Object Oriented Programming
USTH, Master ICT, year 1

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2017/2018

Lecture 5 – Inheritance

- Simple inheritance
- Inheritance and access control
- Canonical form of derived class
- Multiple inheritance

Notion of inheritance

First example: a *colored* point, by inheritance from Point

```
class Point { /// Class "mother"
  int m_x, m_y;
 public:
  void initialize( int, int );
  void move( int, int );
  void print();
};
```

```
class ColoredPoint : public Point { /// Derive from
  short m_color;
 public:
  void color( short color ) {
    m_color = color;
  }
};
```

Interest of this inheritance

- Mainly: code *reusing* from Point ...
- But also: respect the principle of encapsulation
- Inherited classes are always reachable (public members)

Example of use:

```
ColoredPoint p;          /// Call to by default constructor
p.initialize( 10, 20);   // Member function inherited from class Point
p.color( 5 );            /// Member function of ColoredPoint
p.print();               // Inherited member function
p.move( 2, 4 );          /// idem
p.print();               /// idem
```

Access to ancestor members into inherited class

Respecting OOP basic principle

Derived class cannot access to private members of its ancestors classes

So, cannot write the following member function:

```
void printc() {
  cout<<"ColoredPoint at (" << m_x << "," << m_y << ")" << endl;
  cout<<"\tof color " << m_color << endl;
}
```

But, we can write this:

```
void printc() {
  print(); // call to inherited member function, idem : (*this).print()
  cout<<"\tof color " << m_color << endl;
}
```

Likewise, a dedicated initialization function will be:

```
void initializec( int x, int y, short color ) {
  initialize( x, y ); // idem : this->initialize( x, y )
  m_color = color;
}
```

Accessible members by inheritance

Derived class has access to PUBLIC members of its ancestor classes

Redefining derived members

- Possible, but hide ancestor class ones
- Range resolution to access them, inside and outside derived class
- Works both for both member function and member data

```
#include <iostream>
#include "point.h"

class ColoredPoint : public Point {
  short m_color;
public:
  void color( short color ) { m_color = color; }
  void print() ; // redefinition, hide inherited eponymous function
  void initialize( int, int, short ); // idem
};
void ColoredPoint::print() {
  Point::print();  // resolution, member function of class Point
  std::cout<<"\tand my color is "<<m_color<<std::endl;
}
void ColoredPoint::initialize( int x, int y, short couleur ) {
  Point::initialize( x, y ); // same thing
  m_color = color;
}

int main () {
  ColoredPoint p;
  p.initialize( 10, 20, 5 ); p.print(); // 2 functions from ColoredPoint
  p.Point::print();                     // Inherited function from Point
  p.move( 2, 4 );            p.print(); // Functions from ColoredPoint
  p.color( 2 );              p.print(); // Idem
  return 0;
}
```

Redefinition and overloading

Overloading: limits search to unique range

- Overloading completely hide inherited eponymous functions
- Possible to associate them to searching mechanism, with instruction `using A::f;` into class inheriting from A ...

First example

```
class A {
 public:
  void f(int n)  { .... }
  void f(char c) { .... }
};

class B : public A {
 public:
  void f(float x) { .... }
};

int main () {
  int n; char c; A a; B b;
  a.f(n); // call A::f(int)
  a.f(c); // call A::f(char)
  b.f(n); // call B::f(float);
  b.f(c); // call B::f(float);
  return 0;
}
```

Exemple 2

```
1  class A {
2   public:
3    void f(int n)  { .... }
4    void f(char c) { .... }
5    void g(int n)  { .... }
6  };
7  class B : public A {
8   public:
9    void f(int n)  { .... }
10   void g(int a, int b) { .... }
11
12 };
13 int main () {
14   int n; char c; B b;
15   b.f(n);    // call B::f(int);
16   b.f(c);    // call B::f(int);
17   b.g(n);    // compilation error ...
18   return 0; // solution: 11– "using A::g;"
19 }
```

Constructors

Hierarchy of calls

Hierarchical calls:

```cpp
class A {
  public:
    A(...);
    ~A();
    ...
};
```

```cpp
class B : public A {
  public:
    B(...);
    ~B();
    ...
};
```

- Writing `B b(...);` $\Longrightarrow$ call constructor of A and then of B
- Inverse order for destructors: ∼B() and then ∼A()

Transmitting information between constructors

- Mechanism allowing that: initialization list

```cpp
class Point {
  int m_x, m_y;
 public:
  Point(int x=0, int y=0) {
    m_x=x; m_y=y;
  }
  ~Point() {}
};
```

```cpp
class ColoredPoint : public Point {
  short m_color;
 public:
  ColoredPoint(int x, int y, short color)
     : Point( x, y )  {
    m_color = color;
  } // call the "good" constructor!
};
```

- Take care about derived class that do not have constructor

  $\Longrightarrow$ How to send initialization values to ancestors?

Access control: protected members

New status, adding to `public` and `private`: `protected`

- Inaccessible for class users
- Accessible to heirs (or successors)

Example

```cpp
class Point {
 protected:
  int m_x, m_y;
 public:
  Point(int x, int y) {
    m_x = x; m_y = y;
  }
  void print() {
    cout<<"Point("<<m_x<<","<<m_y<<")\n";
  }
};
```

```cpp
class ColoredPoint : public Point {
  short m_color;
 public:
  ColoredPoint(int x, int y, short color)
    : Point(x,y) {
    m_color = color;
  }
  void print() {// access to protected members
    cout<<"ColoredPoint("<<m_x<<","<<m_y
                                   <<","<<m_color")\n";
  }
};
```

Half public, half private

Example:

```cpp
1 int main () {
2   ColoredPoint cp( 10, 2, 1 );
3   cp.print(); // displays using ColoredPoint::print();
4   cout<<"Point at ("<<pc.m_x<<","<<pc.m_y<<")\n";
5   return 0;
6 }
```

⟹ Compilation error line 4: `m_x` and `m_y` are encapsulated

Public and private derivations

Three authorized derivation modes, same keywords than members ...

```
class ColorPoint
      : public Point
{  short m_color
 public:
  ColorPoint(int, int, short);
  void print();
  void color( int );
};
```

```
class ColorPoint
      : protected Point
{  short m_color
 public:
  ColorPoint(int, int, short);
  void print();
  void color( int );
};
```

```
class ColorPoint
      : private Point
{  short m_color
 public:
  ColorPoint(int, int, short);
  void print();
  void color( int );
};
```

$\Longrightarrow$ Modify access to public or protected members ...

- Except explicit mention (re-declaration, or using instruction)
- Example with member function move() ...

Summary

Base class			public		protected		private	
Initial Status	Access FMF	User access	New status	User Access	New status	User Access	New status	User Access
public	Y	Y	public	Y	protected	N	private	N
protected	Y	N	protected	N	protected	N	private	N
private	Y	N	private	N	private	N	private	N

NB: access FMF means Friend of Member Functions

Compatibility between base and derived classes

Basic rules: derived class object may replace base class object

upcasting example

```
enum note { middleC, Csharp, Cflat }; /// Etc.

class Instrument {
public:
  void play(note) const {}
};

/// Wind objects are Instruments
/// because they have the same interface:
class Wind : public Instrument {};
```

```
void tune(Instrument& i) {
  /// ...
  i.play(middleC);
}

int main() {
  Wind flute;
  tune(flute); // Upcasting
  return 0;
}
```

Pointer cast

```
class Point {
  int m_x, m_y;
 public:
  ...
  void print();
};
```

```
class ColorPoint : public Point {
  short m_color;
 public:
  ...
  void print(); // redefinition
};
```

Only (natural) cast bottom to “the top”:

```
Point      p (1,2) ,   *adp  = &p;
ColorPoint cp(0,0,1) , *adcp = &cp;
adp  = adcp; // OK, go up into tree view
adcp = adp ; // Compilation error (without cast operator)
```

Limitations linked to static type of object

```
class Point { /// Again, same object definition
protected:
  int m_x, m_y;
public:
  Point( int a=0, int o=0 ) : m_x(a), m_y(o) {}
  void print() const { cout<< "Point(" << m_x << "," << m_y << ")" <<endl;  }
};
class ColoredPoint : public Point { /// Child
  short m_color;
public:
  ColoredPoint( int a=0, int o=0, short color=1 ) : Point( a, o ), m_color( color ) {}
  void print() const {
    cout<< "ColoredPoint(" << m_x << "," << m_y << "," << m_color << ")" <<endl;
  }
};
int main () {
  Point p( 3, 5 );               Point *adp = &p;
  ColoredPoint cp( 8, 6, 2 ); ColoredPoint *adcp = &cp; // IT WILL DISPLAYS
  adp->print();                  adcp->print();          // Point(3,5)
  cout<< "---------------------------------" <<endl;    // ColoredPoint(8,6,2)
  adp = adcp;                                            // ---------------------------------
  adp ->print();                                         // Point(8,6)
  adcp->print();                                         // ColoredPoint(8,6,2)
  return 0;
}
```

- Method identification done by compiler, statically
  - Virtual function allows dynamic choice (next lecture)
- Risk to access to private member of base class ...

By-copy constructor (CC)

First case: no CC into derived class

Then, usage of “default” constructor

1. Using CC base class when it exists
2. Else using default CC base class
3. Warning: if CC constructor is private in base class ...

Second case: writing CC into derived class

C++ do not handle automatic call of base class CC

```
class Point {
protected:  int m_x, m_y;
public:     Point( int a=0, int o=0 ) : m_x(a), m_y(o) {}
            Point( Point& p ) : m_x(p.m_x), m_y(p.m_y) {}
};
class ColoredPoint : public Point { // We explicitly call the base class constructor
private: short m_c;                 // (following hierarchical order)
public:  ColoredPoint(int a=0, int o=0, short c=1) : Point( a, o ) , m_c(c) { };
         ColoredPoint( ColoredPoint& cp ) : Point(cp), m_c(cp.m_c) {};
};
void fct ( ColoredPoint cp ) {  cout<< "fct()" << endl;  }
int main () {  ColoredPoint cp(2,4,6);
               fct( cp );                /// What the constructor call order is?
               return 0;                 /// Same for destructors and functions?
}
```

Assignment operator and inheritance

First case: derived class does not overload =

Behavior is similar to by-copy constructor case ...

Second case: derived class does overload =

Base class assignment have to be considered ...

```cpp
class Point {
  int m_x, m_y;
public:
  ...
  Point& operator=(Point& p) {
    m_x = p.m_x;
    m_y = p.m_y;
    return *this;
  }
};
```

```cpp
class ColoredPoint : public Point {
  short m_color;
public:
  ...
  ColoredPoint& operator=(ColoredPoint& pc) {
    Point::operator=( pc ); // <- DO NOT FORGET
    m_color = pc.m_color;   //    TO COPY THE
    return *this;           //    INHERITED PARTS
  }
};
```

```cpp
int main () {
  ColoredPoint cp(2,4,6);
  ColoredPoint cp2 = cp; // by-copy constructor
  cp2 = cp;              // assignment operator
  return 0;
}
```

Canonical form of derived class

Complete base class scheme seen in lecture 4:

```
/// Base class
class T
{
 public:
  T ( ... ) ;                       /// constructors, others than by-copy
  T ( const T& ) ;                  /// by-copy constructor (recommended form)
  ~T ();                            /// destructor
  T& T::operator=( const T& ); /// assignment operator (recommended form)
};

/// Derived class
class U : public T
{
 public:
  U (...) : T( ... ) , ...      {} // Recommended to use complete initialization list
  U ( const U& x) : T(x) , ... {} // (including all members, plus the base class)

  ~U ();

  U& U::operator=( const U& x )
  {
    T::operator=( x ) ;             // first, copy the base class
     ... // then do what you have to
  }
};
```

The limits of inheritance

Let us consider following situation:

```
class A {
  ...
 public:
  T f(...);
  ...
};
```

```
class B : public A
{
  ....
  ....
};
```

Type of return value of f()

- Do not worry if `T` is any
- If `T == A`, how to return `B` in `B::f`? Is it desirable?
  - Solution using virtual function (next lecture)

Argument types of f()

Example with `T f(A);`

- Sending instance of A: ok
- Sending instance of B: ok, but after cast

Example `limits.cpp`: addition and equals ...

Example: limits.cpp

```
#include <iostream>
using namespace std;
class Point {
protected:
  int m_x, m_y;
public:
  Point( int a=0, int o=0) : m_x(a), m_y(o) {};
  Point( const Point& p ) : m_x(p.m_x), m_y(p.m_y) {};
  Point &operator+( const Point& p ) { /// What meaning for ColoredPoint?
    m_x += p.m_x;
    m_y += p.m_y;
    return (*this);
  }
  friend int equals ( const Point&, const Point& ); /// Quid with ColoredPoint?
  void print() { cout<<"Point("<<m_x<<","<<m_y<<")"<<endl; }
};
int equals( const Point& a, const Point& b ) {  return a.m_x == b.m_x && a.m_y == b.m_y; }
class ColoredPoint : public Point {
  short m_color;
public:
  ColoredPoint( int a=0, int o=0, short c=1 ) : Point( a, o ), m_color(c) {};
  ColoredPoint( const ColoredPoint& p ) : Point( p ), m_color(p.m_color)  {};
};
int main () {
  ColoredPoint a(2,5,3), b(2,5,9);
  Point c;
  if ( equals( a, b ) ) cout<<"a equals to b"<<endl;
  else cout<<"a differs from b"<<endl;       // Yes, they are equals as points!
  if ( equals( a, c ) ) cout<<"a equals to c"<<endl;
  else cout<<"a differs from c"<<endl;       // No, different coordinates
  c = a+b;     c.print(); /// Compilation error if c was ColoredPoint
  return 0;
}
```

Example of derived class

Let us restart with dynamic vector seen in lecture 4, slide 20:

```
class Vector {
  int  m_n;
  int *m_v;
public:
  Vector (int n) { m_v = new int[ m_n = n ]; } /// lacks of by-copy constructor
  ~Vector () { delete m_v; }                   /// and assignment operator
  int & operator [] ( int idx ) { return m_v[ idx<0? 0 : idx>=n ? n-1 : idx ]; }
};
```

Let us build dynamic vector with variable limits:

```
VVector v( 15, 24 ) ; // vector with 10 elements, indexed from 15 to 24 ...
```

Constructor with two arguments, and two supplementary instance variables:

```
class VVector : public Vector {
  int m_start, m_end;
public:
  VVector( int start, int end ) : Vector(end-start+1), m_start(start), m_end(end) {}
```

Do we need a destructor? No, it is useless ...

Access to elements: mandatory to overload [] operator ...

```
  int &operator[] ( int i ) {
    return Vector::operator[] ( i-m_start );
  }
};
```

NB: It lacks by-copy constructor and assignment operator ;-)

Introduction to multiple inheritance

An class may naturally inherits from many others ...

- Unique constraint: oriented graph without circuit (no self inheritance)
- Almost all things seen for simple inheritance apply to multiple case ...
- Some problems

Owed difficulties to multiple inheritance

- How to express multiple dependency?
- Which order for constructor calls / destructor calls?
- Conflict management: D inherits both from B and from C, what inherit from A

Multiple inheritance application

Similar to multiple composition ... Let us take an example:

```
class Point {
  int m_x, m_y;
public:
  Point(int a=0, int o=0) : m_x(a), m_y(o) {}
  ~Point() {}
  print() { cout<< ... << endl; }
};
```

```
class Color {
  short m_color;
public:
  Color(short c=1) : m_color(c) {}
  ~Color() {}
  print() { cout<< ... << endl; }
};
```

```
class ColoredPoint : public Point, public Color {
public:                                       // Call both constructors ...
  ColoredPoint( int a=0, int o=0, short c=1 ) : Point( a, o ), Color( c ) {}
  ~ColoredPoint() { cout<<"----- ColoredPoint() releasing" << endl; }
  void print() {
    Point::print();  /// range resolution allows correct selection
    Color::print();  /// of inherited methods and data members
  }
};
```

Order of constructors and destructors calls:

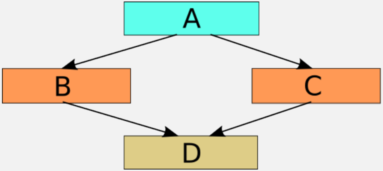
- Constructors: order of base classes declaration (eventually recursive), then constructor ...
- Destructors : the reverse ;-)

Example by instrumenting the previous 3 classes (`sources/multiple1`)...

Multiples occurrences of a same base class

Let us consider following situation:

- B inherits from A
- C inherits from A
- D inherits from B and C



It is like if any D's instance contains:

- 1 instance of B, 1 instance of C, and 2 different instances of A !
- Differentiation into D:

```
class A { int m_x; ... };
class B : public A { ... };
class C : public A { ... };
class D ; public B, public C {
  ...
  void f () {
    cout << "m_x = " << B::m_x << " and " << C::m_x << endl;
  }
};
```

Example with `sources/multiple2.cpp`

Example

```
#include <iostream>
using namespace std;

class A {
protected:
  int m_x;
public:
  A(int x=0) : m_x(x) { cout<< "++++ A("<< m_x << ")" << endl; }
  ~A()                { cout<< "---- A("<< m_x << ")" << endl; }
};

class B : protected A {
public:
  B(int x=0) : A(x + 10) { cout<< "++++ B("<< A::m_x << ")" << endl; }
  ~B()                   { cout<< "---- B("<< A::m_x << ")" << endl; }
};

class C : protected A {
public:
  C(int x=0) : A(x + 100) { cout<< "++++ C("<< A::m_x << ")" << endl; }
  ~C()                    { cout<< "---- C("<< A::m_x << ")" << endl; }
};

class D : protected B, protected C {
public:
  D(int x=0) : B(x), C(x) { cout<< "++++ D("<< B::m_x << "," << C::m_x << ")" << endl; }
  ~D()                    { cout<< "---- D("<< B::m_x << "," << C::m_x << ")" << endl; }
};

int main () {     D(3);
                  return 0;
}
```

Notion of virtual class

It is possible to avoid this duplication with virtual classes

```
class B : public virtual A { ... }; // or: virtual public A
class C : public virtual A { ... }; // (order does not mind)
class D : public B, public C {
  ...
  void f () { /// no more double, so no more range resolution
    cout << " x = " << m_x << endl;
  }
};
```

Defining A as virtual into B's declaration means that A will be copied once into all heirs of B ...

For B, it changes nothing ...

Order of constructors and destructors calls

- First come constructor of virtual classes
- Then, the others

Example: constructor calls order

```
#include <iostream>
using namespace std;
//////////////////////////////////////////
class O {
public:
  O()  { cout << "++++ O()" << endl; }
  ~O() { cout << "---- O()" << endl; }
};
//////////////////////////////////////////
class A : public O {
protected:
  int m_x;
public:
  A(int x=0) : O(), m_x(x) {
    cout<< "++++ A("<< m_x << ")" << endl;
  }
  ~A() {
    cout<< "---- A("<< m_x << ")" << endl;
  }
};

//////////////////////////////////////////
class B : public virtual A {
public:
  B(int x=0) { // no direct constructor
    m_x = x + 10;
    cout<< "++++ B("<< A::m_x << ")" << endl;
  }
  ~B() {
    cout<< "---- B("<< A::m_x << ")" << endl;
  }
};
//////////////////////////////////////////
class C : virtual public A {
public:
  C(int x=0) {
    m_x = x+100;
    cout<< "++++ C("<< A::m_x << ")" << endl;
  }
  ~C() {
    cout<< "---- C("<< A::m_x << ")" << endl;
  }
};

//////////////////////////////////////////
class D : public B, public C {
public:
  D(int x=0) : B(x), C(x) {
    cout<< "++++ D("<< B::m_x << ","
        << C::m_x << ")" << endl;
  }
  ~D() {
    cout<< "---- D("<< B::m_x << ","
        << C::m_x << ")" << endl;
  }
};

//////////////////////////////////////////
int main () {
  D(3);
  return 0;
}
// test : ./sources/multiple3
```

Example of multiple inheritance I

```cpp
#include <iostream>
using namespace std;
///
class Point {
protected:
  int m_x, m_y;
public:
  Point( int abs=0, int ord=0) : m_x(abs), m_y(ord) {
    cout << "++++++ Point(" << abs << "," << ord << ")" << endl;
  }
  void print() { cout << "Coordinates: " << m_x << " and " << m_y << endl; }
};
///
class Color {
  short m_color;
public:
  Color( short color=1 ) : m_color( color ) {
    cout << "++++ Color(" << m_color << ")" << endl;
  }
  void print() { cout << "Color : " << m_color << endl; }
};
///
class Mass {
  int m_mass;
public:
  Mass( int m=100 ) : m_mass( m ) {
    cout << "++++ Mass(" << m_mass << ")" << endl;
  }
  void print () { cout << "Mass: " << m_mass << endl; }
};
```

Example of multiple inheritance II

```
class ColoredPoint : public virtual Point, public Color {
public:
  ColoredPoint( int abs, int ord, int cl ) : Point(abs, ord), Color( cl ) {
    cout << "++ ColoredPoint(" << m_x << "," << m_y << "," << cl << ")" << endl;
  }
  ColoredPoint( int cl ) : Color( cl ) { cout << "++ ColoredPoint(" << cl << ")" << endl; }
  void print() {    Point::print();    Color::print();  }
};
///
class MassPoint : public virtual Point, public Mass {
public:
  MassPoint( int abs, int ord, int ms ) : Point(abs, ord), Mass( ms ) {
    cout << "++ MassPoint(" << m_x << "," << m_y << "," << ms << ")" << endl;
  }
  void print() {    Point::print();    Mass::print();  }
};
///
class ColoredMassPoint : public ColoredPoint, public MassPoint {
public:
  ColoredMassPoint( int abs, int ord, short c, int m )
    : Point( abs, ord ), ColoredPoint( c ), MassPoint( abs, ord, m ) {
    cout << "ColoredMassPoint(" << abs << "," << ord << "," << c << "," << m << ")" << endl;
  }
  void print() {    Point::print();    Color::print();    Mass::print();  }
};
///
int main () {
  cout << "****************" << endl;  ColoredPoint     p( 3, 9, 2 );        p.print();
  cout << "****************" << endl;  MassPoint        mp( 12, 25, 100 );   mp.print();
  cout << "****************" << endl;  ColoredMassPoint cmp( 2, 5, 10, 20 ); cmp.print();
  return 0;
}
```