Inheritance and polymorphism

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Object extensions

A `class` can be “extended”, adding new member data and functions to it

The “extended” `class` definition can make use of the existing one:

- the “new” `class` has all the member data and functions of the “old” one,
- the “new” class can (usually) be used anywhere the “old” one is required,
- this mechanism is called “inheritance”.

Example:
a 3D vector can be seen as a 2D vector plus a z component

Object behaviour

A `class` inheriting from another one can modify its member functions and define a specific behaviour

The "extended" `class` can (usually) be used where its "base" is required:

- the object can behave according to its actual type, and not the base type, e.g.:
  - triangles, squares, hexagons are all geometrical shapes,
  - they can be described by classes sharing a common interface,
  - functions to compute their areas and perimeters must be different;
- this functionality is called "polymorphism".

Public inheritance

A `class` is said to “publicly inherit” from another one when it can be used anywhere in place of its base

```
class Vector3D: public Vector2D {
 public:
  Vector3D(float x, float y, float z);
  ~Vector3D();
  float getZ() const;
  float mod() const;
 private:
  float zv;
};
```

When a `class` “privately inherit” from another one it includes all its members and functions but it cannot be used in place of its base

Base initialization

The derived `class` (e.g. `Vector3D`) has an "hidden" member with base `class` type (e.g. `Vector2D`)

- Requests for members of the base `class` are automatically forwarded to it.
- The base object is created before the execution of the constructor of the derived object.
- An explicit initialization is required if the base `class` does not provide a default constructor.

```
Vector3D::Vector3D():
 zv(0.0) { // implicit default construction
}
Vector3D::Vector3D(float x,float y,float z):
 Vector2D(x,y),    // explicit construction
 zv(z) {
}
```

Function redefinition

Base `class` functions can be re-defined by the derived `class`

- All the functions of the base `class` with the same name as any function in the derived `class` are hidden (independently on the parameters).
- The function of the base `class` is actually called if a derived object is accessed as a base object.

```
float Vector3D::mod() {
  return sqrt((getX()*getX())+
              (getY()*getY())+(zv*zv));
}
  ...
  Vector3D u(3.4,4.5,7.2);
  cout << u.mod() << endl; // Vector3D::mod()
  Vector2D& v=u;
  cout << v.mod() << endl; // Vector2D::mod()
```

Function resolution

The base `class` function can be called by using the scope resolution operator

```
float Vector3D::mod() {
  float m2d = Vector2D::mod();
  return sqrt((m2d*m2d)+(zv*zv));
}
```

Name hiding

The declaration of a function in a derived `class` hides all the functions with the same name in the base `class`, also the ones with different parameters.

Access rights for derived `class`es

Derived `class` functions may have “special” rights in the access to base `class` members: `protected` specifier

- Members declared as `protected` can be accessed by the same `class` and the derived ones.
- Members declared as `protected` cannot be accessed by other `class`es and functions.

Non-`public` inheritance

A derived `class` may have a `private` or `protected` base

- The derived class may access `public` and `protected` members of the base.
- A derived object cannot be used in place of a `private` or `protected` base object.

Base member access specifier	Base `class` access specifier		
	`public`	`protected`	`private`
`public`	`public`	`protected`	`private`
`protected`	`protected`	`protected`	`private`
`private`	Not accessible	Not accessible	Not accessible

Name “unhiding” and inheritance prevention

C++11 only

An hidden name can be “unhidden” with an `using` declaration.

```
class Vector3D: public Vector2D {
 public:
   ...
   using Vector2D::transform;
   ...
};
```

C++11 only

A `class` cannot be used as base if declared `final` .

```
class Pippo final {
   ...
};
```

`virtual` functions

Functions of a base `class` can be declared to be "automatically" replaced by functions of the derived `class` even when called through the base `class` interface

Functions behaving in this way are called "`virtual`" functions.

```
class Shape {
 public:
   ...
   virtual float perimeter() const;
   virtual float area() const;
   ...
};
```

Function override

C++11 only

A function in a derived `class` can be explicitly declared to override a `virtual` function and not to be a new function.

```
class Triangle: public Shape {
  ...
  float area() const override;
  ...
};
```

C++11 only

A function in a base `class` can prevent overriding.

```
class Shape {
  ...
  void print() const final;
  ...
};
```

Function overriding, old style

```
class Triangle: public Shape {
 public:
   ...
   virtual float area() const;
   ...
};
```

```
class Square: public Shape {
 public:
   ...
   virtual float area() const;
   ...
};
```

- The "`virtual`" specification can be included in the function re-declaration, but this is not required.
- Re-declaring as "`virtual`" a function declared "non-`virtual`" in the base `class` is uneffective.

`virtual` functions call

Calls of a `virtual` function by pointers or references
query a “virtual table”, and
the function of the actual (derived) object is selected

```
Shape* t = new Triangle(...);
Shape* s = new Square(...);
cout << t->area() << endl;
cout << s->perimeter() << endl;
Shape& r = *s;
cout << r.area() << endl;
```

The “virtual table” is used in the call of `virtual` functions inside the base class functions, too.

```
void Shape::print() {
  cout << "perimeter: " << perimeter()
       << " and area: " << area() << endl;
}
```

Functions call by concrete objects

In the call of `virtual` functions by a concrete object the object function is (obviously) used.

```
Shape* s;
...
Shape& r = *s;
Shape  o = *s; // a copy of the object
               // is created
r.print(); // the actual object (pointed by s)
           // function is called
o.print(); // Shape::print() is called
```

- If a derived object is copied onto a base object, the "extensions" are lost ("slicing").
- Special care is required when an object is passed to a function: calls by value could alter the object type and behaviour.

Destruction of derived `class`es

Derived objects can be deleted through pointers to base `class` objects

- Any resource allocated by the derived object must be released when the object is deleted, however this is done.
- The destructor should be declared `virtual` .

```
class Base {
 public:
  Base();
  virtual ~Base();
  ...
};
```

Function override summary

Function override for derived objects accessed through base interface

Access mode	Function declaration	
	`virtual`	non-`virtual`
pointer	YES	NO
reference	YES	NO
copy	NO	NO

Construction and destruction sequence

Derived objects contain an instance of their base

- The base `class` constructor is run before the derived `class` constructor.
- The base `class` destructor is run after the derived `class` destructor.
- When the base `class` constructor is executed, the derived object has not yet been created.
- When the base `class` destructor is executed, the derived object has already been deleted.

The base `class` constructor and destructor cannot call the derived `class` functions (including overridden ones).

Pure `virtual` functions declaration

A `class` can contain functions to be necessarily (re)implemented in derived `class`es, called “pure `virtual` functions”

Member functions are declared being pure `virtual` by a trailing “ `= 0` ”.

```
class Shape {
 public:
   ...
   virtual float perimeter() const = 0;
   virtual float area() const = 0;
   ...
};
```

Pure `virtual` functions implementation

A pure `virtual` function can be implemented also in the base `class` , to be called with scope resolution.

```
class Base {
   ...
   virtual void f() = 0;
   ...
};
void Base::f() {
   ...
}
```

```
class Derived:
      public Base {
   ...
   void f() override;
   ...
};
void Derived::f() {
   ...
   Base::f();
   ...
}
```

Abstract base `class`es

Base `class`es with at least one pure `virtual` function are called “abstract base `class`es”

- No instance of an abstract base `class` can be created.
- Only instances of derived `class`es implementing all pure `virtual` functions can be created.
- A (direct or indirect) call to a pure `virtual` function in the base `class` constructor or destructor results in a fatal error.

Base to derived type casts

A pointer to a base `class` object can be “forced” to point to a derived `class` object

The operation returns a null pointer if the actual object type does not match the required one.

```
Shape* s;
...
Square* q = dynamic_cast<Square*>(s);
if(q!=nullptr)cout << q->side() << endl;
```

A `dynamic_cast` of a reference throws an exception if the actual object type does not match the required one.

Multiple bases

A `class` can derive from multiple bases

```
class BaseA {
  ...
};
class BaseB {
  ...
};
class Derived: public BaseA, public BaseB {
  ...
};
```

- The derived `class` gets all the data and function members of all its bases.
- Any call to a function having the same name in more than one base is ambiguous.

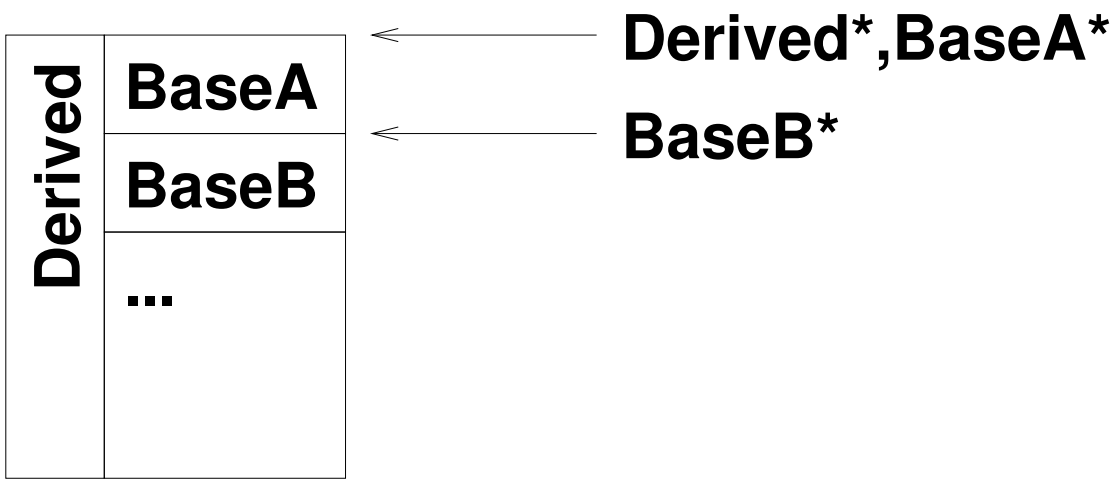
Function disambiguation

```
class BaseA {
  ...
  void f();
  ...
};
class BaseB {
  ...
  void f();
  ...
};
  ...
  Derived* d;
  ...
  d->f(); // ambiguous
  d->BaseA::f();
  ...
```

Pointers and multiple bases

Pointers to objects derived from multiple bases can change when copied onto pointers to a base class

- The derived `class` has an “hidden” member for each base.
- They are stored in different memory locations.



Inheritance from derived classes

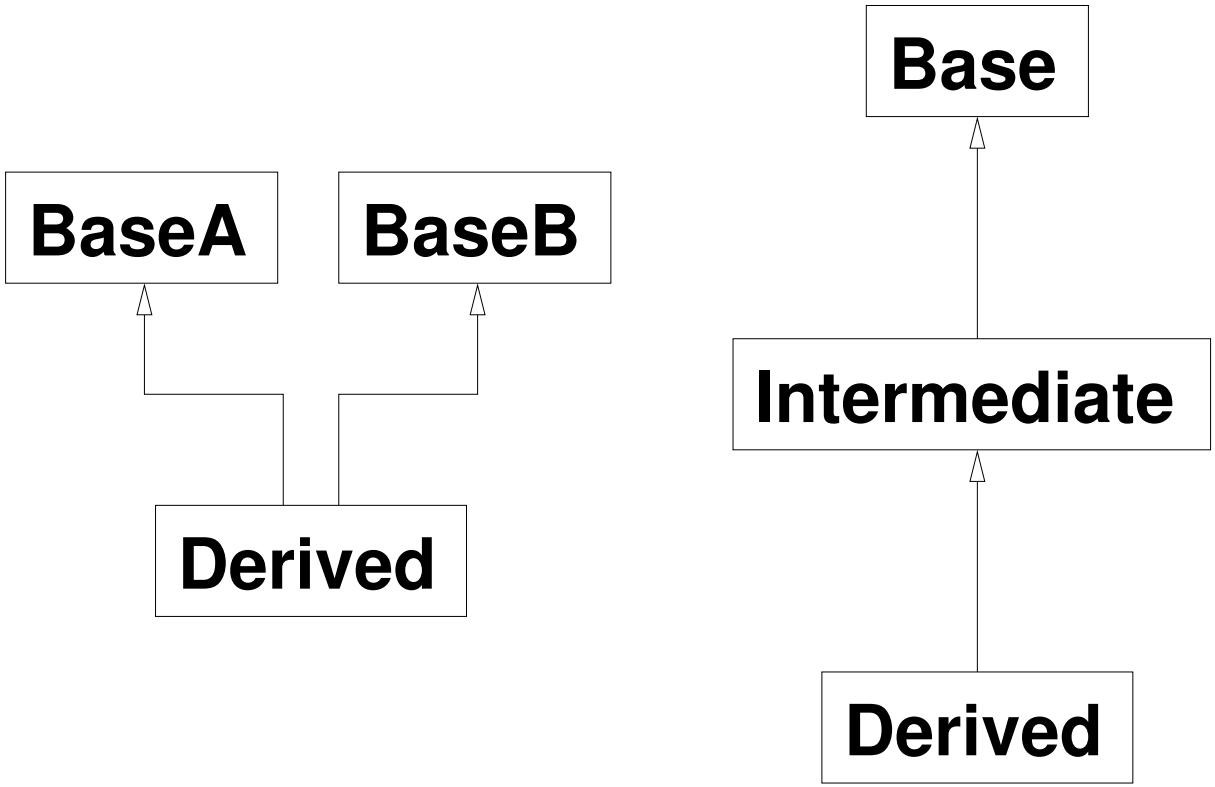
A `class` can derive from a `class` deriving in its turn from another one

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

The derived `class` gets the members of its “immediate” base, and the members of the “next” base according to their visibility.

UML graphs

Relations among `class`es can be drawn in “UML graphs”



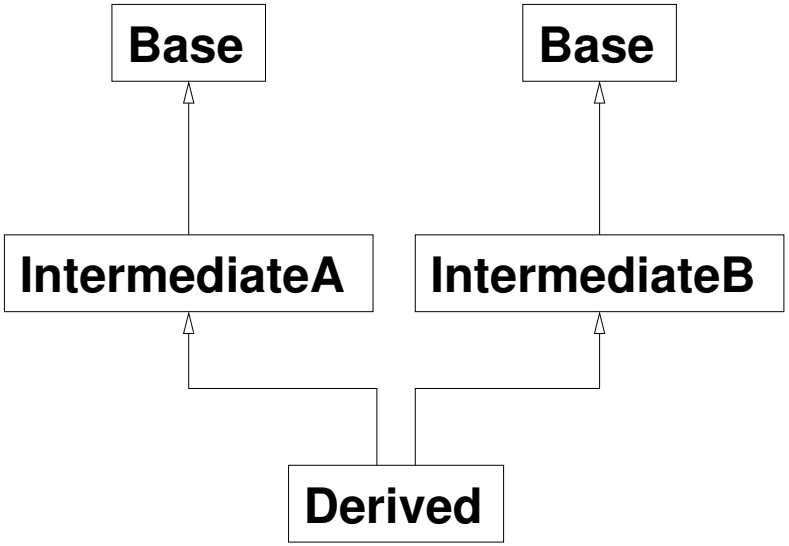
Inheritance is shown by an arrow pointing from the derived `class` to the base `class` .

Multiple inheritance with common bases

A `class` can derive from multiple bases in their turn inheriting from a common base

```
class Base {
  ...
};
class IntermediateA: public Base {
  ...
};
class IntermediateB: public Base {
  ...
};
class Derived: public IntermediateA,
               public IntermediateB {
  ...
};
```

Multiple inheritance disambiguation



- Each intermediate object contains a base object
- A call to a `Base` function from a `Derived` object can be ambiguous.

Such a structure is allowed, but `Base` function calls from `Derived` need disambiguation

```
Derived* d;
...
d->IntermediateA::f();
d->IntermediateB::f();
```

`virtual` inheritance

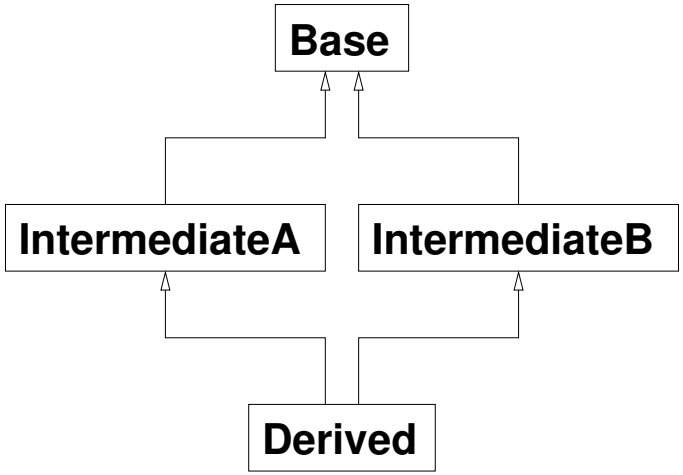
A “common” base can be declared to be shared by all its derived `class`es

- This can be achieved by including a `virtual` keyword before the base `class` name.
- The base `class` becomes a direct base for all derived `class`es in the inheritance chain.

```
class Base {
  ...
};
class IntermediateA: public virtual Base {
  ...
};
class IntermediateB: public virtual Base {
  ...
};
```

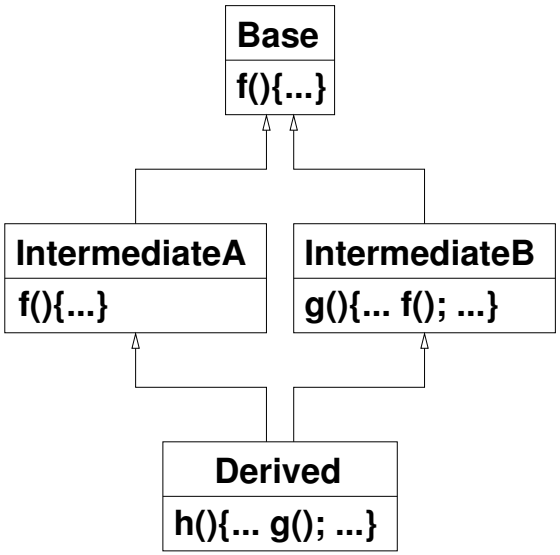
Diamond graphs

`virtual` inheritance allows to implement the so-called "diamond graph"



- `Base` can be created and initialized by any of `IntermediateA` , `IntermediateB` or `Derived` .
- When a `Derived` object is created:
  - `Base` is first created by `Derived` constructor,
  - `IntermediateA` and `IntermediateB` are then created,
  - the creation of `Base` in `IntermediateA` and `IntermediateB` contructors is neglected.

`virtual` inheritance and `virtual` functions



- `Base` can declare and implement a `virtual` function `f()`,
- `IntermediateA` can override that function,
- a function `g()` of `IntermediateB` can call `f()`,
- when `g()` is called:
  - for an `IntermediateB` object:
    `g()` in its turn calls `Base::f()`,
  - for a `Derived` object:
    `g()` in its turn calls `IntermediateA::f()`.