Creative Software Design

Polymorphism 1

Yunho Kim
yunhokim@hanyang.ac.kr
Dept. of Computer Science

Today's Topics

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

What is Polymorphism?

- From a Greek word: “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 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; }
```

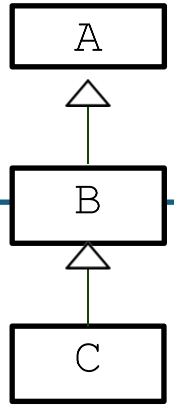
```
int main()
{
    Cat cat;
    Dog dog;
    letsHear(cat);
    letsHear(dog);
    return 0;
}
```

Pointers, References and Inheritance

- To use subtype 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....

Pointers with Inheritance



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

```cpp
#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;
    }
};
```

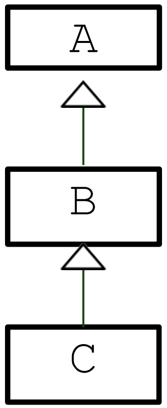
```cpp
int main()
{
    Student* s1 = new Person; // error
 // A Person CANNOT be regarded as a Student.

    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;
}
```

```cpp
#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;
    }
};
```

```cpp
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`)
  - **CAN** access the members of its own class (`B`)
  - **CANNOT** access the members of its derived class (`C`)



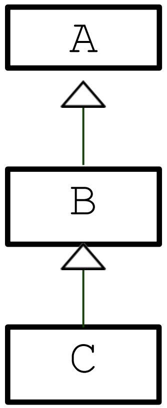
```cpp
#include <iostream>
using namespace std;

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;
    }
};
```

```cpp
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;
}
```

```cpp
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
  - **CAN** refer to its derived class `(C)` object
  - **CANNOT** refer to its base `(A)` class object



- Exactly same as the pointers!

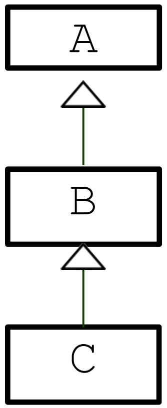
```cpp
#include <iostream>
using namespace std;

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;
    }
};
```

```cpp
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)`
  - **CAN** access the members of its own class `(B)`
  - **CANNOT** access the members of its derived class `(C)`

- Exactly same as the pointers



```cpp
#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;
    }
};
```

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

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

    return 0;
}
```

```cpp
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

- What is required for the subtype polymorphism in C++?

Recall: Overriding Member Function

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

```cpp
// 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_;
};
```

```cpp
// 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 matches a function call with the correct function definition ***at compile time*** based on ***declared type*** (called ***static binding***).

- Base class pointers and references only know the base class members *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();
```

Q: What does calling a virtual function mean?

A: C++ compiler match 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 in the derived class.
  - But specifying ‘virtual’ for all virtual functions in descendant classes is recommended.

Virtual Function Example

```cpp
// 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";
  }
};
```

```cpp
// 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

- What is the expected output? (including compile/runtime error)

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

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

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

int main(void)
{
    Base *bp = new Derived;
    bp->show();

    Base &br = *bp;
    br.show();

    return 0;
}
```

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\n AA'.
  delete pa;        // prints ' ~AA\n ~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\n 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?**

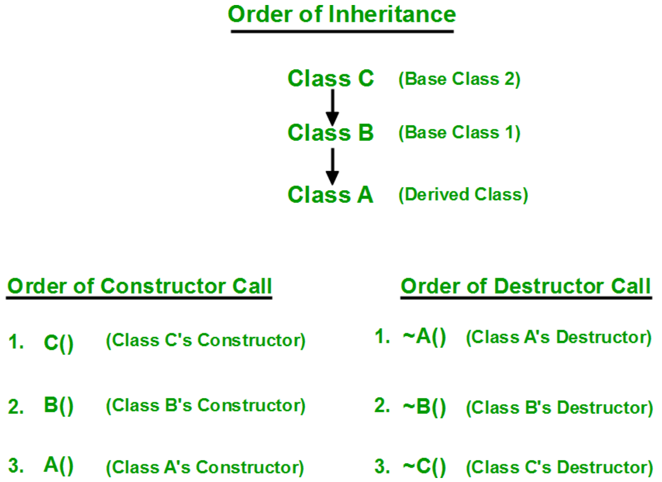
- If the base class destructor **is not `virtual`**,
  - only the base class destructor is called
  - the derived class destructor is **not** called

- **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

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)



When Do We Need a Virtual Destructor?

- A destructor of a base class **should be** `virtual` if
  - its descendant class instance is **deleted by the base class pointer.** (..or)
  - 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 interfaces 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

- When and why do we need to use a virtual destructor?

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.**