Inheritance

Capturing similarities between types

Overview

- This lecture and the next one will describe object-oriented programming
- Most of the ideas described here are useful in more than one language
- Specific examples, as usual, are in C++

Philosophical note

- Abstraction is selective ignorance
- How do you decide what to ignore?
- One way is to note similarities and differences among several things
  - Sometimes, you want to concentrate on the similarities
  - Other times, you want to ignore the similarities and look only at the differences

Inheritance

- Inheritance is a way of describing a class by saying how it differs from another class
- Example: "Class Y is just like class X except for the following additions…"
  - Class Y is called a *derived class* or *subclass*
  - Class X is called a *base class* or *superclass*

Why use inheritance?

- The usual reason is when you have two types where one is necessarily an extension of the other
- Sometimes (but not all the time) you are going to want to ignore the differences and look only at the base class (which is what they have in common)

The classic example

- Consider a system that can manipulate various kinds of shapes
- Sometimes you don’t care what particular kind of shape you have (example: move to a different location)
- Sometimes you do care (example: draw the shape on a display)

Specifying inheritance in C++

```
class Shape {
public:
    Point position;
    // …
};
class Circle: public Shape {
public:
    int radius;
    // …
};
```

What it means

- When we say

```
class Circle: public Shape { /* … */ };
```

we are saying that
  - A `Circle` is a kind of `Shape`
  - Therefore, in addition to its own members, class `Circle` inherits all the members of class `Shape`, and
  - The fact that a `Circle` is a kind of `Shape` is publicly available

When to use inheritance

- When you want to be able to say “Every Y is really a kind of X with some extra properties”
- When you really want Y to be able to do everything X can do
- This state of affairs leads to…

The Liskov substitution principle

- If a class Y is “just like” a class X except for extensions, then it should be possible to use a Y object anywhere you can use an X object
- You should design your classes to preserve that property unless you have a strong reason to do otherwise

Examples

- An aircraft is a kind of vehicle
- An airplane is a kind of aircraft
- So is a helicopter
- A square is a kind of shape
- So is a triangle
- So is a generalized polygon
- Is a square a kind of polygon?

Is a square a (kind of) polygon?

- The answer depends on whether we can follow the Liskov principle:
  - Suppose we have a program that uses polygon objects
  - The Liskov principle says that we should be able to rewrite the program using square objects instead
  - Can we do that?

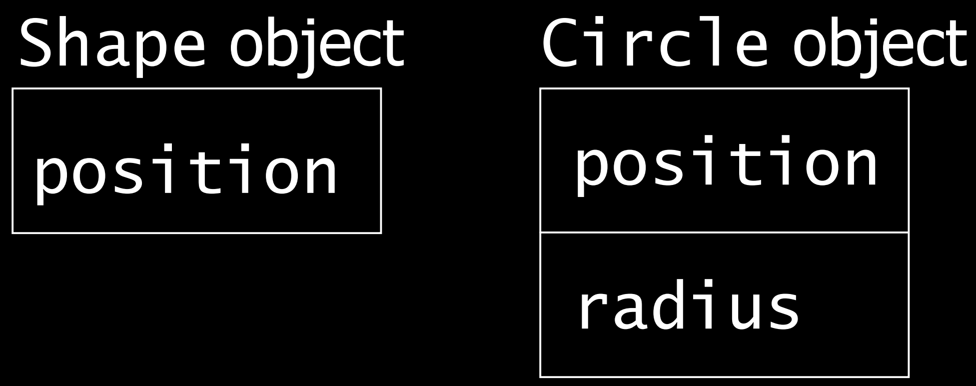
Squares and polygons

- Whether a (class that represents a) square is a kind of a (class that represents a) polygon depends on what properties of polygons we're capturing
  - If a polygon object contains a list of sides, the answer is probably no
  - If a polygon object contains just a position, and implies that there are no curves, the answer might be yes

Other examples

- A circle is not a kind of ellipse, nor is an ellipse a kind of circle
- A square is not a kind of rectangle, nor is a rectangle a kind of square
- But an immutable square might be a kind of rectangle, and an immutable circle a kind of ellipse

Implementation



Access to base class

- Derived-class members can access `protected` and `public` members of corresponding base-class objects
- Pointer (or reference) to derived can be converted to pointer (or reference) to `public` base (or, within member function body, to `protected` base)

Inheritance of members

- Every `public` member of the base class is a member of the derived class

```
Circle c;
// …
Point p = c.position;
```

Classes are scopes

- A member of a derived class hides all base-class members with that name

```
class X {
public: void f(int);
};
class Y: public X {
public: void f(char);  // hides X::f
};
Y y;
y.f(123456);       // calls Y::f(char)
y.X::f(123456);    // calls ::f(int)
```

Conversion examples

```
Shape s;
Circle c;
Shape* sp = &c;        // OK
Circle* cp = &s;       // Ill-formed
Shape& s1 = c;         // OK
Circle& c1 = s;        // Ill-formed
s = c;                 // OK
c = s;                 // Ill-formed
```

Why allow `s = c`?

- Class `Shape` implicitly has a `Shape::Shape(const Shape&)` copy constructor and an analogous assignment operator
- We can bind a `const Shape&` parameter to (the Shape part of) a `Circle` object
- Only the `Shape` part is actually copied

A tiny vector class

```
class Vector {
public:
    Vector(int n): data(new int[n]) { }
    ~Vector() { delete[] data; }
    int& operator[](int n) {
        return data[n];
    }

private:
    int* data;
};
```

A vector class with explicit bounds

```
class BVec: public Vector {
public:
    BVec(int begin, int end):
        b(begin), Vector(end-begin) { }
    int& operator[](int n) {
        return Vector::operator[](n-b);
    }

private:
    int b;
};
```

Treating a BVec as a Vector

```
//  Sum the first n Vector elements
int sum(Vector& v, int n)
{
    int r = 0;
    for (int i = 0; i < n; ++i)
        r += v[i];
    return r;
}


    BVec b(10, 40);
    int s = sum(b, 20);  // [10, 30)
```

Why does this example work?

- A `BVec` is a kind of `Vector`
- Calling `sum(b, 20)` binds v to the `Vector` part of b
- When `sum` is running, it doesn't care whether it's working on a `Vector`, a `BVec`, or an object of some other class derived from `Vector`.

This example is ...

- Unusual: Usually, derived-class operations will not hide base-class operations
- Incomplete: The classes should have copy constructors and assignment operators
- Slightly naughty: It does not follow the Liskov substitution principle

Where is the violation?

- Remember: A derived class object should be able to substitute for a base class object without changing the behavior of the program
  - A `Circle` should do everything a plain `Shape` can do (but not vice versa)
  - A `Bvec` should do everything a plain `Vector` should do (but not vice versa)
- But we can't create, say, `Bvec(10)`, or, necessarily, use `b[0]`

Does `operator[]` violate the principle?

- The definitions are definitely different in the base and derived classes
- However, they do the same thing when the lower bound is zero
- A `Vector` has a lower bound of zero
- So there is no problem here
- Note: A base class does not have to substitute for a derived class

Cleaning up `Bvec`

- The `operator[]` member doesn't violate the Liskov principle
- Therefore, all we really have to do is give `Bvec` a second constructor, with no arguments

Examples of inheritance

- In chess, a capture is a kind of move
- A `while` statement is a kind of statement
- A manager is a kind of employee
- A directory is a kind of file (though we may want to think about whether this notion follows the Liskov principle)

Examples where inheritance is inappropriate

- An automobile is not a kind of engine
- An integer array might be a kind of array, but it is *not* a kind of integer

Squares and polygons

- A square might seem at first to be a kind of polygon, but
  - a polygon can have any number of sides
  - a square is restricted to having four sides
- A polygon might seem to be able to do everything a square can do, but
  - a square has one number (the length of a side) that makes no sense for a polygon
  - a polygon is not substitutable for a square

Other non-inheritance situations

- Squares and rectangles
- Circles and ellipses
- Strings and file names
  - Not every valid string is a valid file name
  - Therefore, file names cannot be substituted for strings
  - But file names support operations that strings do not

Review

- Inheritance lets us use a base class to describe properties that are common to several classes
- We can convert a pointer (reference) to a class object into a pointer (reference) to a sub-object whose type is a public base class of the object's class

What’s next

- Suppose we have a pointer to a base class object:
```
Shape* sp = /* some expression*/;
```
- How do we know whether that pointer actually points to a `Shape` or, say, to a `Circle`? Why might we care?

Homework (due Monday)

- Take a program that uses inheritance and dynamic binding and translate it so that it doesn't rely on the corresponding language features (In other words, pretend you're a compiler)
- You're not going to have all the information you need until Wednesday, but you might want to think about it