CS32 Summer 2013

Object-Oriented Programming in C++

Inheritance

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Plan for Today

- Inheritance: State, Implementation, Interface
- Accessing Base
- Construction and Destruction
- Slicing
- Polymorphism and Virtual Functions

Next time:

- Alternatives to Virtual Functions, RTTI
- Abstract Classes
- Multiple Inheritance and Class Hierarchies
- ...

Inheritance of State

- Classes may share a great deal of their internals (their *state*, in particular)

```
class HighSchoolStudent {
private:
   char *_full_name;
   time_t _dob;
   char *_ssn;
};

class UniversityStudent {
private:
   char *_full_name;
   time_t _dob;
   char *_ssn;
   char *_perm;
   char *_major;
   int advisor_id;
};
```

- Can we describe the part classes *share* only once?

Inheritance of State

- Solution: *derive* one class from another

```
class HighSchoolStudent {
private:
    char *_full_name;
    time_t _dob;
    char *_ssn;
};
```

– "base class for UniversityStudent"

```
class UniversityStudent : public HighSchoolStudent {
private:
    char *_perm;
    char *_major;
    int advisor_id;
};
```

– "class derived from HighSchoolStudent"

Inheritance of State

- Solution: *derive* one class from another

```
class HighSchoolStudent {
private:
    char *_full_name;
    time_t _dob;
    char *_ssn;
};
```

HighSchoolStudent	
_full_name	(4 bytes)
_dob	(4 bytes)
_ssn	(4 bytes)

```
class UniversityStudent  : public HighSchoolStudent {
private:
    char *_perm;
    char *_major;
    int advisor_id;
};
```

UniversityStudent	
_full_name	(4 bytes)
_dob	(4 bytes)
_ssn	(4 bytes)
_perm	(4 bytes)
_major	(4 bytes)
_advisor_id	(4 bytes)

Accessing Base State

- Derived class cannot access private members of its base class

```
class HighSchoolStudent {
private:
   char *_full_name;
   time_t _dob;
   char *_ssn;
public:
   void print() const;
};

class UniversityStudent  : public HighSchoolStudent {
private:
   char *_perm;
   char *_major;
   int advisor_id;
public:
   void mymethod() {
     print(); // ok; member print() is public
     _dob = 12345; // error; _dob is private
   }
};
```

Accessing Base State

- Making private members public is a bad idea
- We can make a member protected:

```
class HighSchoolStudent {
private:
   char *_full_name;
   char *_ssn;
protected:
   time_t _dob; // - still not accessible from "the outside"
public:
   void print() const;
};

class UniversityStudent  : public HighSchoolStudent {
private:
   char *_perm;
   char *_major;
   int advisor_id;
public:
   void mymethod() {
      _dob = 12345; // ok; _dob is protected
   }
};
```

Accessing Base State

- Protected is better than public (but not very much)
- Rules for choosing access specifiers:
  - Never give direct access to class' state to anyone; *fields* should always be private
  - If you provide public getter and setter for a field, it is not always the same as making such a field public
  - If “the outside” needs to access class' internals, provide a public *method*
  - If a derived class needs to access class' internals, provide a protected *method*
  - Never make anything (fields or methods) public if it can live fine as private (– best) or protected
- Be conservative!

Accessing Base State

```
class HighSchoolStudent {
private:
   char *_full_name;
   time_t dob;
   char *ssn;
protected:
   void set_dob(time_t dob) { … }
public:
   time_t get_dob() const { … }
};

class UniversityStudent  : public HighSchoolStudent {
private:
   char *_perm;
   char *_major;
   int advisor_id;
public:
   void mymethod() {
       set_dob(12345); // ok; set_dob(time_t) is protected
   }
};

UniversityStudent st;
time_t dob = st.get_dob(); // ok; get_dob() is public
st.set_dob(333); // error; set_dob(time_t) is protected
```

Inheritance of Implementation

- Behavior (“implementation”) is also inherited

```
class HighSchoolStudent {
private:
   time_t dob;
public:
   time_t get_dob() const { … }
};

class UniversityStudent : public HighSchoolStudent {
  ...
};

HighSchoolStudent s1;
UniversityStudent s2;
bool same_dob = s1.get_dob() == s2.get_dob();
```

Inheritance of Interface

- Objects of derived classes can be treated as objects of base classes

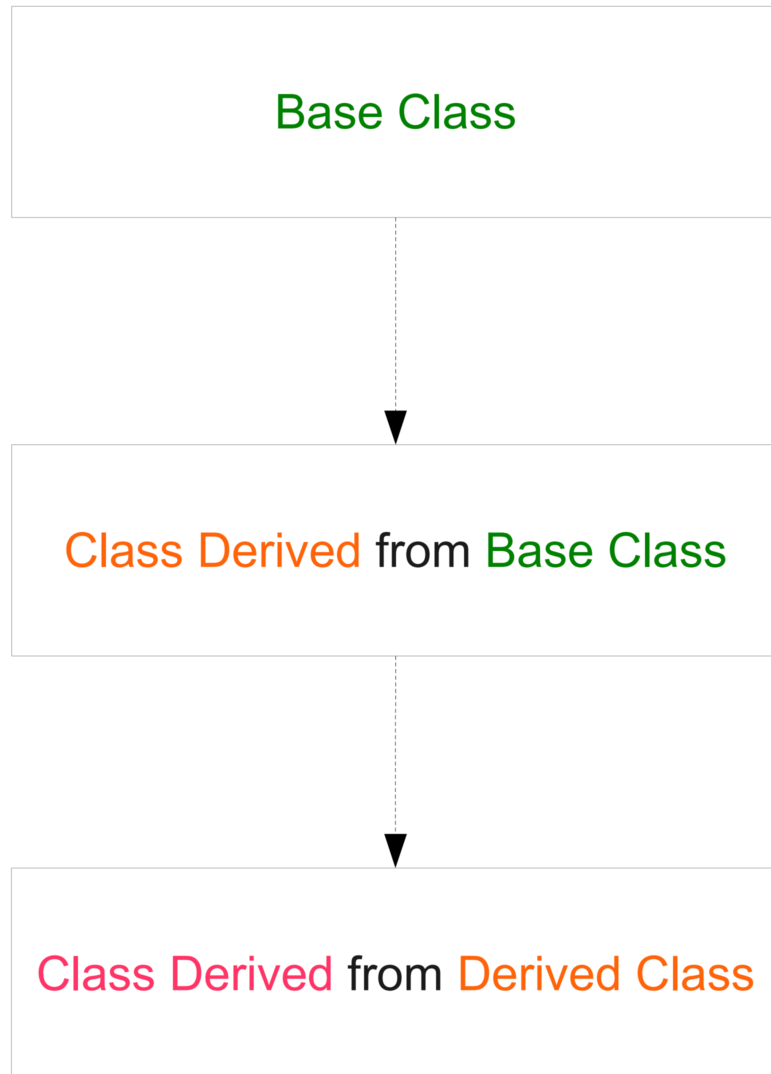
```
class HighSchoolStudent {
public:
   time_t get_dob() const { … }
};

class UniversityStudent : public HighSchoolStudent {
  ...
};

// pstud will point to an object of class UniversityStudent
HighSchoolStudent *pstud = new UniversityStudent(...);
pstud->get_dob();
```

Public/Protected/Private Inheritance

- Types of inheritance differ in how access specifiers are inherited

```
class Base {
  private: int private_member;
  protected: int protected_member();
  public: int public_member();
};

class DerivedPublic : public Base {
   // private_member is not accessible here
   // protected_member() is protected here
   // public_member() is public here
};

class DerivedProtected : protected Base {
   // private_member is not accessible here
   // protected_member() is protected here
   // public_member() is protected here
};

class DerivedPrivate : private Base {
   // private_member is not accessible here
   // protected_member() is private here
   // public_member() is private here
};
```

Inheritance and Construction



“Bottom-up” construction

Bjarne Stroustrup draws his class diagrams with derived classes above and base classes below. Hence the name “bottom-up” construction.

Inheritance and Construction

- Demo: http://cs.ucsb.edu/~victor/ta/cs32/disc4/code/constr.cpp

```
class Class1 {
public:
   Class1() { cout << "Class1 default ctor called.\n"; }
   Class1(int i) {
     cout << "Class1 ctor(int " << i << ") called.\n";
   }
};

class Class2 : public Class1 {
public:
   Class2() { cout << "Class2 default ctor called.\n"; }
   Class2(char c) {
     cout << "Class2 ctor(char '" << c << "') called.\n";
   }
};

class Class3 : public Class2 {
public:
   Class3() : Class2('x') {
     cout << "Class3 default ctor is called.\n";
   }
};
```

Inheritance and Construction

```
Class1 obj;
>> Class1 default ctor is called.

class Class1 {
public:
   Class1() { cout << "Class1 default ctor called.\n"; }
   Class1(int i) {
     cout << "Class1 ctor(int " << i << ") called.\n";
  }
};

class Class2 : public Class1 {
public:
   Class2() { cout << "Class2 default ctor called.\n"; }
   Class2(char c) {
     cout << "Class2 ctor(char '" << c << "') called.\n";
   }
};

class Class3 : public Class2 {
public:
   Class3() : Class2('x') {
     cout << "Class3 default ctor is called.\n";
  }
};
```

Inheritance and Construction

```
Class1 obj2(123);
>> Class1 ctor(int 123) is called.

class Class1 {
public:
   Class1() { cout << "Class1 default ctor called.\n"; }
   Class1(int i) {
     cout << "Class1 ctor(int " << i << ") called.\n";
   }
};

class Class2 : public Class1 {
public:
   Class2() { cout << "Class2 default ctor called.\n"; }
   Class2(char c) {
     cout << "Class2 ctor(char '" << c << "') called.\n";
    }
};

class Class3 : public Class2 {
public:
   Class3() : Class2('x') {
     cout << "Class3 default ctor is called.\n";
   }
};
```

Inheritance and Construction

```
Class2 obj3;
>> Class1 default ctor is called.
>> Class2 default ctor is called.

class Class1 {
public:
   Class1() { cout << "Class1 default ctor called.\n"; }
   Class1(int i) {
     cout << "Class1 ctor(int " << i << ") called.\n";
   }
};

class Class2 : public Class1 {
public:
   Class2() { cout << "Class2 default ctor called.\n"; }
   Class2(char c) {
     cout << "Class2 ctor(char '" << c << "') called.\n";
    }
};

class Class3 : public Class2 {
public:
   Class3() : Class2('x') {
     cout << "Class3 default ctor is called.\n";
   }
};
```

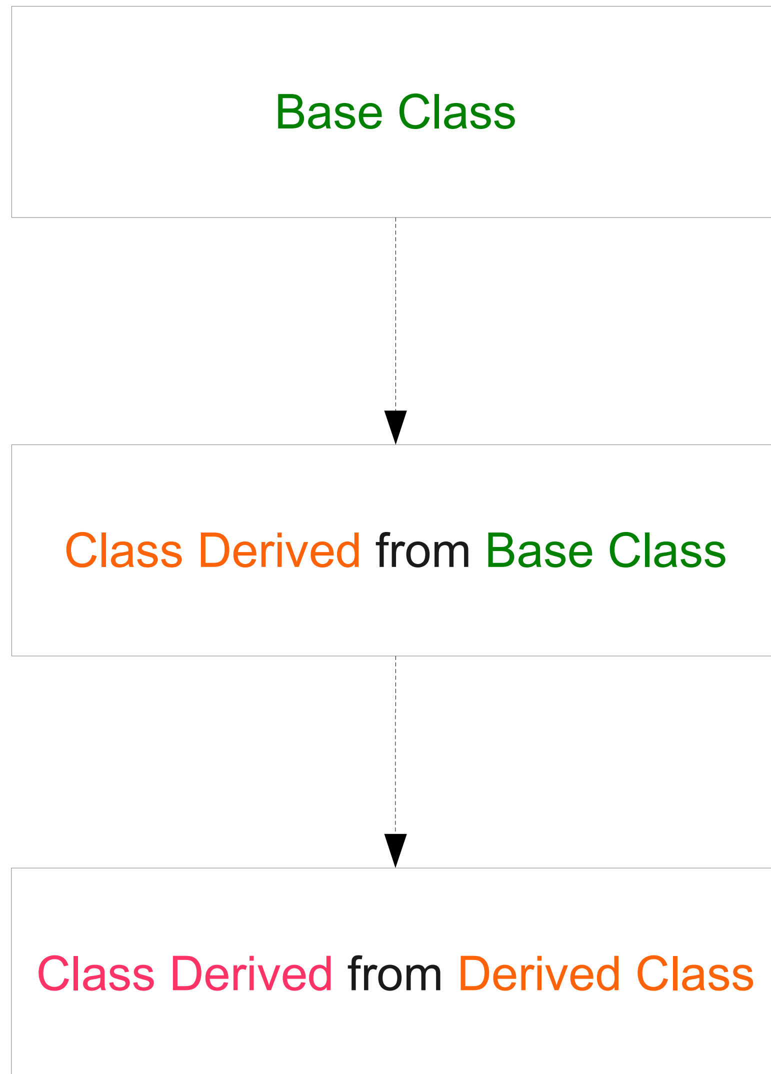
Inheritance and Construction

```
Class2 obj4('z');
>> Class1 default ctor is called.
>> Class2 ctor(char 'z') is called.

class Class1 {
public:
   Class1() { cout << "Class1 default ctor called.\n"; }
   Class1(int i) {
     cout << "Class1 ctor(int " << i << ") called.\n";
   }
};

class Class2 : public Class1 {
public:
   Class2() { cout << "Class2 default ctor called.\n"; }
   Class2(char c) {
     cout << "Class2 ctor(char '" << c << "') called.\n";
   }
};

class Class3 : public Class2 {
public:
   Class3() : Class2('x') {
     cout << "Class3 default ctor is called.\n";
   }
};
```

Inheritance and Construction

```
Class3 obj5;
>> Class1 default ctor is called.
>> Class2 ctor(char 'x') is called.
>> Class3 default ctor is called.

class Class1 {
public:
   Class1() { cout << "Class1 default ctor called.\n"; }
   Class1(int i) {
     cout << "Class1 ctor(int " << i << ") called.\n";
   }
};

class Class2 : public Class1 {
public:
   Class2() { cout << "Class2 default ctor called.\n"; }
   Class2(char c) {
     cout << "Class2 ctor(char '" << c << "') called.\n";
   }
};

class Class3 : public Class2 {
public:
   Class3() : Class2('x') {
     cout << "Class3 default ctor is called.\n";
   }
};
```

Inheritance and Destruction



"Top-down" destruction

Bjarne Stroustrup draws his class diagrams with derived classes above and base classes below. Hence the name "top-down" destruction.

Inheritance and Destruction

- Demo http://cs.ucsb.edu/~victor/ta/cs32/disc4/code/destr.cpp

```
class Class1 {
public:
    ~Class1() { cout << "Class1 destructor called.\n"; }
};

class Class2 : public Class1 {
public:
    ~Class2() { cout << "Class2 destructor called.\n"; }
};

class Class3 : public Class2 {
public:
    ~Class3() { cout << "Class3 destructor called.\n"; }
};
```

Inheritance and Destruction

```
Class1 *pobj = new Class1; delete pobj;
>> Class1 destructor called.

class Class1 {
public:
   ~Class1() { cout << "Class1 destructor called.\n"; }
};

class Class2 : public Class1 {
public:
   ~Class2() { cout << "Class2 destructor called.\n"; }
};

class Class3 : public Class2 {
public:
   ~Class3() { cout << "Class3 destructor called.\n"; }
};
```

Inheritance and Destruction

```
Class2 *pobj = new Class2; delete pobj;
>> Class2 destructor called.
>> Class1 destructor called.

class Class1 {
public:
    ~Class1() { cout << "Class1 destructor called.\n"; }
};

class Class2 : public Class1 {
public:
    ~Class2() { cout << "Class2 destructor called.\n"; }
};

class Class3 : public Class2 {
public:
    ~Class3() { cout << "Class3 destructor called.\n"; }
};
```

Inheritance and Destruction

```
Class3 *pobj = new Class3; delete pobj;
>> Class3 destructor called.
>> Class2 destructor called.
>> Class1 destructor called.

class Class1 {
public:
   ~Class1() { cout << "Class1 destructor called.\n"; }
};

class Class2 : public Class1 {
public:
   ~Class2() { cout << "Class2 destructor called.\n"; }
};

class Class3 : public Class2 {
public:
   ~Class3() { cout << "Class3 destructor called.\n"; }
};
```

Inheritance and Destruction

```
Class1 *pobj = new Class3; delete pobj;
>> Class1 destructor called. // see virtual dtor slide

class Class1 {
public:
    ~Class1() { cout << "Class1 destructor called.\n"; }
};

class Class2 : public Class1 {
public:
    ~Class2() { cout << "Class2 destructor called.\n"; }
};

class Class3 : public Class2 {
public:
    ~Class3() { cout << "Class3 destructor called.\n"; }
};
```

Intermezzo: Initialization Lists vs. Assignment

- Demo http://cs.ucsb.edu/~victor/ta/cs32/disc4/code/initlist.cpp
- Before executing ctor's body, object's fields get initialized

```
class Value {
private:
  int state;
public:
  Value() : state(0) { … }
  Value(int i) : state(i) { … }
  Value(const Value& other) : state(other.state) { … }
  Value& operator=(const Value &other) { … }
};

class MyClass {
private:
  Value val;
public:
  MyClass(const Value &v) { val = v; }
  MyClass(const Value &v, int dummy) : val(v) { }
  // need dummy since 2'nd ctor must have different signature
};
```

Intermezzo: Initialization Lists vs. Assignment

```
Value v(123);
>> Value's ctor(int 123) is called.

MyClass obj1(v);
>> Value's default ctor is called.
>> Entered MyClass ctor (assignment version).
>> Value's op=(Value{state=123}) is called.

MyClass obj2(v, 0);
>> Value's ctor(int 123) is called.
>> Entered MyClass ctor (initialization list version).


class MyClass {
private:
  Value val;
public:
  MyClass(const Value &v) { cout …; val = v; }
  MyClass(const Value &v, int dummy) : val(v) { cout …; }
};
```

Inheritance of Overloads (Lack of)

- Method overloading does not work across scopes

```
class Base {
public:
   int doit(int n);
};

class Derived {
public:
   int doit(double d); // overloading doit
};

Derived obj;
obj.doit(1); // Derived::doit(double) is called

Base *pobj = &obj;
pobj->doit(1); // Base::doit(int) is called
```

Inheritance of Overloads (Lack of)

- We can explicitly "invite" overloads to the new scope

```
class Base {
public:
   int doit(int n);
};

class Derived : public Base {
public:
   using Base::doit; // import all overloads of doit
   int doit(double d); // overloading doit
};

Derived obj;
obj.doit(1); // Derived::doit(int) is called

Base *pobj = &obj;
pobj->doit(1); // Derived::doit(int) is called
```

- Demo `http://cs.ucsb.edu/~victor/ta/cs32/disc4/code/overloading.cpp`

Inheritance of Constructors (Lack of)

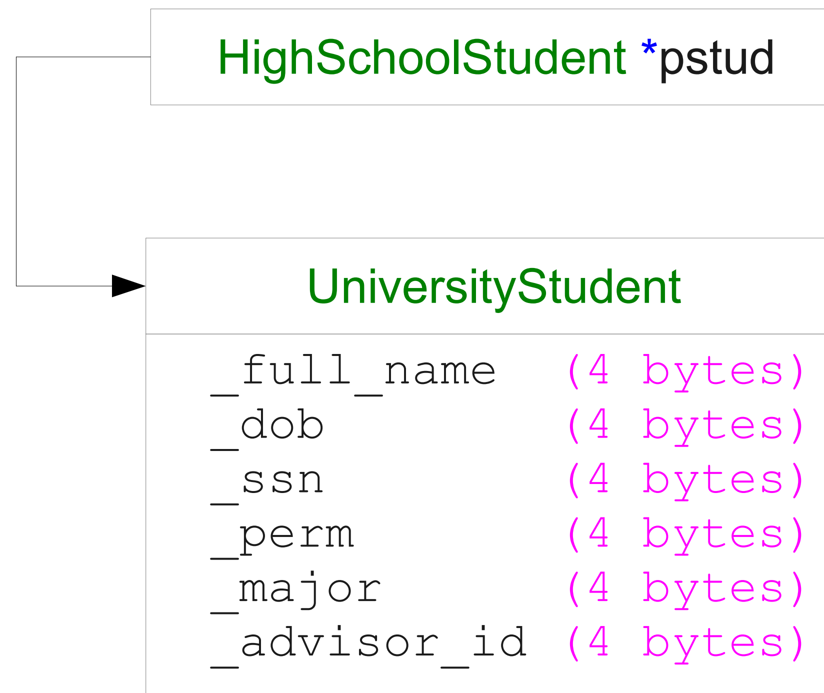
- Constructors are also not inherited
- We can “invite” constructors from the base like it has been done with overloads

```
class Base {
public:
   Base(int n) { }
};

class Derived : public Base {
public:
   using Base::Base; // imports ctor(int n)
};
```

Slicing

- Objects of derived classes can be treated as objects of base classes **if used through pointers or references**

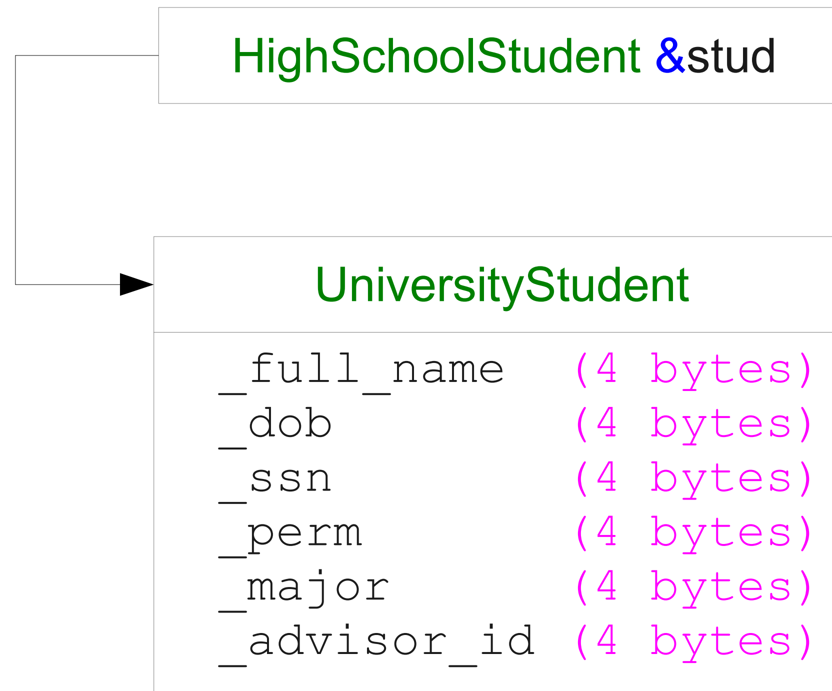
```
class HighSchoolStudent { … }
class UniversityStudent : public HighSchoolStudent { … };

HighSchoolStudent *pstud = new UniversityStudent(...);
```



Slicing

- Objects of derived classes can be treated as objects of base classes **if used through pointers or references**

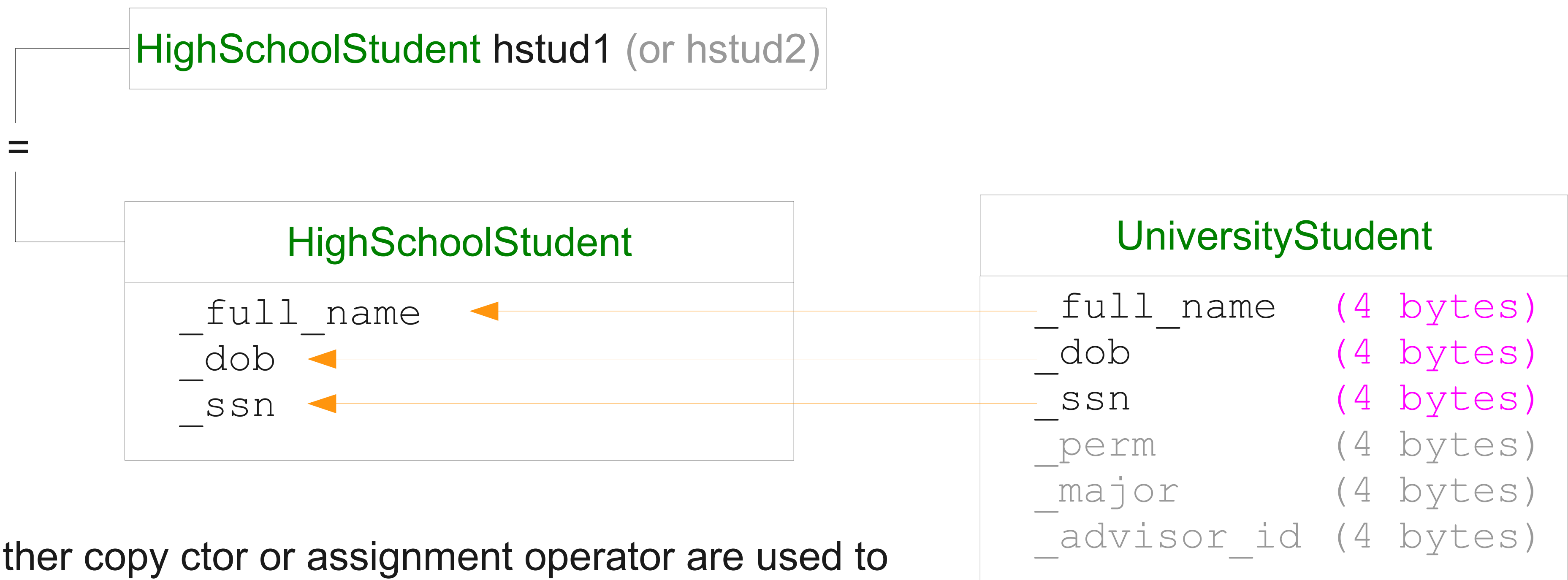
```
class HighSchoolStudent { … }
class UniversityStudent : public HighSchoolStudent { … };

HighSchoolStudent &stud = univ_student;
```



Slicing

- Not using pointers or references, assignment results in *slicing*

```
class HighSchoolStudent { … }
class UniversityStudent : public HighSchoolStudent { … };

UniversityStudent ustud;
HighSchoolStudent hstud1(ustud); // ustud gets sliced
HighSchoolStudent hstud2 = ustud; // ustud gets sliced
```



Either copy ctor or assignment operator are used to initialize fields of hstud1 with field values from ustud.

Polymorphism and Virtual Functions

- Inheritance prevents code duplication
- Common functionality is defined in the base class
- Then, it is inherited by derived classes
- What if an inherited method needs to be *redefined (“overridden”)* in a derived class?

```
class Class1 { void doit() { } };
class Class2 : public Class1 { … };
class Class3 : public Class2 {
   // void doit() has been inherited from Class1
   // want to override void doit() for Class3
};
```

Polymorphism and Virtual Functions

- Why not to simply define method doit() in Class3?

```
class Class1 {
   void doit() { cout << "hello from Class1"; }
};

class Class2 : public Class1 { … };

class Class3 : public Class2 {
   void doit() { cout << "hello from Class3"; }
};

Class1 obj1; obj1.doit();
>> hello from Class1
Class2 obj2; obj2.doit();
>> hello from Class1
Class3 obj3; obj3.doit();
>> hello from Class3

Class1 *pobj = &obj3; pobj->doit();
>> hello from Class1
```

- Demo http://cs.ucsb.edu/~victor/ta/cs32/disc4/code/polymotiv.cpp

Polymorphism and Virtual Functions

- We may want to have a pointer/reference of base type pointing to an object of a derived type

```
class Shape {
public:
   void draw() {
      /* do nothing; do not know what to draw */
   }
};

class Triangle : public Shape { …draw() is redefined… };
class Sphere : public Shape { …draw() is redefined… };
class Rect : public Shape { …draw() is redefined… };

void drawShape(Shape *pshape) {
   // pshape can point to any shape (Triangle, Sphere, Rect)
   pshape->draw();
}

drawShape(&my_triangle_obj); // should draw a triangle
drawShape(&my_sphere_obj); // should draw a sphere
```

- “Polymorphism”: pshape can take many forms (sphere, triangle, ...)

Polymorphism and Virtual Functions

- In C++, polymorphism is implemented through virtual functions (aka virtual methods)

```
class Shape {
public:
   virtual void draw() { }
};

class Triangle : public Shape {
   void draw() { … draw triangle … }
};

class Sphere : public Shape {
   void draw() { … draw sphere …  }
};

Triangle triangle; Sphere sphere;

Shape shape1(triangle); shape1.draw();
>> Nothing is drawn (Shape's draw() is called)

Shape &shape2 = sphere; shape2.draw();
>> Circle is drawn (Circle's draw() is called)

Shape *pshape3 = &triangle; pshape3->draw();
>> Triangle is drawn (Triangle's draw() is called)
```

- Demo http://cs.ucsb.edu/~victor/ta/cs32/disc4/code/shapes.cpp

Polymorphism and Virtual Functions

- Which *regular* function is called depends on the *declared type* of the variable

```
Base obj(my_derived_obj); // my_derived_obj is sliced
obj.regular_method(); // Base'es method is called
```

- Which *virtual* function is called depends on *the actual type of the object* a pointer/reference points to

```
Base *pobj = new Derived();
pobj->virtual_method(); // Derived's method is called
                        // (it is overridden in Derived)
```

- If a function is declared virtual, it is virtual in all derived classes
- In C++11, we can mark overridden virtual functions with override

```
class Shape { public: virtual void draw() { } };

class Triangle : public Shape {
   // the reader sees that draw has been decl'ed virtual
   void draw() override { … draw triangle … }
};
```

Virtual Functions: Calling Base

- Virtual methods can call other methods
- In particular, they can call their base implementations

```
// http://cs.ucsb.edu/~victor/ta/cs32/disc4/code/virtbase.cpp
class Base {
public:
   virtual int doit() { cout << "Base::doit()\n"; }
};

class Derived : public Base {
public:
   int doit() {
      cout << "Entered Derived::doit()\n";
      Base::doit();
      cout << "Leaving Derived::doit()\n";
   }
};

Derived derived;
Base *pbase = &derived;
pbase->doit();

>> Entered Derived::doit()
>> Base::doit()
>> Leaving Derived::doit()
```

Virtual Destructor

- Destructors are methods
- A non non-virtual destructor, like any other method, will not be called through a pointer/reference to a base class

```
class Base {
public:
   ~Base() { cout << "Base::~Base()\n"; }
};

class Derived : public Base {
public:
   ~Derived() { cout << "Derived::~Derived()\n"; }
};

Base *pobj = new Derived();
delete pobj; // only Base::~Base() is called
```

Virtual Destructor

- If a chain of destructors should be called (like on the slide with top-down destruction) when operating on pointers/references, destructor needs to be virtual

```
// http://cs.ucsb.edu/~victor/ta/cs32/disc4/code/virtdest.cpp
class Base {
public:
   virtual ~Base() { cout << "Base::~Base()\n"; }
};

class Derived : public Base {
public:
   ~Derived() { cout << "Derived::~Derived()\n"; }
};

Base *pobj = new Derived();
delete pobj;
>> Derived::~Derived()
>> Base::~Base()
```

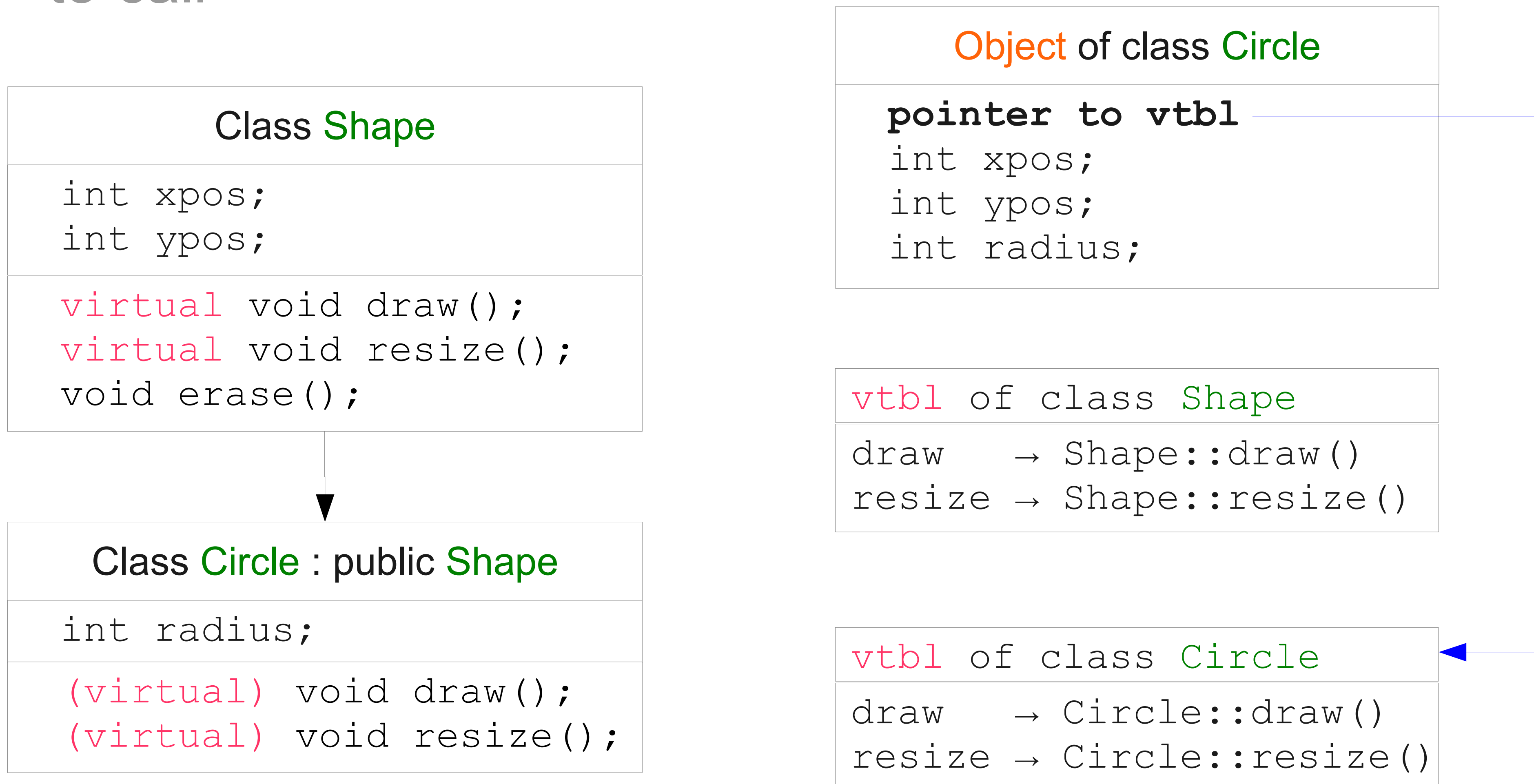
Bypass of Dynamic Dispatch

- Calling a virtual method through a pointer/reference will by done by the means of *dynamic dispatch* – which implementation to call will be chosen automatically based on the pointed object
- If needed, *static dispatch* can be enforced by the means of *explicit qualification*, thereby, allowing to call any implementation of a (virtual) method

```
class Base {
public:
   virtual void doit() { cout << "Base::doit()\n"; }
};

class Derived : public Base {
public:
   void doit() { cout << "Derived::doit()\n"; }
};

Derived obj;
Base *pobj = &obj;
pobj->doit(); // calling Derived::doit() (dynamic dispatch)
pobj->Base::doit(); // calling Base::doit() (static dispatch)
```

Cost of Polymorphism

- Objects of a class that has virtual functions contain a pointer to the **table of virtual functions** (aka **vtbl**) – this is how *dynamic dispatch* knowns which implementation to call



Calling Virtual Functions from Ctors/Dtors

- Dynamic dispatch does not work as usually inside constructors/destructors
- Instead of the implementation from the "most derived" class, the current or the closest base implementation is called (– feature; not a bug)
- To avoid problems, you may want to refrain from calling virtual functions from ctors/dtors

~ The End ~

(To be continued...)