# 3.2 Inheritance

Sam has just finished a `Position` class to represent where a drawn object resides on the screen for his Skeet game. This class has a collection of getters and setters allowing the client to move objects as the game is played. Next Sam is going to write a class to represent the `Bird`. This means that all the getters and setters for the `Position` class needs to be reproduced in the `Bird` class. If only there was a better way…

### Objectives

By the end of this chapter, you will be able to:

- Define inheritance and explain when it would be useful
- Define a class that inherits off of a base class

### Prerequisites

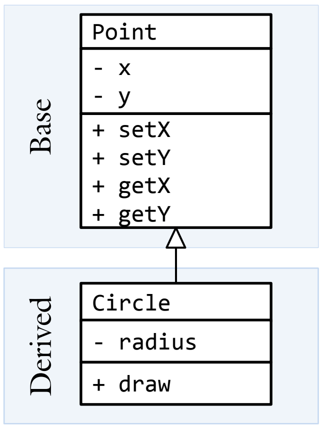
Before reading this chapter, please make sure you are able to:

- Define a class matching a UML class diagram (Chapter 2.0, 3.0)
- Draw a UML class diagram representing an "is-a" relation (Chapter 3.0)
- Design a program with UML class diagrams utilizing "is-a" relations (Chapter 3.0)

## What is inheritance and why you should care

Inheritance is the process of building one class off of another. It represents the simplest form of "is-a" object relationships. There are two classes involved with inheritance: the base class and the derived class. The **base class**, also known as the parent class, is the class we start with. Any class can be a base class. The **derived class**, also known as the child class, is the class that is built from the base class. Inheritance occurs when the derrived class inherits all the properties and methods from the base class.

Consider a class that stores a `Point`. In this case, `Point` represents the base class because another class will be built from it. Now we will build a derived class called `Circle` that will inherit the `Point` properties and methods. In addition to `Point`'s properites, `Circle` will also have a `radius`. In other words, the `Circle` is "all that and more" to the `Point`.



Inheritance helps us leverage what is common (or invariant) between related classes with zero duplicate code. There is no need to write another version of `Point`'s getters and setters with inheritance, `Circle` simply inherits them from the base class.

## Syntax of inheritance

When specifying inheritance relations, all the syntax exists in the base class. C++ does not allow the programmer to indicate inheritance from the standpoint of the base class. If, for example, we wish to inherit `Circle` from `Point`, then the `Point` definition is completely standard:

```
class Point                           // no indication of inheritance in base class
{
   public:
      Point() : x(0), y(0)   {                        }
      Point(int x, int y)    { setX(   x); setY(   y); }
      Point(const Point &pt) { setX(pt.x); setY(pt.y); }
      int  getX() const      { return x;              }
      int  getY() const      { return y;              }
      void setX(int x)       { this->x = x;           }
      void setY(int y)       { this->y = y;           }
      friend ostream & operator << (ostream & out, const Point & pt);
      friend istream & operator >> (istream & in ,       Point & pt);
   private:
      int x;
      int y;
};
```

To indicate a derived class is inherited from a base class, it is necessary to put an inheritance indicator in the derived class definition. Consider the `Circle` class:

Here we indicate that **`Circle`** is a derived class from **`Point`**. We inherit all that **`Point`** has, including the member variables and methods.

```
class Circle : public Point           // this indicates we inherit off of Point
{
   public:
      Circle()                     : Point(), radius(0) {                   }
      Circle(int r, int x, int y) : Point(x, y)        { setRadius(r);      }
      Circle(const Circle & circle);
      int  getRadius()                                  { return radius;     }
      void setRadius(int r)                             { this->radius = r;  }
      friend ostream & operator << (ostream & out, const Circle & c);
      friend istream & operator >> (istream & in ,       Circle & c);
   private:
      int radius;
};
```

The `Circle` class definition begins by inheriting all that `Point` has with the "` : public Point`" part of the class definition. Notice how a circle, in this case, is just a point with a radius. This is usually how class relationships work; the derived class will have everything the base class does, and then some.

```
{
   Circle c(100, 10, 10);             // this constructor also initializes x and y
   c.setX(20);                        // the member functions from Point are
   c.setY(20);                        //    inherited in Circle
   c.setRadius(5);                    // we also get our own member functions

   cout << c << endl;                 // since the RHS of << is a Circle, we call
}                                     //    Circle's method instead of Point's
```

## What is inherited?

In a derived class, all the member variables and all the member functions of the base class are made a part of (or inherited from) the new class. There are three exceptions to this rule: constructors, destructors, and the assignment operator. They are not inherited.

### Constructors and destructors are not inherited

Consider the following code:

```
class Base
{
   public:
      Base()                              // default constructor
      {
         pBase = new int(0);              // allocate an int and assign to 0
         cout << "Base constructor\n";    // display a message
      }
     ~Base()                              // destructor
      {
         delete pBase;                    // free the allocated memory
         cout << "Base destructor\n";     // display a message
      }
   private:
      int * pBase;
};
```

```
class Derived : public Base
{
   public:
      Derived()                           // default constructor. Note that
      {                                   //      Base() gets called
         pDerived = new float(0.0);       // allocate a float to 0.0
         cout << "Derived constructor\n"; // display a message
      }
     ~Derived()                           // destructor. Note that
      {                                   //     ~Base gets called
         delete pDerived;                 // free the allocated memory
         cout << "Derived destructor\n";  // display a message
      }
   private:
      float * pDerived;
};
```

Here we have a simple base class and a derived class. Note that when we instantiate a `Derived` object, the base class constructor is not inherited but it is called.

```
int main()
{
   Derived d;
   return 0;
}
```

The output is:

```
Base constructor
Derived constructor
Derived destructor
Base destructor
```

The complete solution is available at 3-2-constructors.html or: `/home/cs165/examples/3-2-constructors.cpp`.

## Assignment operators are not inherited

Assignment operators are also not inherited. This means that we commonly need to define assignment operators for all the derived classes if one is defined for the base class. Consider the following code:

```
class Base
{
   public:
      Base()  { pBase = new int(0); }            // constructor allocates
     ~Base()  { delete pBase;       }            // destructor frees
      Base & operator = (const Base & rhs)       // assignment operator will
      {                                          //    copy the values (not the
         *pBase = *rhs.pBase;                    //    addresses) of pBase
         cout << "Base assignment operator\n";   // display a message
         return *this;
      }
   private:
      int * pBase;
};
```

```
class Derived : public Base
{
   public:
      Derived() { pDerived = new float(0.0); }   // constructor allocates
     ~Derived() { delete pDerived;           }   // destructor frees
   private:
      float * pDerived;
};
```

Note that there is no assignment operator defined for `Derived`. The compiler will generate a new one for us, one that will copy the member variables (addresses in this case! This will be a bug due to the pointers!) and will call the base-class assignment operator:

```
/**************************** default assignment operator ***************************/
Derived & operator = (const Derived & rhs)       // default assignment operator
{
   Base::operator=(rhs);                         // calls the base-class assignment
   pDerived = rhs.pDerived;                      // ERROR: this copies the member
   return *this;                                 //    variables which is a pointer!
}                                                //    We should copy the data instead!
```

Now if we define our own assignment operator, the assignment operator in `Base` is not called!

```
/***************** assignment operator failing to call the base class ****************/
Derived & operator = (const Derived & rhs)       // our own assignment operator
{
                                                 // ERROR: base-class = not called
   *pDerived = *rhs.pDerived;                    // we need to copy the data, not the
   return *this;                                 //    pointers
}
```

Note that `Base`'s assignment operator is not called! We therefore need to call it explicitly. The correct implementation for the assignment operator in the `Derived` class is:

```
/************************* the correct assignment operator *************************/
Derived & operator = (const Derived & rhs)
{
   Base::operator=(rhs);                         // call the base-class assignment
   *pDerived = *rhs.pDerived;                    // copy the data, not the addresses
   return *this;                                 // return *this
}
```

The complete solution is available at 3-2-assignment.html or: `/home/cs165/examples/3-2-assignment.cpp`.

## Constructors

Thus far the syntax of inheritance seems straight-forward. The only thing that is necessary to derive off of a base-class is to include the " `: public BaseClass`" indication in the class definition.

To illustrate this point, consider the following example:

```
class Base
{
   public:
      Base() : value(0)           {                    } // default constructor
      Base(int value) : value(value) {                 } // non-default constructor
      Base(const Base & rhs)      { value = rhs.value; } // copy constructor
      int get() const             { return value;      }
   private:
      int value;
};
```

```
class Derived : public Base                    // inherit Base::getBase() and value
{
   public:
      Derived()                                    { }   // Base::Base() gets called
      Derived(int value) : Base(value)             { }   // call Base::Base(int)
      Derived(const Derived & rhs);
};
```

We can explicitly call any version of the base classes' constructor we choose. If none is explicitly called, the default will be called for us. Otherwise, we can specify the version we wish in the initialization section.

Note that the only place we can call the base classes' constructor is from the initialization section. If we attempt to do so from the body of the constructor, we will get unexpected results.

```
Derived :: Derived(const derived & rhs)
{
   Base(rhs.get());                       // ERROR: we will create a new Base object
}                                         //        and this->value is not set!
```

In this example, we create a new instance of `Base` in the body of the copy constructor. This object never gets assigned to a variable so it is called an "anonymous object."

**Sue's Tips**

It is a good idea to explicitly call the base classes's constructor from each constructor in the derived class. This makes the intention of the programmer clear.

## Redefining

A derived class can add additional methods and variables to those provided by the base class. It is also possible for the derived class to define a method with the same signature as that of the base class. This is called "redefining." Consider the following example:

```
class Point
   public:
      void display() const { cout << '(' << x << ", " << y << ")\n"; }
... code removed for brevity ...
   private:
      int x;
      int y;
};
```

```
class Circle : public Point
   public:
      void display() const
      {
         cout << '(' << getX() << ", " << getY() << " r=" << radius << ")\n"; }
      }
... code removed for brevity ...
   private:
      int radius;
};
```

In this example, we have two functions (`Circle::display()` and `Point::display()`) with the same signature. When we call `display()` from a `Circle` object, we get the `Circle` version.

```
{
   Point pt;
   pt.display();                        // call Point::display()

   Circle c;
   c.display();                         // since display() is redefined in Circle, we
}                                       //    call Circle::display() here
```

**Sam's Corner**

Just because we re-defined a method in a derived class does not mean that we will never have access to it again. With the scope resolution operator (`::`), we can specify which version of a given redefined class we want to call. Back to our `Point` and `Circle` example from above:

```
{
   Point pt(4, 7);
   pt.display();                     // (4, 7)

   Circle c(10, 3, 8);
   c.display();                      // (10, 3 r=8)

   c.Point::display();               // (10, 3)
}
```

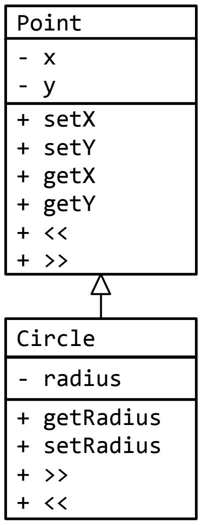
## Example 3.2 – Circle

**Demo**

This example will demonstrate how to do simple inheritance with a single base class and a single derived class.

**Problem**

Write a class called `Circle` which inherits off of `Point`. Both `Circle` and `Point` implement the usual getters and setters as well as the insertion and extraction operators.



**Solution**

The class definition to `Point` and `Circle` is presented earlier in the chapter. The following functions and methods illustrate how much access each has to private member variables.

```
ostream & operator << (ostream & out, const Circle & circle)
{
   out << '('    << circle.getX()    // need to use getters here.  The member
       << ", "   << circle.getY()    //   variables are not accessible.
       << ", r=" << circle.radius    // we do have access to the radius private
       << ')';
   return out;
}
```

```
istream & operator >> (istream & in, Circle & circle)
{
   int x;                            // we don't have access to Point::x so
   int y;                            //    we need to read into variables

   // read data from in
   in >> x >> y >> circle.radius;    // since radius is part of Circle and >>
                                     //    is a friend, we use circle.radius
   // now set the values
   circle.setX(x);                   // only the public Point::setX() and
   circle.setY(y);                   //    Point::setY() is visible to Circle
   return in;
}
```

**See Also**

The complete solution is available at 3-2-circle.html or:

```
/home/cs165/examples/3-2-circle.cpp
```

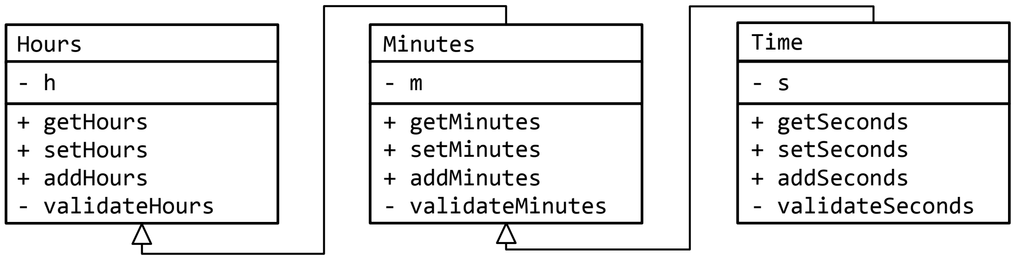
## Example 3.2 – Time

Demo

This example will demonstrate how to accomplish multiple levels of inheritance. In other words, a derived class can also serve as a base class.

Problem

Write a class called `Hours`, one called `Minutes` which inherits off of `Hours`, and one called `Time` which adds seconds to `Minutes`.



Solution

The `Hours` class is the base class so it has no indications of inheritance:

```
class Hours
{
public:
   Hours()       : h(12)              {                                   }
   Hours(int h) : h(0)                { setHours(h);                      }
   Hours(const Hours & hours)         { setHours(hours.getHours());       }
   int  getHours() const              { return h;                         }
   void setHours(int h)               { if (validateHours(h)) this->h = h;    }
   void addHours(int h);
private:
   bool validateHours(int h) const    { return (0 <= h && h <= 23);       }
   int h;
};
```

The `Minutes` class inherits from `Hours`. Notice how we must call our parent's constructor in the initialization section or `Hours::h` will not get set:

```
class Minutes : public Hours
{
public:
   Minutes()      : m(0), Hours()     {                                   }
```
*... code removed for brevity ...*
```
private:
   int m;
};
```

Finally, the `Time` class inherits from `Minutes` which, in turn, inherits off of `Hours`.

```
class Time : public Minutes
{
public:
   Time()      : s(0), Minutes()      {                                   }
```
*... code removed for brevity ...*
```
private:
   int s;
};
```

See Also

The complete solution is available at 3-2-time.html or:

```
/home/cs165/examples/3-2-time.cpp
```

Unit 3

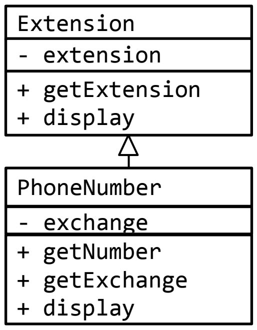
## Example 3.2 – PhoneNumber

Demo

This example will demonstrate multiple levels of inheritance as well as redefining member functions.

Problem

Write a class called `PhoneNumber` which inherits from `Extension`.



Solution

The class definition of `PhoneNumber` is the following:

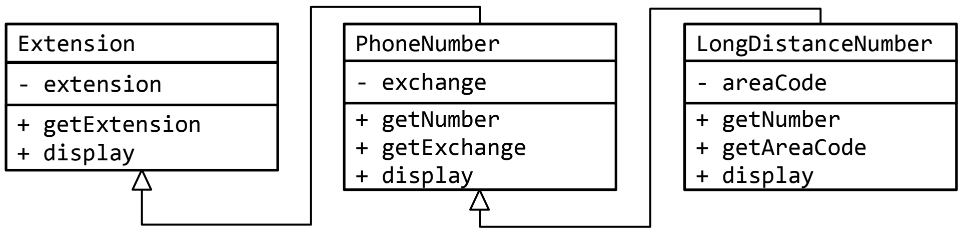
```
class PhoneNumber : public Extension
{
   public:
      PhoneNumber(int exchange, int ext) : Extension(ext),
                                           exchange(exchange) {             }
      int getNumber()   const { return exchange * 10000 + getExtension();  }
      int getExchange() const { return exchange;                            }
      void display()    const { cout << exchange << '-' << getExtension(); }
   private:
      int exchange;
};
```

Notice how the constructor for `PhoneNumber` calls `Extension`'s constructor in the initialization section. Notice also how `PhoneNumber::display()` redefines `Extension::display()`.

```
   cout << "phoneNumber.display(): ";
   phoneNumber.display();                        // redefined from Extension
   cout << endl;
   cout << "phoneNumber.Extension::display(): ";
   phoneNumber.Extension::display();             // call Extension's version
   cout << endl;
```

Challenge

As a challenge, see if you can create a new class called `LongDistanceNumber` which adds the area code to `PhoneNumber`.



See Also

The complete solution is available at [3-2-phoneNumber.html](3-2-phoneNumber.html) or:

```
/home/cs165/examples/3-2-phoneNumber.cpp
```

## Problem 1

Consider the following class:

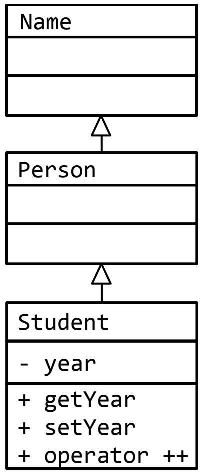
```
class Name
{
   public:
      Name();
      Name(const Name & name);
      void setFirst( const string & s);
      void setMiddle(const string & s);
      void setLast(  const string & s);
      const string & getFirst()  const;
      const string & getMiddle() const;
      const string & getLast()   const;
   private:
      string first;
      string middle;
      string last;
};
```

Derive a class `Person` that adds gender to `Name`.

*Please see page* 222 *for a hint.*

## Problem 2

Given the above defined `Name` and `Person` class, define a class called `Student` adding academic year:



*Please see page* 228 *for a hint.*