
Creative Software Design

9 – Polymorphism 1

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Outline

- What is Polymorphism?
- Pointers & References with Inheritance
- Polymorphism in C++
- Virtual Function
- Virtual Destructor
- Caution: Object Slicing

What is Polymorphism?

- From Greek words: “poly” means "many, much" and “morphism” means "form, shape“
- The ability to create a variable, a function, or an object **that has more than one form**. [wikipedia] - 다형성 (多形性).
- In other words,
 - Ability of an object of type A **to appear as and be used like another type B**
 - Ability to provide **access to entities of different types through the same interface**
- One of the fundamental OOP principles

Real-world Examples

- Steering wheel + accelerator + brake in trucks or cars.
the same interface for *entities of different types*
- Volume + channel control in TV or DVD player remotes.
the same interface for *entities of different types*
- Shutter button for film or digital cameras.
the same interface for *entities of different types*

Types of Polymorphism

- **Subtype polymorphism (today's topic)**
 - Ability to **access a derived class object** through **its base class interface**
 - Often simply referred to as just “polymorphism”.
- Ad hoc polymorphism
 - Allows functions with the same name to work differently for each type
 - Overloading in C++
- Parametric polymorphism
 - Allows a function or a data type to be written generically
 - Templates in C++
- Coercion polymorphism
 - (Implicit or explicit) casting in C++

An Example of Subtype Polymorphism

```
class Animal
{
public:
    virtual string talk() = 0;
};

class Cat : public Animal
{
public:
    virtual string talk()
    { return "Meow!"; }
};

class Dog : public Animal
{
public:
    virtual string talk()
    { return "Woof!"; }
};

void letsHear(Animal& animal)
{ cout << animal.talk() << endl; }

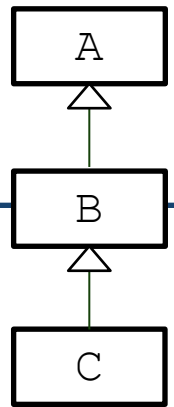
int main()
{
    Cat cat;
    Dog dog;
    letsHear(cat);
    letsHear(dog);
    return 0;
}
```

Pointers & References with Inheritance

- To use polymorphism in C++, you first have to understand **how to use pointers and references with inheritance**
- Recall that inheritance implies “is-a” relationship
 - A car is a vehicle.
 - A truck is a vehicle.
 - A cart is a vehicle.
 - ...

Pointers with Inheritance

- A class (B) pointer can store
 - the address of its own class (B) object
 - the address of its derived class (C) object
 - CANNOT store the address of its base (A) class object




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

class Person
{
public:
    void talk()
    {
        cout << "talk" << endl;
    }
};

class Student : public Person
{
public:
    void study()
    {
        cout << "study" << endl;
    }
};

class CSStudent : public Student
{
public:
    void writeCode()
    {
        cout << "writeCode" << endl;
    }
};
```

```
int main()
{
    Student* s1 = new Person; // error
    // A Person CANNOT be regarded as a Student.

    Student* s2 = new Student;
    // A Student is regarded as a Student

    Student* s3 = new CSStudent;
    // A CSStudent is regarded as a Student

    Person* p1 = new Person;
    Person* p2 = new Student;
    Person* p3 = new CSStudent;

    delete p1;
    delete p2;
    delete p3;

    delete s1;
    delete s2;
    delete s3;

    return 0;
}
```

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

class Person
{
public:
    void talk()
    {
        cout << "talk" << endl;
    }
};

class Student : public Person
{
public:
    void study()
    {
        cout << "study" << endl;
    }
};

class CSStudent : public Student
{
public:
    void writeCode()
    {
        cout << "writeCode" << endl;
    }
};
```

```
int main()
{
    Student st;

    Person* person_st = &st; // ok
    // A Student is regarded as a Person.

    Student* student_st = &st; // ok
    // A Student is regarded as a Student.

    CSStudent* csstudent_st = &st; //error!
    // A Student CANNOT be regarded as a CSStudent.

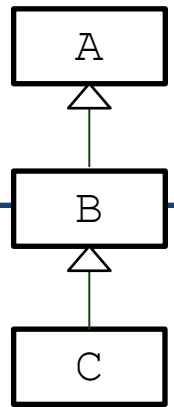
    CSStudent csst;

    Person* person_csst = &csst; // ok
    Student* student_csst = &csst; // ok
    CSStudent* csstudent_csst = &csst; //ok

    return 0;
}
```

Pointers with Inheritance

- A class (B) pointer can access
 - the members of its base class (A)
 - the members of its own class (B)
 - CANNOT access the members of its derived class (C)



```

#include <iostream>
using namespace std;

class Person
{
public:
    void talk()
    {
        cout << "talk" << endl;
    }
};

class Student : public Person
{
public:
    void study()
    {
        cout << "study" << endl;
    }
};

class CSStudent : public Student
{
public:
    void writeCode()
    {
        cout << "writeCode" << endl;
    }
};

```

```

int main()
{
    Student st;
    Person* person_st = &st;
    // A Student is regarded as a Person.

    person_st->talk();
    person_st->study(); // error!
    person_st->writeCode(); // error!
    // You cannot call them because not
all Persons are Students or CSStudents.

    return 0;
}

```

```

int main()
{
    Student st;
    Student* student_st = &st;

    student_st->talk();
    student_st->study();
    student_st->writeCode(); // error!

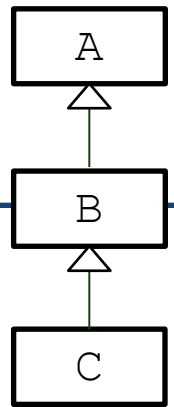
    return 0;
}

```

References with Inheritance

- A class (B) reference can refer to
 - its own class (B) object
 - its derived class (C) object
 - CANNOT refer to its base class (A) object

- Exactly the same as the pointers!



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

class Person
{
public:
    void talk()
    {
        cout << "talk" << endl;
    }
};

class Student : public Person
{
public:
    void study()
    {
        cout << "study" << endl;
    }
};

class CSStudent : public Student
{
public:
    void writeCode()
    {
        cout << "writeCode" << endl;
    }
};
```

```
int main()
{
    Student st;

    Person& person_st = st; // ok
    Student& student_st = st; // ok
    CSStudent& csstudent_st = st; //error!

    CSStudent csst;

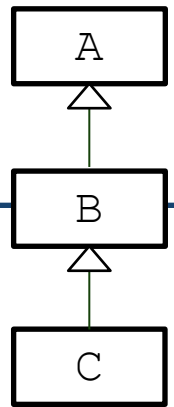
    Person& person_csst = csst; // ok
    Student& student_csst = csst; // ok
    CSStudent& csstudent_csst = csst; //ok

    return 0;
}
```

References with Inheritance

- A class (B) reference can access
 - the members of its base class (A)
 - the members of its own class (B)
 - CANNOT access the members of its derived class (C)

- Exactly the same as the pointers!



```

#include <iostream>
using namespace std;

class Person
{
public:
    void talk()
    {
        cout << "talk" << endl;
    }
};

class Student : public Person
{
public:
    void study()
    {
        cout << "study" << endl;
    }
};

class CSStudent : public Student
{
public:
    void writeCode()
    {
        cout << "writeCode" << endl;
    }
};

```

```

int main()
{
    Student st;
    Person& person_st = st;

    person_st.talk();
    person_st.study(); // error!
    person_st.writeCode(); // error!

    return 0;
}

```

```

int main()
{
    Student st;
    Student& student_st = st;

    student_st.talk();
    student_st.study();
    student_st.writeCode(); // error!

    return 0;
}

```


Polymorphism in C++

- Subtype polymorphism (*will be referred to as just “polymorphism” in this lecture*) in C++ requires **references or pointers**
 - In C++, polymorphic behavior is **only possible when an object is referenced by a reference or a pointer**
- **A derived class object is treated as if it were its base class type** by accessing through a pointer or reference!

Polymorphism in C++

- In this example,
- Derived class objects (Student st, CSStudent csst)
- are treated as if they were their base class type (Person)
- by accessing through references (person_st, person_csst)

```
int main()
{
    Student st;
    CSStudent csst;

    Person& person_st = st;
    Person& person_csst = csst;

    person_st.talk();
    person_csst.talk();
    ...
}
```

Quiz 1

- Go to <https://www.slido.com/>
- Join #csd-ys
- Click "Polls"

- Submit your answer in the following format:
 - **Student ID: Your answer**
 - e.g. **2017123456: 4)**

- Note that your quiz answer must be submitted **in the above format** to receive a quiz score!

Recall: Overriding Member Function

- You can override a member function to provide a custom functionality of the derived class.

```
// Vehicle class.

class Vehicle {
public:
    Vehicle() {}
    void Accelerate();
    void Decelerate();

    LatLng GetLocation() const;
    double GetSpeed() const;
    double GetWeight() const;

private:
    LatLng location_;
    double speed_;
    double weight_;
};
```

```
// Car class.
class Car : public Vehicle {
public:
    Car() : Vehicle() {}

    int GetCapacity() const;

    // Override the parent's GetWeight().
    double GetWeight() const {
        return Vehicle::GetWeight()+passenger_weight_;
    }

private:
    int capacity_;
    double passenger_weight_;
};
```

Overriding in CSStudent Example

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

class Person
{
public:
    void talk()
    {
        cout << "I'm a person" << endl;
    }
};

class Student : public Person
{
public:
    void talk()
    {
        cout << "I'm a student" << endl;
    }
    void study()
    {
        cout << "study" << endl;
    }
};
```

```
class CSStudent : public Student
{
public:
    void talk()
    {
        cout << "I'm a CS student" <<
endl;
    }
    void writeCode()
    {
        cout << "writeCode" << endl;
    }
};

int main()
{
    CSStudent csst;
    csst.talk();
    // Output: "I'm a CS student"

    Person& person_csst = csst;
    person_csst.talk();
    // Output: "I'm a person" ??

    return 0;
}
```

Why is `Person::talk()` called instead of `CSStudent::talk()`?

- By default, C++ compiler generates code that matches a function call with the correct function definition *at compile time* based on *declared type* (called *static binding*).
- The *actual type* of the object referenced / pointed by the base class reference / pointer is **unknown at compile time**.
- Only the *declared type* (base class reference / pointer type) is **known at compile time**.

More Examples

```
int main()
{
    Person p;
    Student st;
    CSStudent csst;

    Person& person_p = p;
    Person& person_st = st;
    Person& person_csst = csst;

    person_p.talk();    // Person::talk()
    person_st.talk();  // Person::talk()
    person_csst.talk(); // Person::talk()

    Student& student_st = st;
    Student& student_csst = csst;

    student_st.talk(); // Student::talk()
    student_csst.talk(); // Student::talk()

    return 0;
}
```

How to get polymorphic behavior?

- But this is not what we want!
- We often want to customize the behavior of the same member function in each derived class
 - so that we get different behaviors through the same interface → **Polymorphism!**

Like this:

```
Person& person_p = p;  
Person& person_st = st;  
Person& person_csst = csst;  
  
person_p.talk();    // Person::talk()  
person_st.talk();  // Student::talk()  
person_csst.talk(); // CSStudent::talk()
```


Virtual Functions

- By declaring the member function **virtual**, you can do this!

```
virtual void talk();
```

- Calling a virtual functions means:
- C++ compiler generates code that matches a function call with the correct function definition *at runtime* based on *actual type* (called *dynamic binding*).

Virtual Functions

- Virtual functions are keys to implement polymorphism in C++.
 - declare polymorphic member functions to be 'virtual',
 - and use the base class pointer / reference to refer an instance of the derived class,
 - then the function call from a base class pointer / reference will execute the function overridden in the derived class.
- Where to specify 'virtual'?
 - Actually, 'virtual' keyword is *not necessary* for the overridden virtual member function in the *derived class*.
 - But specifying 'virtual' for all virtual functions in descendant classes is recommended.

Virtual Function Example

```
// Vehicle classes.
```

```
class Vehicle {  
public:  
    virtual void Accelerate() {  
        cout << "Vehicle.Accelerate";  
    }  
};
```

```
class Car : public Vehicle {  
public:  
    virtual void Accelerate() {  
        cout << "Car.Accelerate";  
    }  
};
```

```
class Truck : public Vehicle {  
public:  
    virtual void Accelerate();  
        cout << "Truck.Accelerate";  
    }  
};
```

```
// Main routine.
```

```
int main() {  
    Car car;  
    Truck truck;  
    Vehicle* pv = &car;  
    pv->Accelerate();  
    // Outputs Car.Accelerate.  
  
    pv = &truck;  
    pv->Accelerate();  
    // Outputs Truck.Accelerate.  
  
    Vehicle vehicle;  
    pv = &vehicle;  
    pv->Accelerate();  
    // Outputs Vehicle.Accelerate.  
    return 0;  
}
```

Virtual Function Example (w/o virtual)

```
// Vehicle classes.

class Vehicle {
public:
    void Accelerate() {
        cout << "Vehicle.Accelerate";
    }
};

class Car : public Vehicle {
public:
    void Accelerate() {
        cout << "Car.Accelerate";
    }
};

class Truck : public Vehicle {
public:
    void Accelerate();
    cout << "Truck.Accelerate";
}
};
```

```
// Main routine.

int main() {
    Car car;
    Truck truck;
    Vehicle* pv = &car;
    pv->Accelerate();
    // Outputs Vehicle.Accelerate.
    car.Accelerate();
    // Outputs Car.Accelerate.

    pv = &truck;
    pv->Accelerate();
    // Outputs Vehicle.Accelerate.
    truck.Accelerate();
    // Outputs Truck.Accelerate.

    Vehicle vehicle;
    pv = &vehicle;
    pv->Accelerate();
    // Outputs Vehicle.Accelerate.
    return 0;
}
```

Virtual Functions in CSStudent Example

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

class Person
{
public:
    virtual void talk()
    {
        cout << "I'm a person" << endl;
    }
};

class Student : public Person
{
public:
    virtual void talk()
    {
        cout << "I'm a student" << endl;
    }
    void study()
    {
        cout << "study" << endl;
    }
};
```

```
class CSStudent : public Student
{
public:
    virtual void talk()
    {
        cout << "I'm a CS student" <<
endl;
    }
    void writeCode()
    {
        cout << "writeCode" << endl;
    }
};

int main()
{
    CSStudent csst;
    csst.talk();
    // Output: "I'm a CS student"

    Person& person_csst = csst;
    person_csst.talk();
    // Output: "I'm a CS student"

    return 0;
}
```

Another Example

```
void makePersonTalk(Person* person)
{
    person->talk();
}

int main()
{
    vector<Person*> people;
    people.push_back(new Person);
    people.push_back(new Person);
    people.push_back(new Student);
    people.push_back(new Student);
    people.push_back(new Person);
    people.push_back(new Student);
    people.push_back(new CSStudent);
    people.push_back(new CSStudent);

    for(int i=0; i<people.size(); ++i)
        makePersonTalk(people[i]);

    for(int i=0; i<people.size(); ++i)
        delete people[i];

    return 0;
}
```

Quiz 2

- Go to <https://www.slido.com/>
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Destructor and Virtual

```
class A {
public:
    A() { cout << " A" << endl; }
    ~A() { cout << " ~A" << endl; }
};

class AA : public A {
public:
    AA() { cout << " AA" << endl; }
    ~AA() { cout << " ~AA" << endl; }
};

int main() {
    AA* pa = new AA; // OK: prints ' A AA'.
    delete pa; // prints ' ~AA ~A'.
    return 0;
}
```


Destructor and Virtual

- What happens if a derived class object is **'deleted'** by its base class pointer?

```
class A {
public:
    A() { cout << " A"; }
    ~A() { cout << " ~A"; }
};

class AA : public A {
public:
    AA() { cout << " AA"; }
    ~AA() { cout << " ~AA"; }
};

int main() {
    A* pa = new AA; // OK: prints ' A AA'.
    delete pa;      // Hmm...: prints only ' ~A'.
    return 0;
}
```

Virtual Destructor

- What happens if a derived class object is **'deleted'** by **its base class pointer?**
- If the base class destructor is **not virtual**,
 - only the base class destructor is called
 - the derived class destructor is **not** called
- **This may cause memory leak**
 - Think about this case: A derived class destructor has the code that `delete` its member variables which are assigned by `new` in its constructor

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

class Shape
{
public:
    Shape() {}
    ~Shape() {}
};

class Rectangle : public Shape
{
private:
    int* width;
    int* height;
public:
    Rectangle()
    {
        width = new int;
        height = new int;
        cout << "Rectangle()" << endl;
    }
    ~Rectangle()
    {
        delete width;
        delete height;
        cout << "~Rectangle()" << endl;
    }
};
```

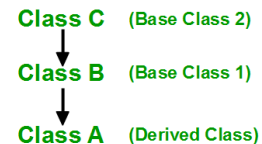
```
int main()
{
    Shape* shapel = new Rectangle;
    delete shapel;

    return 0;
}
```

Virtual Destructor

- What happens if a derived class object is **'deleted'** by its base class pointer?
- If the base class destructor is **virtual**,
 - the derived class destructor is called
 - and then base class destructors is called (reverse order of constructor calls)

Order of Inheritance



Order of Constructor Call

1. C() (Class C's Constructor)
2. B() (Class B's Constructor)
3. A() (Class A's Constructor)

Order of Destructor Call

1. ~A() (Class A's Destructor)
2. ~B() (Class B's Destructor)
3. ~C() (Class C's Destructor)

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

class Shape
{
public:
    Shape() {}
    virtual ~Shape() {}
};

class Rectangle : public Shape
{
private:
    int* width;
    int* height;
public:
    Rectangle()
    {
        width = new int;
        height = new int;
        cout << "Rectangle()" << endl;
    }
    virtual ~Rectangle()
    {
        delete width;
        delete height;
        cout << "~Rectangle()" << endl;
    }
};
```

```
int main()
{
    Shape* shapel = new Rectangle;
    delete shapel;

    return 0;
}
```

When do we need a virtual destructor?

- A destructor of a base class **should be** `virtual` if
 - its descendant class instance can be **deleted by the base class pointer**.
 - in other words, any of member function is **virtual** (which means it's a polymorphic base class).

```
class A {
public:
    A() { cout << " A"; }
    virtual ~A() { cout << " ~A"; }
};

class AA : public A {
public:
    AA() { cout << " AA"; }
    virtual ~AA() { cout << " ~AA"; }
};

int main() {
    A* pa = new AA; // OK: prints ' A AA'.
    delete pa;      // OK: prints ' ~AA ~A'.
    return 0;
}
```

Virtual Destructor

- Note that constructors cannot be `virtual`
 - "virtual" allows us to call a function knowing only an interface and not the exact type of the object.
 - But to create an object, you need to know the exact type of what you want to create.
 - Bjarne Stroustrup's C++ Style and Technique FAQ: [Why don't we have virtual constructors?](#)

Quiz 3

- Go to <https://www.slido.com/>
- Join #csd-ys
- Click "Polls"

- Submit your answer in the following format:
 - **Student ID: Your answer**
 - e.g. **2017123456: 4)**

- Note that your quiz answer must be submitted **in the above format** to receive a quiz score!

CAUTION: Copying a derived class object to a base class object

```
#include <iostream>
using namespace std;
class Animal{
public:
    virtual void makeSound() {cout << "(none)" << endl;}
};
class Dog : public Animal{
public:
    virtual void makeSound() {cout << "bark" << endl;}
};
int main()
{
    Animal animal;
    animal.makeSound(); // "(none)"

    Dog dog;
    dog.makeSound(); // "bark"

    // A typical way for polymorphism
    Animal& goodDog = dog;
    goodDog.makeSound(); // "bark"

    // ???
    Animal badDog = dog;
    badDog.makeSound(); // "(none)"
}
```

CAUTION: Avoid Object Slicing

- In C++, **object slicing** occurs when a derived class object is copied to a base class object.
 - Additional attributes of a derived class object are “sliced off”

```
class Base { int x, y; };

class Derived : public Base { int z, w; };

int main()
{
    Derived d;
    Base b = d; // Object Slicing, z and w of d are sliced off
}
```

- Note that C++ **polymorphism** works only with references or pointers, **not with objects**.

Next Time

- Labs for this lecture:
 - Lab1: Assignment 9-1
 - Lab2: Assignment 9-2

- Next lecture:
 - 10 - Polymorphism 2