



Objective:

- To look into the technical and theoretical aspects of the Polymorphism.

Task 1:

Discussed in class also.

A student is assigned to make a program. The program is supposed to play the voice of animal selected. For this purpose, student comes up with two alternate designs. Which design do you think is better and WHY (give some logical reason(s))?

<pre>//Solution-A class Animal { public: Animal(); virtual void speak() { } }; class Cat : public Animal { public: void speak() { cout<<"Meeaaaaauun"; } }; class Dog : public Animal { public: void speak() { cout<<"Baoo Baaaaaaoooo"; } }; class Rat : public Animal { public: void speak() { cout<<"chi een eeen"; } };</pre>	<pre>//Solution-B class Animal { public: enum EnumType { Cat, Dog, Rat }; Animal(EnumType type); void speak(); private: EnumType animalType; }; void Animal::speak() { switch (animalType) { case Cat: cout<<"Meeaaaaauun"; break; case Dog: cout<<"Baoo Baaaaaaoooo"; break; case Rat: cout<<"chi een eeen"; break; } };</pre>
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Task 2: just zip through it today

Ship, CruiseShip, CargoShip and BattleShip Classes

1. Ship class

Design a Ship class that has the following members:

- A member variable for the name of the ship (a string)
- A member variable for the year that the ship was built (a string)
- A constructor and appropriate accessors and mutators
- A virtual print function that displays the ship's name and the year it was built.

2. CruiseShip class

Design a CruiseShip class that is derived from the Ship class. The CruiseShip class should have the following members:

- A member variable for the maximum number of passengers (an int)
- A constructor and appropriate accessors and mutators
- A print function that overrides the print function in the base class. The CruiseShip class's print function should display the ship's name, year of built and the maximum number of passengers.

3. CargoShip class

Design a CargoShip class that is derived from the Ship class. The CargoShip class should have the following



members:

- A member variable for the cargo capacity in tonnage (an int).
- A constructor and appropriate accessors and mutators.
- A print function that overrides the print function in the base class. The CargoShip class's print function should display only the ship's name and the ship's cargo capacity.

4. BattleShip class

Design a BattleShip class that is derived from the Ship class. The BattleShip class should have the following members:

- A member variable for the total number of missiles (an int).
- A constructor and appropriate accessors and mutators.
- A print function that overrides the print function in the base class. The BattleShip class's print function should display only the ship's name and the missiles' capacity.

5. A Driver Program

Demonstrate the classes in a program that has an array of Ship pointers. The array elements should be initialized with the addresses of dynamically allocated Ship, CruiseShip, CargoShip and BattleShip objects. The program should then step through the array, calling each object's print function.

Task 3: do it before coming lab

A bank holds different types of accounts for its customers: **deposit accounts**, **loan accounts** and **mortgage accounts**.

- Customers could be **individuals** or **companies**.
- All accounts have **customer**, **balance** and **interest rate** (monthly based).
- **Deposit** accounts are allowed to deposit and withdraw money. **Loan** and **mortgage** accounts can only deposit money.
- All accounts can calculate their interest for a given period (in months) using the formula
$$A = \text{money} * (1 + \text{interest rate} * \text{months})$$
- **Loan** accounts have no interest for the first 3 months if held by **individuals** and for the first 2 months if held by a **company**.
- **Deposit** accounts have no interest if their balance is positive and less than 1000.
- **Mortgage** accounts have 1/2 interest for the first 12 months for **companies** and no interest for the first 6 months for **individuals**.

Write a program to model the bank system with classes. You should identify the classes and their relationship and implement the calculation of the interest functionality through overridden methods. Write a program to demonstrate that your classes work correctly.



Task 4: POLYMORPHISM Thoroughly understand the contents till page 5 of this document before next lecture.

Polymorphism appears in C++ in two different forms

1. **Static/Compile Time/adhoc Polymorphism**
 - 1.1. Function/Operator Overloading
 - 1.2. Parameterized [Template] Polymorphism
2. **Dynamic/Runtime Polymorphism**

1.1 Function/Operator Overloading

In order to overload a function, a different list of parameters is used for each overloaded version. For example, a set of valid overloaded versions of a function named f() might look similar to the following:

```
void f(char c, int i);  
void f();  
void f(int i);
```

So, a function named as 'f' exists in more than one shapes (different parameter list). And which shape of 'f' to call? The decision is made on compile time.

Similarly, if we observe the following + operations:

```
int a; float b; double d; char t;  
a+b;      b+a;      a+d;      t+a;
```

The same '+' operator is performing "additions operation" on different types of data. And this concept can be extended to user defined classes.

So which overloaded operator function to call? The decision is made at compile time.

1.2 Parameterized [Template] Polymorphism

A generic (template) function/class can be defined out of which actual function /class can be generated. The generation of actual function/class is dependent on the (in case of function: on function call parameter, in case of class: on object creation)

So, again the decision is made at compile time,

```
template<class T>  
void f(T a)  
{  
}  
template<typename T>  
class Test  
{  
    T data;  
public:  
    Test()  
    { data=0; }  
};
```

```
f(12); //compiler generates void f(int) considering the call parameter.  
Test<float> fun; //Compiler generates class "Test<float>" replacing type T by float  
//Wherever T is used in class template  
Test<int> you; //this time: class Test<int> is generated.
```

2. Dynamic/Runtime Polymorphism

Object interaction take place by sending messages to them.

When a message (member function call) is sent to an object, it will react by executing an appropriate method (function body).

Let's see an example:

<pre>class base { public: void f() {} };</pre>	<pre>class derive: public base { public: void f() {} };</pre>	<pre>void main() { derived d; base *pb = & d; pb->f(); }</pre>
--	---	---

In the above example "static type" of "pb" is "base*" and "dynamic type" of "pb" is the type of pb's referent (derive*).



If we put the duty of "appropriate method invocation (binding)" to compiler it will do silly things. Because compiler has knowledge of only "static type" of an identifier, It will invoke `base::f()` rather than `derive::f()` due to the "static type" of "pb" is "base*". We have to find another mechanism that has access to "dynamic type" of an identifier. Let's update the above example:

Updated example:		
<pre>class base { public: virtual void f() {} };</pre>	<pre>class derive: public base { public: void f() {} };</pre>	<pre>void main() { derived d; base *pb = &d; pb->f(); }</pre>

Now `pb->f()` binds to `derive::f()`;
Miracle: because of overriding

Overriding:

1. The method in base class is declared as virtual"
2. The derive class method is exactly "same type function" as the base class method. That means the derive class method has the same return type, the same formal arguments, and it is a const member function if and only if the base member function is also const.

Overriding is precisely what is necessary for runtime polymorphism/binding
So, in short runtime **polymorphism** means:

Polymorphism:

"Objects of different classes related by inheritance respond differently to the same message."

Binding: means; which function body to invoke on a function call. If the decision is taken at compile time, it is called **compile/static binding** and if the decision is taken at runtime then it is called **runtime binding**.

<pre>class base { public: virtual void f() {} };</pre>	<pre>class derive: public base { public: void f() {} };</pre>	<pre>class Leaf: public derive { public: void f() {} };</pre>
<pre>void main() { derived d; Leaf f; base *pb = &d; 1.....pb->f(); //derive::f() pb = &f; 2.....pb->f(); //Leaf::f() }</pre>		

The same message "`pb->f()`" at line 1 & 2 but different responses(different method invocation/binding).

The following are synonyms:

- Early=Compile Time=Static binding
- Late=Dynamic=Runtime binding



Overloading vs Hiding vs Overriding:

- **Overloading**

- Two functions that are overloaded must have the same scope but different signatures. Their formal argument lists are different or one of them is const and the other is not.

- **Hiding**

- A function declared in derived class with the same as in base class hides the base class method and does not override it.

- **Overriding**

- Already defined above....

Coding Example to differentiate among hiding, overriding and overloading.

<pre>class base { int a; public: virtual void f(int) {} virtual void g(int) {} void h(float) {} };</pre>	<pre>class derive: public base { int b; public: void f(int) // overrides base::f(int) {} void f(double) //overloads derive::f(int) doesn't override {} //base::f(int) char g(int) //illegal: return must mach for overriding {} //virtual functions. char g(char) //Legal : but doesn't override base::g(int). {} //signatures are different void h(float) //just hides base::h(float) {} void h(int) //Legal: since base::h is not virtual. Overloads {} //derived::h(float) };</pre>
--	--



Runtime Polymorphism

Some points to ponder:

1. If the return type is a pointer or reference to the base class, then it may be a pointer or reference to the derived class in the derived class signature. Otherwise, the return type must match in any derived class. Not supported by the all the compilers.

<pre>class base { public: virtual base * f() {} virtual ~base() {} };</pre>	<pre>class derive : public base { public: virtual derive * f() {} virtual ~derive() {} };</pre>
---	---

2. Virtual global friend is illegal, but virtual functions in one class may be designated as friend in another class.
3. Virtual function may be inline and have default arguments.
4. Changing the access level of a virtual function in a derived class is a poor idea. For example:

<pre>class base { public: virtual void fun() {} };</pre>	<pre>class derive: public base { private: virtual void fun() {} };</pre>	<pre>void main() { base *pb=new derive; pb->fun(); }</pre>
--	--	---

Note: The statement above "pb->fun()" is valid, because access specifiers are compile time check, so at compile time, compiler checks the type of pointer "pb" which is "base", so "pb" can access "base::fun()", But at runtime because of dynamic binding "pb->fun()" resolves to derive::fun().

5. **Using** declaration help derived class to avoid hiding of base class functions.

Example 1:

```
class base
{
public:
    void print(int , int)    {}
};
class derive: public base
{
public:
    using base::print;        //bring into local scope
    void print(char)    {}    //overloads with derive::print(char)
};
```

Example 2:

```
class base
{
public:
    virtual void fun(int , int) {}
    virtual int fun(float) {}
    virtual void fun(char *) {}
    virtual void fun() {}
};
class derive: public base
{
public:
    using base::fun; //bring rest of three functions into local scope
```



```
}; void fun(int , int) {}
```

NOTE:

Without making use of "using declaration", `derive::fun(int,int)` hides the other versions of `fun()`.

6. The virtual function mechanism works only with public derivation.

7. The virtual function mechanism doesn't work with private derivation.

<pre>class base { public: virtual void fun() {} };</pre>	<pre>class derive: private base { public: void fun() {} };</pre>
--	--

```
void main()
{
    base *pb = new derive; //illegal: conversion from 'class derive *' to
                          // 'class base *' does not exists
    base *pb=(base*) new derive; //Legal: now pb->fun() resolves to
    pb->fun();                    //derive::fun()
}
```

But what about this?

<pre>class base { public: virtual void fun() {} };</pre>	<pre>class derive: private base { public: void fun() { base *pb = new derive; //Legal pb->fun(); } };</pre>
--	--

REASON:

The main function is just like a client which is using base and derive classes. So, no one knows that class derive has features of class base except the class derive itself. So, the idiom 'base class reference can refer to derive class object' works only on class derive.

8. The virtual function mechanism doesn't work with protected derivation.

<pre>class base { public: virtual void fun() {} };</pre>	<pre>class derive: protected base { public: void fun() {} };</pre>
--	--

```
void main()
{
    base *pb = new derive; // illegal: conversion from 'class derive *' to
                          // 'class base *' doesn't exists
    base *pb=(base*) new derive;
    pb->fun();now pb->fun() resolves to derive::fun()
}
```

9. But what about this?

<pre>class base {</pre>	<pre>class derive: protected base {</pre>
-------------------------	---



<pre>public: virtual void fun() {} };</pre>	<pre>public: void fun() { base *pb = new derive; //Legal pb->fun(); } };</pre>
---	---

REASON:

The same reason as in point 8, the only difference is that the class `derive` inherits features of class `base` is only known by class `derive` himself or any down the hierarchy.

10. What happens when we call virtual function inside constructor or destructor:

Example

```
class base
{
public:
    int bdata;
    virtual void f()
    {
        wow();          //if class to f() is from constructor/destructor of
                        //base class then base::wow() Otherwise //derive::wow()
    }
    virtual void wow()    {}
    virtual void hi()     {}
    base()
    {
        hi();           //base::hi()
    }
    virtual ~base()
    {
        hi();           //base::hi()
    }
};

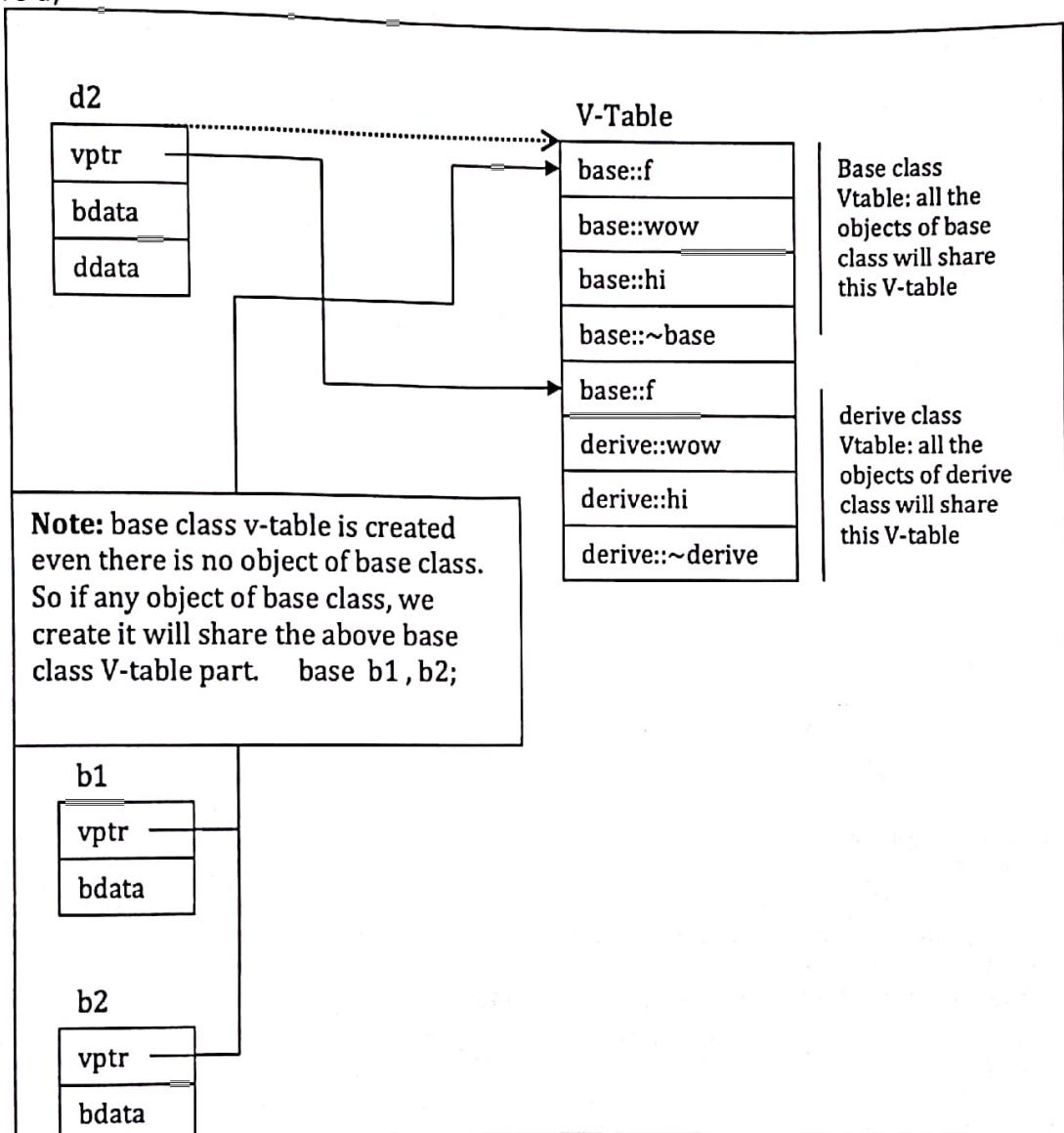
class derive: public base
{
public:
    int ddata;
    virtual void wow()    {}
    virtual void hi()     {}
    derive()
    {
        hi(); //derive::hi()
        f();  //base::f()
    }
    virtual ~derive()
    {
        hi(); //derive::hi()
        f();  //base::f()
    }
};
```

NOTE: Strange? let's look at the layout of v-table construction

When the derive object `d2` is created the following layout in memory was constructed (i.e; the base class v-table part along with derive class v-table part. So, the interesting thing about this figure is that the `d2` vptr is pointing to two different location; Certainly not at a time. Actually, when `d2` object was being constructed/initialized, in constructor/destructor of base class the `d2` vptr was pointing to base class v-table part and other than this vptr value of `d2` object will remain same: pointing to its own derive class v-table part.)



.....
derive d;





11. Pure Virtual functions can also have definition but out of line.

12. A destructor can also be pure virtual and we have to give its definition out of line otherwise all the derive classes will be abstract. Important point over here is that if the base class defines a pure virtual dtor then all the derive classes have to define their dtors.

```
class base
{
public:
    virtual void f()=0;
    virtual ~base()=0;
};
void base::f()      // always out of line
{}
base::~~base()      // always out of line
{}
class derive : public base
{
public:
    virtual void f() {}
    virtual ~derive() {}
};
void main()
{
    derive d;
    d.f();
    d.base::~~base(); //Now there will be
    d.base::f();      //no linker error
}
```

13. What is a "Virtual Constructor"?

Technically speaking, there is no such thing. You can get the effect you desire by a virtual "clone()" member fn (for copy constructing), or a "fresh()" member fn (also virtual) which constructs/creates a new object of the same class but is "fresh" (like the "default" [zero parameter] ctor would do).

The reason ctors can't be virtual is simple: a ctor turns raw bits into a living object. Until there's a living respondent to a message, you can't expect a message to be handled "the right way". You can think of ctors as "factories" which churn out objects.

Thinking of ctors as "methods" attached to an object is misleading.

Here is an example of how you could use "clone()" and "fresh()" methods:

```
class Set
{
public:
    virtual void insert(int);    //Set of "int"
    virtual int remove();
    //...
    virtual Set& clone() const = 0; //pure virtual; Set is an ABC
    virtual Set& fresh() const = 0;
    virtual ~Set()
    {}
};
class SetHT: public Set
{
public:
    //...
    Set& clone() const
    { return *new SetHT(*this); }
    Set& fresh() const
    { return *new SetHT(); }
};
```



"new SetHT(...)" returns a "SetHT*", so "*new" returns a SetHT&. A SetHT is-a Set, so the return value is correct. The invocation of "SetHT(*this)" is that of copy construction ("*this" has type "SetHT&"). Although "clone()" returns a new SetHT, the caller of clone() merely knows he has a Set, not a SetHT (which is desirable in the case of wanting a "virtual ctor"). "fresh()" is similar, but it constructs an "empty" SetHT. Clients can use this as if they were "virtual constructors":

```
void client_code(Set& s)
{
    Set& s2 = s.clone();
    Set& s3 = s.fresh();
    //...
    delete &s2;    //relies on destructor being virtual!!
    delete &s3;    //
}
```

Another Example

If the class "owns" the object pointed to by the (abstract) base class pointer, use the Virtual Constructor Idiom in the (abstract) base class. As usual with this idiom, we declare a pure virtual clone() method in the base class:

```
class Shape
{
public:
    Shape()
    {}
    Shape(Shape &ref)
    {}
    virtual Shape* clone() const = 0;    // The Virtual (Copy) Constructor
};
```

Then we implement this clone() method in each derived class:

```
class Circle : public Shape
{
public:
    Circle()
    {}
    Circle(Circle &ref):Shape(ref)
    {}
    virtual Shape* clone() const
    { return new Circle(*this); }
};

class Square : public Shape
{
public:
    Square()
    {}
    Square(Square &ref):Shape(ref)
    {}
    virtual Shape* clone() const
    { return new Square(*this); }
};
```

Now suppose that each Fred object "has-a" Shape object. Naturally the Fred object doesn't know whether the Shape is Circle or a Square or ... Fred's copy constructor and assignment operator will invoke Shape's clone() method to copy the object:

```
class Fred
{
public:
    Fred(Shape* p)
    { p_ = p; }
    ~Fred() { delete p_; }
    Fred(const Fred& f) : p_(f.p_>clone())
    {}
    Fred& operator= (const Fred& f)
    {
        if (this != &f)    // Check for self-assignment
```



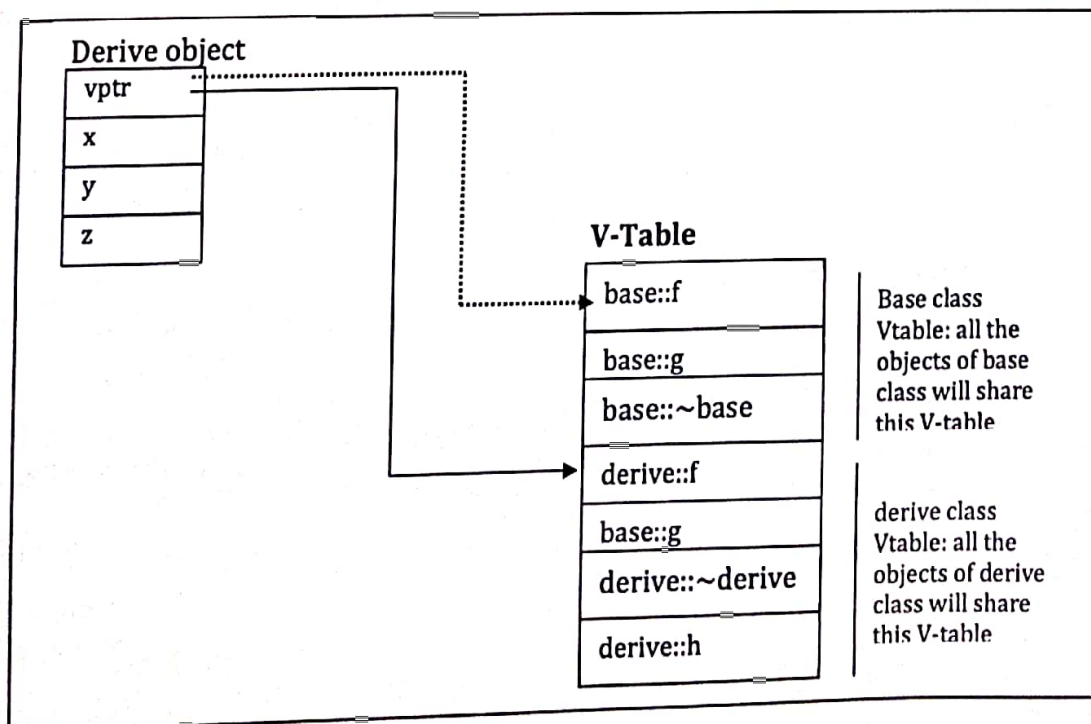

```
{
    Shape* p2 = f.p_ -> clone(); // Create the new one FIRST...
    delete p_;                 // ...THEN delete the old one
    p_ = p2;
}
return *this;
}
private:
    Shape* p_;
};
void main()
{
    Fred f(new Circle);
    Fred f1(f);
    Fred f2(new Square);
    Fred f3(new Square);

    f1=f3;
    Fred f4=f;
}
```

14.V-Table Structure

Case : a.

<pre>class base { public: int x , y; virtual void f() {} virtual void g() {} virtual ~base() {} };</pre>	<pre>class derive: public base { public: int z; virtual void f() {} virtual void h() {} virtual ~derive() {} };</pre>
--	---





Case : b.

<pre>class base { public: int x, y; virtual void f() {} virtual void g() {} virtual ~base() {} };</pre>	<pre>class base1:public base { public: int x; virtual void f() {} virtual ~base1() {} };</pre>	<pre>class derive:public base1 { public: int z; virtual void g() {} virtual void h() {} virtual ~derive() {} };</pre>
---	--	---

