl is that both *ppoly1 and *ppoly2 are of type Polygon* and therefore we can only use these pointers to refer to the members that Rectangle and Triangle inherit from Polygon. For that reason

when we call the area() members at the end of the program we have had to use directly the objects rect and trgl instead of the pointers *ppoly1 and *ppoly2.

In order to use area() with the pointers to class Polygon, this member should also have been declared in the class Polygon, and not only in its derived classes, but the problem is that Rectangle and Triangle implement different versions of area, therefore we cannot implement it in the base class.

Virtual member functions

The word **polymorphism** means having many forms. Typically, polymorphism occurs when there is a hierarchy of classes and they are related by inheritance.

C++ polymorphism means that a call to a member function will cause a different function to be executed depending on the type of object that invokes the function.

A member of a class that can be redefined in its derived classes is known as a **virtual member**. In order to declare a member of a class as virtual, we must precede its declaration with the keyword virtual:

Consider the following example where a base class has been derived by other two classes:

```
// virtual members                          20
#include <iostream>                          10
using namespace std;                         0

class Polygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area ()
      { return (0); }
  };

class Rectangle: public Polygon {
  public:
    int area ()
      { return (width * height); }
  };

class Triangle: public Polygon {
  public:
    int area ()
      { return (width * height / 2); }
  };

int main () {
  Rectangle rect;
  Triangle trgl;
  Polygon poly;
  Polygon * ppoly1 = &rect;
  Polygon * ppoly2 = &trgl;
  Polygon * ppoly3 = &poly;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  ppoly3->set_values (4,5);
```

```
   cout << ppoly1->area() << endl;
   cout << ppoly2->area() << endl;
   cout << ppoly3->area() << endl;
   return 0;
}
```

Now the three classes (Polygon, Rectangle and Triangle) have all the same members: width, height, set_values() and area().

The member function area() has been declared as virtual in the base class because it is later redefined in each derived class. You can verify if you want that if you remove this virtual keyword from the declaration of area()within Polygon, and then you run the program the result will be 0 for the three polygons instead of 20, 10 and 0. That is because instead of calling the corresponding area() function for each object (Rectangle::area(), Triangle::area() and Polygon::area(), respectively), Polygon::area() will be called in all cases since the calls are via a pointer whose type is Polygon*.

Therefore, what the virtual keyword does is to allow a member of a derived class with the same name as one in the base class to be appropriately called from a pointer, and more precisely when the type of the pointer is a pointer to the base class but is pointing to an object of the derived class, as in the above example.

A class that declares or inherits a virtual function is called a *polymorphic class*.

Note that despite of its virtuality, we have also been able to declare an object of type Polygon and to call its own area() function, which always returns 0.

Abstract base classes

Abstract base classes are something very similar to our Polygon class of our previous example. The only difference is that in our previous example we have defined a valid area() function with a minimal functionality for objects that were of class Polygon (like the object poly), whereas in an abstract base classes we could leave that area()member function without implementation at all. This is done by appending =0 (equal to zero) to the function declaration.

An abstract base Polygon class could look like this:

```
// abstract class Polygon
class Polygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area () =0;
};
```

Notice how we appended =0 to virtual int area () instead of specifying an implementation for the function. This type of function is called a **pure virtual function**, and all classes that contain at least one pure virtual function are **abstract base classes**.

The main difference between an abstract base class and a regular polymorphic class is that

because <mark>in abstract base classes at least one of its members lacks implementation we cannot create instances (objects) of it.</mark>

But a class that cannot instantiate objects is not totally useless. We can create pointers to it and take advantage of all its polymorphic abilities. Therefore a declaration like:

```
Polygon poly;
```

would not be valid for the abstract base class we have just declared, because tries to instantiate an object. Nevertheless, the following pointers:

```
1 Polygon * ppoly1;
2 Polygon * ppoly2;
```

would be perfectly valid.

This is so for as long as Polygon includes a pure virtual function and therefore it's an abstract base class. However, pointers to this abstract base class can be used to point to objects of derived classes.

Here you have the complete example:

```
// abstract base class                          20
#include <iostream>                             10
using namespace std;

class Polygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area (void) =0;
  };

class Rectangle: public Polygon {
  public:
    int area (void)
      { return (width * height); }
  };

class Triangle: public Polygon {
  public:
    int area (void)
      { return (width * height / 2); }
  };

int main () {
  Rectangle rect;
  Triangle trgl;
  Polygon * ppoly1 = &rect;
  Polygon * ppoly2 = &trgl;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  cout << ppoly1->area() << endl;
```

```
  cout << ppoly2->area() << endl;
  return 0;
}
```

If you review the program you will notice that we refer to objects of different but related classes using a unique type of pointer (Polygon*). This can be tremendously useful. For example, now we can create a function member of the abstract base class Polygon that is able to print on screen the result of the area() function even though Polygon itself has no implementation for this function:

```
// pure virtual members can be called
// from the abstract base class
#include <iostream>
using namespace std;

class Polygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area (void) =0;
    void printarea (void)
      { cout << this->area() << endl; }
  };

class Rectangle: public Polygon {
  public:
    int area (void)
      { return (width * height); }
  };

class Triangle: public Polygon {
  public:
    int area (void)
      { return (width * height / 2); }
  };

int main () {
  Rectangle rect;
  Triangle trgl;
  Polygon * ppoly1 = &rect;
  Polygon * ppoly2 = &trgl;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  ppoly1->printarea();
  ppoly2->printarea();
  return 0;
}
```
```
20
10
```

Virtual members and abstract classes grant C++ the polymorphic characteristics that make object-oriented programming such a useful instrument in big projects. Of course, we have seen very simple uses of these features, but these features can be applied to arrays of objects or dynamically allocated objects.

Let's end with the same example again, but this time with objects that are dynamically allocated:

```cpp
// dynamic allocation and polymorphism          20
#include <iostream>                              10
using namespace std;

class Polygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area (void) =0;
    void printarea (void)
      { cout << this->area() << endl; }
  };

class Rectangle: public Polygon {
  public:
    int area (void)
      { return (width * height); }
  };

class Triangle: public Polygon {
  public:
    int area (void)
      { return (width * height / 2); }
  };

int main () {
  Polygon * ppoly1 = new Rectangle;
  Polygon * ppoly2 = new Triangle;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  ppoly1->printarea();
  ppoly2->printarea();
  delete ppoly1;
  delete ppoly2;
  return 0;
}
```

Notice that the ppoly pointers:

```cpp
Polygon * ppoly1 = new Rectangle;

Polygon * ppoly2 = new Triangle;
```

are declared being of type pointer to Polygon but the objects dynamically allocated have been declared having the derived class type directly.

Home work:

1. Differentiate between the base class pointer and derived class pointer with respect to their scope of functionalities.

2. What are the benefits of making a base class member virtual? Differentiate between virtual member function and pure virtual function.