Dynamic binding

Noticing differences between types when it matters

A simple view of the problem

- Suppose we have a class `Circle` derived from a base class `Shape`.
- If we have a pointer or reference to a `Shape`, it might actually be pointing or referring to a `Circle`.
- Why should we care?
- How can we tell?

Why do we care?

- The usual reason is that we want to take one action if the `Shape` is a `Circle` and some other action if it isn t
- Example: rotating a `Circle` requires no action at all

An obvious solution

- Put a type code in each object
- Make sure that the type code is at the same offset in all objects
- Use the type code to decide what to do

The obvious solution can be made to work

- C (and C++) guarantees that if two structures begin with the same sequence of component types, they will have compatible layouts

Implementation (in C)

```
struct Shape {
    int type;
    Point center;
};
struct Circle {
    int type;        // Same as in
    Point center;    // the Shape structure
    int radius;
};
```

Using the type code

```
struct Shape *sp;
/* … */
switch (sp->type) {
case CIRCLE:
    /* … */
    break;
    /* and so on… */
};
```

What's wrong with the simple approach?

- Nothing is wrong with it
  - It can be made to work
- But it does have disadvantages
  - Adding a new type entails changing all the `switch` statements
  - Layout compatibility comes about only through convention
  - The code to deal with `Circles` is scattered all over the place

The C++ approach: virtual functions

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

The function definitions look normal

```
void Shape::draw() {
    // …
}
void Circle::draw() {
    // …
}
```

Calling a virtual function

- When a pointer (or reference) to a base class actually points (or refers) to a derived class object, *and*
- You use that pointer (or reference) to call a function that is declared virtual in the base class, then
- The derived-class function is the one that is actually called.

Examples

```
Shape s;  Circle c;
Shape* sp;  Circle* cp;
Shape& sr = /* something */;
Circle& cr = /* something */;
s.draw();       // Shape::draw
c.draw();       // Circle::draw
sp->draw();     // depends on the object
cp->draw();     // depends on the object
sr.draw();      // depends on the object
cr.draw();      // depends on the object
```

A virtual call happens when

- A function is virtual in the base class
- A pointer or reference to a base class actually points or refers to a derived class object

Typical implementation

- Every object of a type with one or more virtual functions includes a pointer to a *virtual function table*
- Every virtual call fetches the address of the function from a known offset (fixed at compile time) in the table
- Typical cost: a few memory references per call

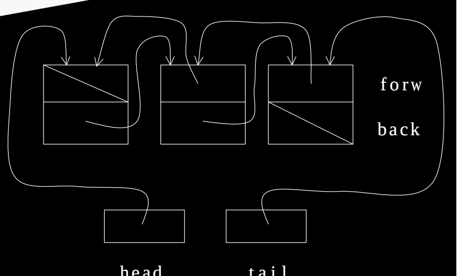
Types of virtual functions

- The argument types must be identical in base and derived classes
- The result types too, unless
  - The base class function returns a pointer (or reference) to some type T, and
  - The derived class function returns a pointer (or reference) to a type derived from T

An example

- We might have every `Shape` in the universe put itself on a doubly-linked list
- Then we could easily draw all the `Shape`s, even if some of them were really objects of classes derived from `Shape`

The data structure



Example code, part 1

```
Class Shape {
public:
    Shape();
    virtual ~Shape();
    virtual void draw();

private:
    Shape* forw;
    Shape* back;
    // …
};
```

Code, part 2

```
Shape* head = 0;
Shape* tail = 0;
Shape::Shape()
{
    forw = tail;
    back = 0;
    (tail? tail->back: head) = this;
    tail = this;
}
```

Code, part 3

```
Shape::~Shape()
{
  (this==head?head:forw->back) = back;
  (this==tail?tail:back->forw) = forw;
}
```

Adding new shapes

- Just do it…

```
class Circle: public Shape {
public:
    virtual void draw();
// …
};
void Circle::draw()
{ /* … */ }
```

Draw all the shapes

```
void drawall()
{
    Shape* p = head;
    while (p) {
        p->draw();   // virtual call
        p = p->back;
    }
}
```

Why the virtual destructor?

- Whenever
  – You say `delete p`, *and*
  – The type of `p` is "pointer to base," *and*
  – `p` actually points at a derived object
- Then the base class must have a virtual destructor, even if it does nothing

What does a virtual destructor do?

- It is a signal to the compiler that using `delete` (which always destroys the object) should go through the virtual call mechanism
- It has no effect otherwise

Multiple abstractions

- A `Shape` is something that can go on the list defined by `head` and `tail`
- A `Shape` is something that supports the `draw` operation
- A `Circle` is a kind of `Shape` whose `draw` operation is implemented in a particular way

Virtual functions and type fields

- You can use virtual functions to implement type fields:

```
enum Kind { SHAPE, CIRCLE /* … */ };
class Shape {
public:
      virtual Kind my_type() {
            return SHAPE;
      }
      // …
};
```

- But it's often unnecessary in practice

Virtual functions and constructors

- While an object is under construction or destruction, its type is what it was declared to be:

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

Why aren't all member functions virtual?

- Not every class needs inheritance
- The overhead, although small, exists
- Sometimes functions shouldn't be virtual (for example, `operator[]` in the `Vector` example from last lecture)

Summary

- Inheritance makes it easier to describe a family of types by describing their similarities and differences
  - The similar parts go in base classes
  - Each set of relevant differences gets its own derived class
- Virtual functions are an efficient way of recovering the differences in C++