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INHERITANCE

By the help of inheritance we can create more "special" classes from general classes

Inheritance is one of the ways in object-oriented programming that makes **reusability** possible.

Reusability

Reusability means taking an existing class and using it in a new program.

By reusing classes, you can reduce the time and effort needed to develop a program, and make software more robust and reliable.

History:

The earliest approach to reusability was simply rewriting existing code.

You have some code that works in an old program, but doesn't do quite what you want in a new project.

You paste the old code into your new source file, make a few modifications to adapt it to the new environment. Now you must debug the code all over again.

Often you're sorry you didn't just write new code.

To reduce the bugs introduced by modification of code, programmers attempted to create self-sufficient reusable program elements in the form of functions.

Function libraries were a step in the right direction, but, functions don't model the real world very well, because they don't include important data.

Reusability in Object-Oriented Programming:

A powerful new approach to reusability appears in object-oriented programming is the class library.

Because a class more closely models a real-world entity, it needs less modification than functions do to adapt it to a new situation.

Once a class has been created and tested it can be used in different ways again.

1. The simplest way to reuse a class is to just use an object of that class directly. The standard library of the C++ has many useful classes and objects.

For example, cin and cout are such built in objects. Another useful class is string , which is used very often in C++ programs.

2. The second way to reuse a class is to place an object (or a pointer) of that class inside a new class. We call this "creating a member object." (Has a relation)

Your new class can be made up of any number and type of other objects, in any combination that you need to achieve the functionality desired in your new class.

Because you are composing a new class from existing classes, this concept is called *composition* (or more generally, *aggregation*). Composition is often referred to as a "has-a" relationship. See the example e410.cpp

3. The third way to reuse a class is **inheritance**, which is described next. Inheritance is referred to as a "*is a*" or "*a kind of*" relationship.

An Example for Using Classes of the Standard Library: Strings

While a character array can be fairly useful, it is quite limited. It's simply a group of characters in memory, but if you want to do anything with it you must manage all the little details. For example memory allocation.

The Standard C++ **string** class is designed to take care of (and hide) all the low-level manipulations of character arrays that were previously required of the C programmer.

To use **string**s you include the C++ header file **<string>**. Because of operator overloading, the syntax for using **string**s is quite intuitive (natural).

```
#include <string>                  // Standard header file of C++ (inc. string class)
#include <iostream>
using namespace std;
int main() {
  string s1, s2;                   // Empty strings
  string s3 = "Hello, World.";     // Initialized
  string s4("I am");               // Also initialized
  s2 = "Today";                    // Assigning to a string
  s1 = s3 + " " + s4;              // Combining strings
  s1 += " 20 ";                    // Appending to a string
  cout << s1 + s2 + "!" << endl;
  return 0;
}
```

See Example: e61.cpp

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Explanation of the program:

The first two **string**s, **s1** and **s2**, start out empty, while **s3** and **s4** show two equivalent ways to initialize **string** objects from character arrays (you can just as easily initialize **string** objects from other **string** objects).

You can assign to any **string** object using the assignment operator '='.
This replaces the previous contents of the string with whatever is on the right-hand side, and you don't have to worry about what happens to the previous contents – that's handled automatically for you.

To combine **string**s you simply use the '**+**' operator, which also allows you to combine character arrays with **string**s.
If you want to append either a **string** or a character array to another **string**, you can use the operator '**+=**'.

Finally, note that **cout** already knows what to do with **string**s, so you can just send a **string** (or an expression that produces a **string**, which happens with **s1 + s2 + "!"** directly to **cout** in order to print it.

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Inheritance

OOP provides a way to modify a class without changing its code.

This is achieved by using **inheritance** to derive a new class from the old one.

The old class (called the *base class*) is not modified, but the new class (the *derived class*) can use all the features of the old one and additional features of its own.

A "*Kind of*" or "*is a*" Relationship

We know that PCs, Macintoshes and Cray are kinds of computers;

a worker, a section manager and general manager are kinds of employee.

If there is a "**kind of**" relation between two objects then we can derive one from other using the inheritance.

Generalization - Specialization

By the help of inheritance we can create more "special" classes from general classes.
Employee → worker → manager (Manager is a worker, worker is an employee.)
Vehicle → air vehicle → helicopter (Vehicle is general, helicopter is special)
Special classes may have more members (data and methods) than general classes.

Inheritance Syntax

The simplest example of inheritance requires two classes: **a base class** and **a derived class**.

The base class does not need any special syntax. The derived class, on the other hand, must indicate that it's derived from the base class.

Example: Modeling teachers and the principal (director) in a school.

First, assume that we have a class to define teachers, then we can use this class to model the principal. Because the principal <u>is a</u> teacher.

```
class Teacher{                       // Base class
  protected:                         // means public for derived class members
     string name;
     int age, numOfStudents;
   public:
     void setName (const string & new_name){ name = new_name; }
};

class Principal : public Teacher{    // Derived class
    string school_name;              // Additional members
    int numOfTeachers;
  public:
    void setSchool(const string & s_name){ school_name = s_name; }
};
```

Principal is a special type of Teacher. It has more members.

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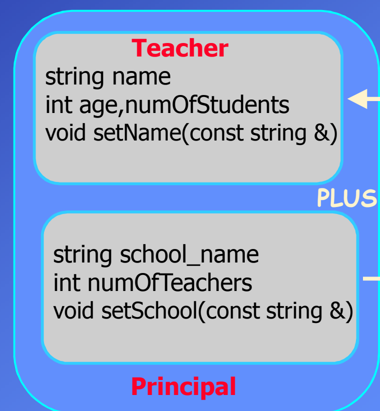
```
int main()
{
  Teacher teacher1;
  Principal principal1;
  principal1.setName("Principal 1");
  teacher1.setName("Teacher 1");
  principal1.setSchool("Elementary School");
  return 0;
}
```



Objects in Memory:

Object of Teacher: name, age, numOfStudents

Object of Principal: name, age, numOfStudents, school_name, numOfTeachers

setName setSchool

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An object of a derived class *inherits all the member data and functions of the base class*.

Thus the child (derived) object principal1 contains not only data items school_name, numOfTeachers, but data items name; age,numOfStudents as well.

The principal1 object can also access, in addition to its own member function setSchool(),
the member function that is inherited from Parent (Base), which is setName().

Private members of the base class are inherited by the derived class, but they are not visible in the derived class.

The members of the derived class can not access private members of the base class directly.

The derived class may access them only through the public interface of the base class.

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Redefining Members (Name Hiding)

Some members (data or function) of the base class may not suitable for the derived class. These members should be redefined in the derived class.

For example, assume that the Teacher class has a print function that prints properties of teachers on the screen.

But this function is not sufficient for the class **Principal**, because principals have more properties to be printed. So the print function must be redefined.

```
class Teacher{                          // Base class
  protected:
    string name;
    int age, numOfStudents;
  public:
    void setName (const string & new_name) { name = new_name; }
    void print() const;
};

void Teacher::print() const             // Print method of Teacher class
{
   cout << "Name: " << name<< "  Age: " << age << endl;
   cout << "Number of Students: " << numOfStudents << endl;
}
```



```
class Principal : public Teacher{                       // Derived class
     string school_name;
     int numOfTeachers;
   public:
     void setSchool(const string & s_name) { school_name = s_name; }
     void print() const;                                // Print function of Principal class
};

void Principal::print() const                           // Print method of principal class
{
    cout << "Name: " << name << "  Age: " << age << endl;
    cout << "Number of Students: " << numOfStudents << endl;
    cout << "Name of the school: " <<  school_name << endl;
}
```

print() function of the Principal class **overrides** (hides) the print() function of the Teacher class.

Now the Principal class has two print() functions. The members of the base class can be accessed by using the scope operator (::).

```
void Principal::print() const              // Print method of Principal class
{
   Teacher::print();                       // invokes the print function of the teacher class
   cout << "Name of the school: " << school_name << endl;
}
```

See Example: e62.cpp

Examples:

```
class A{
 public:
   int ia1,ia2;
   void fa1();
   int fa2(int);
};
class B: public A{
 public:
   float ia1;          // overrides ia1
   float fa1(float);   // overrides fa1
};
int main()
{
    B b;
    int j=b.fa2(1);          //A::fa2
    b.ia1=4;                 // B::ia1
    b.ia2=3;                 // A::ia2   if  ia2 is public in A
    float y=b.fa1(3.14);     // B::fa1
    b.fa1();                 // ERROR!  fa1 function in B hides  the function of A
    b.A::fa1();              // OK
    b.A::ia1=1;              // OK if ia1 is public in A
    return 0;
}
```

Overloading vs. Overriding

If you modify the signature and/or the return type of a member function from the base class then the derived class has two member functions with the same name. (See previous example print.)

But this is not overloading,

it is **overriding**.

If the author of the derived class redefines a member function, it means he or she changes the interface of the base class. In this case the member function of the base class is hidden.

See Example: e63.cpp

Access Control

Remember, when inheritance is not involved, class member functions have access to anything in the class, whether public or private,

but objects of that class have access only to public members.

Once inheritance enters the picture, other access possibilities arise for derived classes.

Member functions of a derived class can access **public** and **protected** members of the base class, but not **private** members.

Objects of a derived class can access only public members of the base class.

Access Specifier	Accessible from Own Class	Accessible from Derived Class	Accessible from Objects (Outside Class)
public	yes	yes	yes
protected	yes	yes	no
private	yes	no	no

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Example:

```
class Teacher{                                  // Base class
  private:                                      // only members of Teacher can access
    string name;
  protected:                                    // Also members of derived classes can
    int age, numOfStudents;
  public:                                       // Everyone can access
    void setName (const string & new_name){ name = new_name; }
    void print() const;
};

class Principal : public Teacher{               // Derived class
  private:                                      // Default
    string  school_name;
    int numOfTeachers;
  public:
    void setSchool(const string & s_name) { school_name = s_name; }
    void print() const;
    int getAge() const { return age; }            // It works because age is protected
    const string & get_name(){ return name;}      //  ERROR! because name is private
};
```

Protected in Teacher

Private in Teacher


```
int main()
{
    Teacher teacher1;
    Principal principal1;
    teacher1.numOfStudents = 100;             // ERROR!  (protected)
    teacher1.setName("Ali Bilir");            // OK (public)
    principal1.setSchool("İstanbul Lisesi");  // OK (public)
    return 0;
}
```

Protected vs. Private Members

In general, class data should be private. Public data is open to modification by any function anywhere in the program and should almost always be avoided.

Protected data is open to modification by functions in any derived class.

Anyone can derive one class from another and thus gain access to the base class's protected data. It's safer and more reliable if derived classes can't access base class data directly.

But in real-time systems, where speed is important, function calls to access private members is a time-consuming process. In such systems data may be defined as protected to make derived classes access data directly and faster.

Private data: Slow and reliable

```
class A{                          // Base class
  private:
    int i;                        // safe
  public:
    void access(int new_i){   // public interface to access i
      if (new_i > 0 && new_i <= 100)
        i=new_i;
    }
};

class B:public A{             // Derived class
  private:
    int k;
  public:
    void set(new_i, new_k){
      A::access(new_i);       // reliable but slow
      :
    }
};
```

Protected data: Fast, author of the derived class is responisble

```
class A{              // Base class
  protected:
    int i;        // derived class can access directly
  public:
    :
};

class B:public A{   // Derived class
  private:
    int k;
  public:
    void set(new_i,new_k){
      i=new_i;                 // fast
      :
    }
};
```


Public Inheritance

In inheritance, you usually want to make the access specifier public.

```
class Base
  { };
class Derived : public Base {
```

This is called *public inheritance* (or sometimes *public derivation*).

The access rights of the members of the base class are not changed.

Objects of the derived class can access public members of the base class.

Public members of the base class are also public members of the derived class.

Private Inheritance

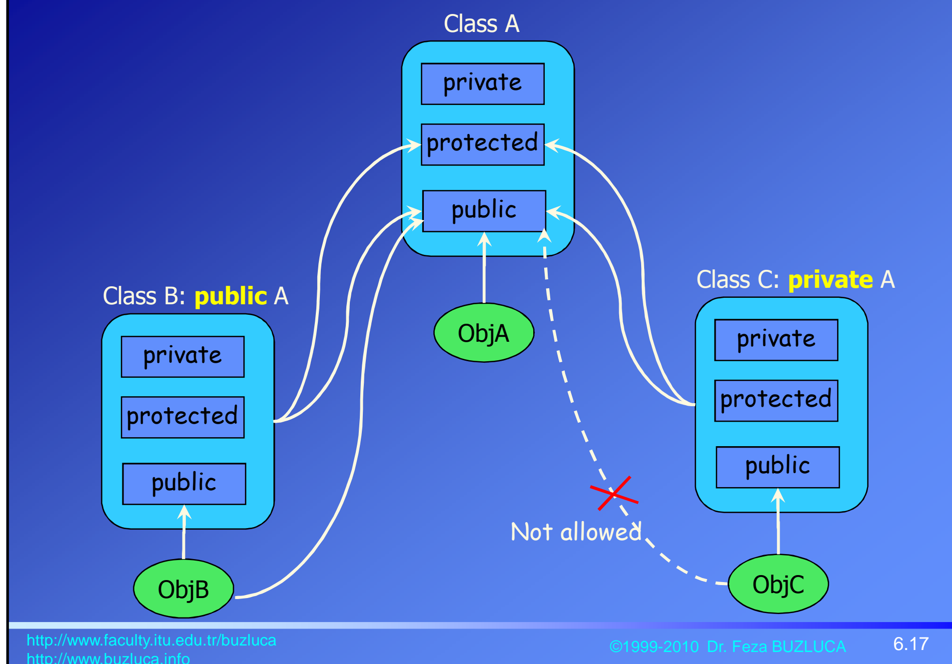
```
class Base
  { };
class Derived : private Base {
```

This is called *private inheritance*.

Now public members of the base class are private members of the derived class.

Objects of the derived class can not access members of the base class.

Member functions of the derived class can still access public and protected members of the base class.



Redefining Access Specifications

Access specifications of public members of the base class can be redefined in the derived class.

When you inherit privately, all the **public** members of the base class become **private**.

If you want any of them to be visible, just say their names (no arguments or return values) along with the **using** keyword in the **public** section of the derived class:

```
class Base{
   private:
      int k;
    public:
      int i;
      void f();
};

class Derived : private Base{   // All members of Base are private now
   int m;
 public:
   using Base::f;               //   f() is public again , i is still private
   void fb1();
};
```

```
int main(){
   Base b;
   Derived d;
   b.i=5;         // OK public in Base
   d.i=0;         // ERROR private inheritance
   b.f();         // OK
   d.f();         // OK
   return 0;
};
```

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Special Member Functions and Inheritance

Some functions will need to do different things in the base class and the derived class.

They are the overloaded = operator, the destructor, and all constructors.

Consider a constructor. The base class constructor must create the base class data, and the derived class constructor must create the derived class data.

Because the derived class and base class constructors create different data, one constructor cannot be used in place of another.

Constructor of the base class cannot be the constructor of the derived class.

Similarly, the = operator in the derived class must assign values to derived class data, and the = operator in the base class must assign values to base class data.

These are different jobs, so assignment operator of the base class cannot be the assignment operator of the derived class.

Constructors and Inheritance

When you define an object of a derived class, the base class constructor will be called before the derived class constructor.

This is because the base class object is a *subobject*—a part—of the derived class object, and you need to construct the parts before you can construct the whole.

See Example: e64.cpp

If the base class has a constructor that needs arguments, this constructor must be called before the constructor of the derived class.

```
class Teacher{                          // Base class
    string name;
    int age, numOfStudents;
  public:
    Teacher(const string & new_name): name(new_name)  // Constructor of base
    { }                                 // Body of the constructor is empty
};
class Principal : public Teacher{  // Derived class
    int numOfTeachers;
  public:
    Principal(const string &, int );    // Constructor of derived class
};
```

```
// Constructor of the derived class
// constructor of the base is called before the body of the constructor of the derived class
Principal::Principal(const string & new_name, int numOT):Teacher(new_name)
{
    numOfTeachers = numOT;
}
```

Remember, the constructor initializer can also be used to initialize members.

```
// Constructor of the derived class
Principal::Principal(const string & new_name, int numOT)
                              :Teacher(new_name), numOfTeachers(numOT)
{ }                                  // body of the constructor is empty

int main()
{
    Principal principal1("Ali Bilir", 20);        // An object of derived class is defined
    return 0;
}
```

If the base class has a constructor, which must take some arguments, then the derived class must also have a constructor that calls the constructor of the base with proper arguments.

See Example: e65.cpp

Destructors and Inheritance

Destructors are called automatically.

When an object of the derived class goes out of scope, the destructors are called in reverse order: The derived object is destroyed first, then the base class object.

```
class B {                            // Base class
  public:
    B() { cout << "B constructor" << endl; }
   ~B() { cout << "B destructor" << endl; }
};

class C : public B {                 // Derived class
  public:
    C() { cout << "C constructor" << endl; }
   ~C() { cout << "C destructor" << endl; }
};

int main()
{
  cout << "Start" << endl;
  C ch;                              // create an object of derived class
  cout << "End" << endl;
  return 0;
}
```

Result:

```
Start
B constructor
C constructor
End
C destructor
B destructor
```

See Example: e66.cpp

Constructors and Destructors in a Chain of Classes

```
class A
{
  private:
    int intA;
    float floA;
  public:
    A(int i, float f) : intA(i), floA(f)  //initialize
       { cout << "Constructor A" << endl;  }
    void display() const
       { cout << intA << ", " << floA << "; "; }
    ~A() { cout << "Destructor A" << endl;  }
};

class B : public A
{
   private:
      int intB;
      float floB;
   public:
      B(int i1, float f1, int i2, float f2) :
         A(i1, f1),                  // initialize A
         intB(i2), floB(f2)          // initialize B
         { cout << "Constructor B" << endl; }
      void display() const
      {
         A::display();
         cout << intB << ", " << floB << "; ";
      }
     ~B() { cout << "Destructor B" << endl;  }
};

class C : public B
{
   private:
      int intC;
      float floC;
   public:
      C(int i1, float f1, int i2, float f2, int i3, float f3) :
         B(i1, f1, i2, f2),          // initialize B
         intC(i3), floC(f3)          // initialize C
         { cout << "Constructor C" << endl; }
      void display() const
      {
         B::display();
         cout << intC << ", " << floC;
      }
      ~C() { cout << "Destructor C" << endl;  }
};

int main()
{
    C c(1, 1.1, 2, 2.2, 3, 3.3);
    cout << endl << "Data in c = ";
    c.display();
    return 0;
}
```

See Example: e67.cpp

A C class is inherited from a B class, which is in turn inherited from a A class.
The constructor in each class takes enough arguments to initialize the data for the class and all ancestor classes.
This means two arguments for the A class constructor, four for B (which must initialize A as well as itself), and six for C (which must initialize A and B as well as itself). Each constructor calls the constructor of its base class.

When a constructor starts to execute, it is guaranteed that all the subobjects are created and initialized.

Incidentally, you can't skip a generation when you call an ancestor constructor in an initialization list. In the following modification of the C constructor:

```
C(int i1, float f1, int i2, float f2, int i3, float f3) :
                 A(i1, f1),                          // ERROR! can't initialize A
                intC(i3), floC(f3)                   // initialize C
   {  }
```

the call to A() is illegal because the A class is not the immediate base class of C.

You never need to make explicit destructor calls because there's only one destructor for any class, and it doesn't take any arguments.
The compiler ensures that all destructors are called, and that means all of the destructors in the entire hierarchy, starting with the most-derived destructor and working back to the root.

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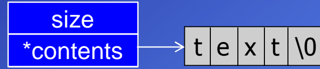
Assignment Operator and Inheritance

Assignment operator of the base class cannot be the assignment operator of the derived class. Recall the String example:

```
class String{
  protected:
    int size;
    char *contents;
  public:
    const String & operator=(const String &);        // assignment operator
    :                                                // Other methods
};

const String & String::operator=(const String &in_object)
{
    size = in_object.size;
    delete[ ] contents;                              // delete old contents
    contents = new char[size+1];
    strcpy(contents, in_object.contents);
    return *this;
}
```



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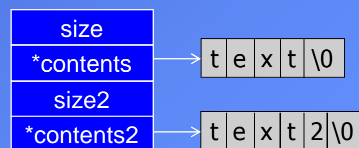
Example: Class String2 is derived from class String. If an assignment operator is necessary it must be written

```
class String2 : public String{                    // String2 is derived from String
    int size2;
    char  *contents2;
 public:
    const String2 & operator=(const String2 &);  // assignment operator for String2
  :        // Other methods
};
// **** Assignment operator for String2 ****
const String2 & String2::operator=(const String2 &in_object)
{
    size = in_object.size;                       // inherited size
    delete[ ] contents;
    contents = new char[size + 1];               // inherited contents
    strcpy(contents, in_object.contents);
-----------------------------------------------
    size2 = in_object.size2;
    delete[ ] contents2;
    contents2 = new char[size2 + 1];
    strcpy(contents2, in_object.contents2);
    return *this;
}
```



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In previous example, data members of String (Base) class must be protected. Otherwise methods of the String2 (Derived) can not access them.

The better way to write the assignment operator of String2 is to call the assignment operator of the String (Base) class.

Now, data members of String (Base) class may be private.

```
//** Assignment operator **
const String2 &  String2::operator=(const String2 & in_object)
{
   String::operator=(in_object);            // call the operator= of String (Base)
   size2 = in_object.size2;
   delete[] contents2;
   contents2 = new char[size2 + 1];
   strcpy(contents2, in_object.contents2);
   return *this;
}
```

See Example: e68.cpp

In this method the assignment operator of the String is called with an argument of type (String2 &). Actually, the operator of String class expects a parameter of type (String &).

This does not cause a compiler error, because as we will see in Section 7, a reference to base class can carry the address of an object of derived class.

Composition: *has a* relation vs. Inheritance: *is a* relation

Every time you place instance data in a class, you are creating a "has a" relationship.

If there is a class Teacher and one of the data items in this class is the teacher's name, I can say that a Teacher object *has a* name.

This sort of relationship is called *composition* because the Teacher object is composed of these other variables.

Remember the class ComplexFrac. This class is composed of two Fraction objects.

Composition in OOP models the real-world situation in which objects are composed of other objects.

Inheritance in OOP mirrors the concept that we call *generalization - specialization* in the real world.

If I model workers, managers and researchers in a factory, I can say that these are all specific types of a more general concept called an employee.

Every kind of employee has certain features: name, age, ID num, and so on.

But a manager, in addition to these general features, has a department that he/she manages.

In this example the manager **has not** an employee. The manager ***is an*** employee

You can use composition & inheritance together. The following example shows the creation of a more complex class using both of them.

```
class A {
  int i;
public:
  A(int ii) : i(ii) {}
  ~A() {}
  void f() const {}
};

class B {
  int i;
public:
  B(int ii) : i(ii) {}
  ~B() {}
  void f() const {}
};

class C : public B {   // Inheritance, C is B
  A a;                 // Composition, C has A
public:
  C(int ii) : B(ii), a(ii) {}
  ~C() {}              // Calls ~A() and ~B()
  void f() const {     // Redefinition
    a.f();
    B::f();
  }
};
```

C inherits from **B** and has a member object ("is composed of") of type **A**. You can see the constructor initializer list contains calls to both the base-class constructor and the member-object constructor.

The function **C::f( )** redefines **B::f( ),** which it inherits, and also calls the base-class version. In addition, it calls **a.f( )**.

Notice that the only time you can talk about redefinition (overriding) of functions is during inheritance; with a member object you can only manipulate the public interface of the object, not redefine it.

In addition, calling **f( )** for an object of class **C** would not call **a.f( )** if **C::f( )** had not been defined, whereas it *would* call **B::f( ).**

See Example: e69.cpp

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Multiple Inheritance

Multiple inheritance occurs when a class inherits from two or more base classes, like this:

```
class Base1{           // Base 1
 public:
   void f1()
   char *f2(int);
};

class Base2{           // Base 2
 public:
   char *f2(int, char);
   int f3();
   void f4();
};

class Derived : public Base1 , public Base2{
public:
    float f1(float);   // override Base1
    void f4();         // override Base2
    int f5(int);
};
```

Base1 + Base2 → Derived

```
int main()
{
  Derived d;
  float y=d.f1(3.14);  // Derived::f1
  d.f3();              // Base2::f3
  d.f4();              // Derived::f4
  d.Base2::f4();       // Base2::f4
  return 0;
}
```

```
d.f1();                // ERROR !
char *c = d.f2(1);     // ERROR !
```

In inheritance functions are not overloaded. They are **overridden**.

You have to write

```
char *c = d.Base1::f2(1);        // Base1::f2
```

or

```
char *cc = d.Base2::f2(1,'A'); // Base2::f2
```

See Example: e610.cpp

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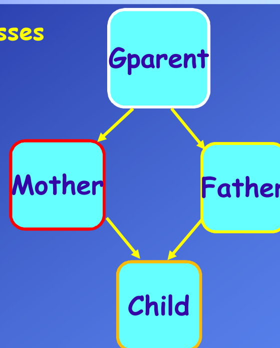
Repeated Base Classes

```
class Gparent
  {  };
class Mother : public Gparent
  {  };
class Father : public Gparent
  {  };
class Child : public Mother, public Father
  {  };
```



Both Mother and Father inherit from Gparent, and Child inherits from both Mother and Father.

Recall that each object created through inheritance contains a subobject of the base class.

A Mother object and a Father object will contain subobjects of Gparent, and a Child object will contain subobjects of Mother and Father, so a Child object will also contain two Gparent subobjects, one inherited via Mother and one inherited via Father.

This is a strange situation. There are two subobjects when really there should be only one.

Suppose there's a data item in Gparent:

```
class Gparent
{
  protected:
    int gdata;
 };
```

and you try to access this item from Child:

```
class Child : public Mother, public Father
 {
  public:
    void Cfunc()
    {
      int temp = gdata;                    // ERROR: ambiguous
    }
 };
```

The compiler will complain that the reference to gdata is ambiguous.

It doesn't know which version of gdata to access: the one in the Gparent subobject in the Mother subobject or the one in the Gparent subobject in the Father subobject.

Virtual Base Classes

You can fix this using a new keyword, **virtual**, when deriving Mother and Father from Gparent :

```
class Gparent
  {  };
class Mother : virtual public Gparent
  {  };
class Father : virtual public Gparent
  {  };
class Child : public Mother, public Father
  {  };
```

See Example: e611.cpp

The virtual keyword tells the compiler to inherit only one subobject from a class into subsequent derived classes. That fixes the ambiguity problem, but other more complicated problems arise that are too complex to delve into here.

In general, you should avoid multiple inheritance, although if you have considerable experience in C++, you might find reasons to use it in some situations.

Conclusion about the Inheritance

- We can create special types from general types.
- We can **reuse** the base class without changing its code.
- We can add new members, redefine existing members and redefine accesses specifications without touching the base class.

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