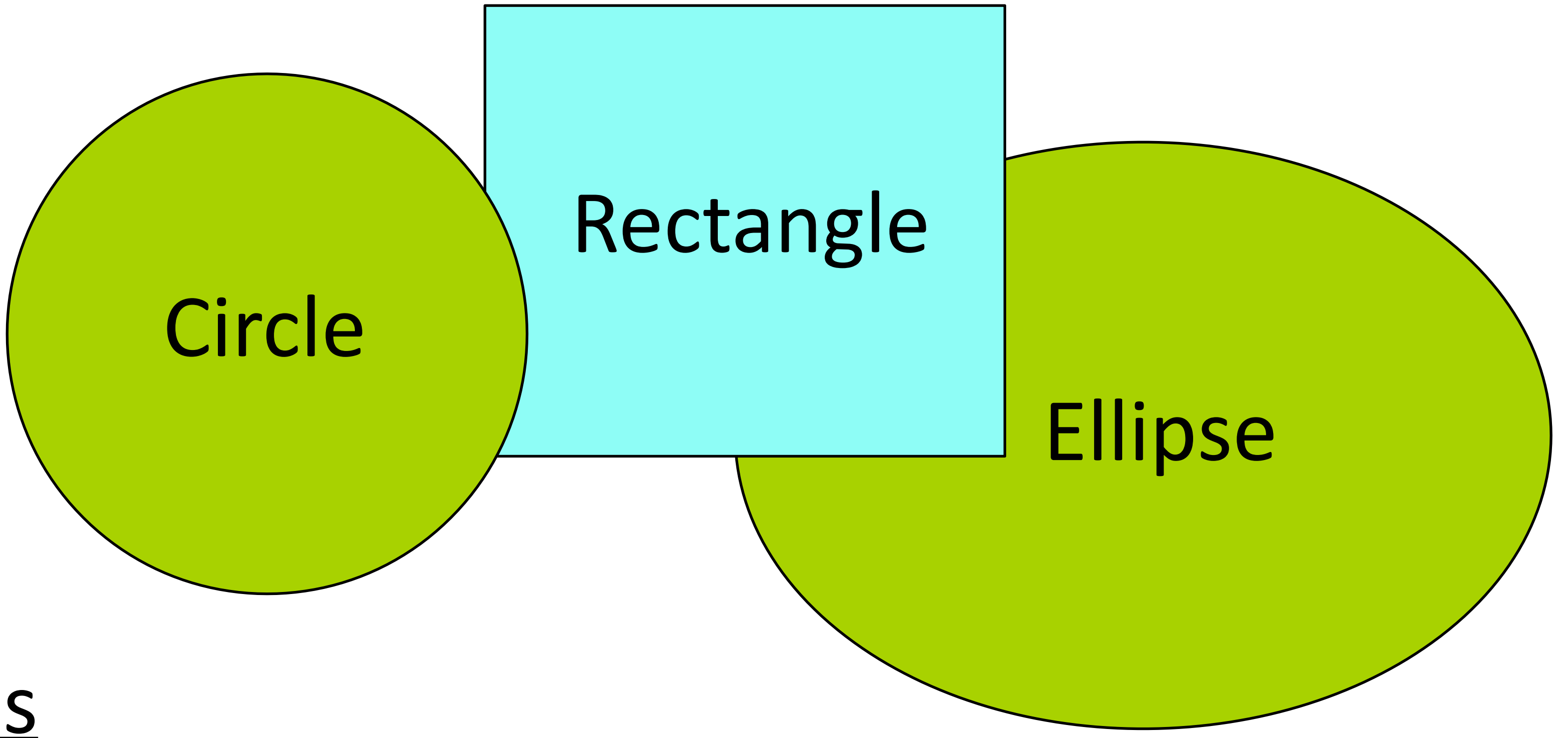
Polymorphism

Object-Oriented Programming with C++

Zhaopeng Cui

A drawing program



<u>Operations</u>

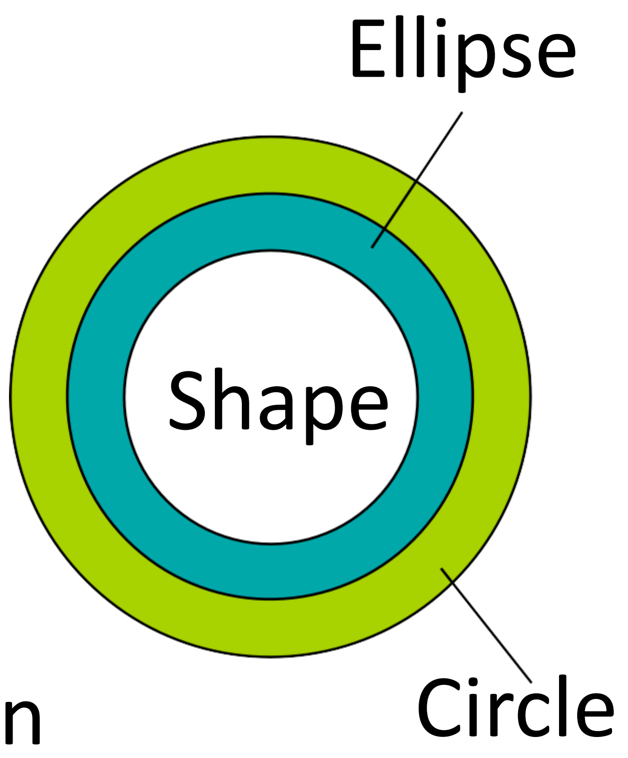
- render
- move
- resize

<u>Data</u>

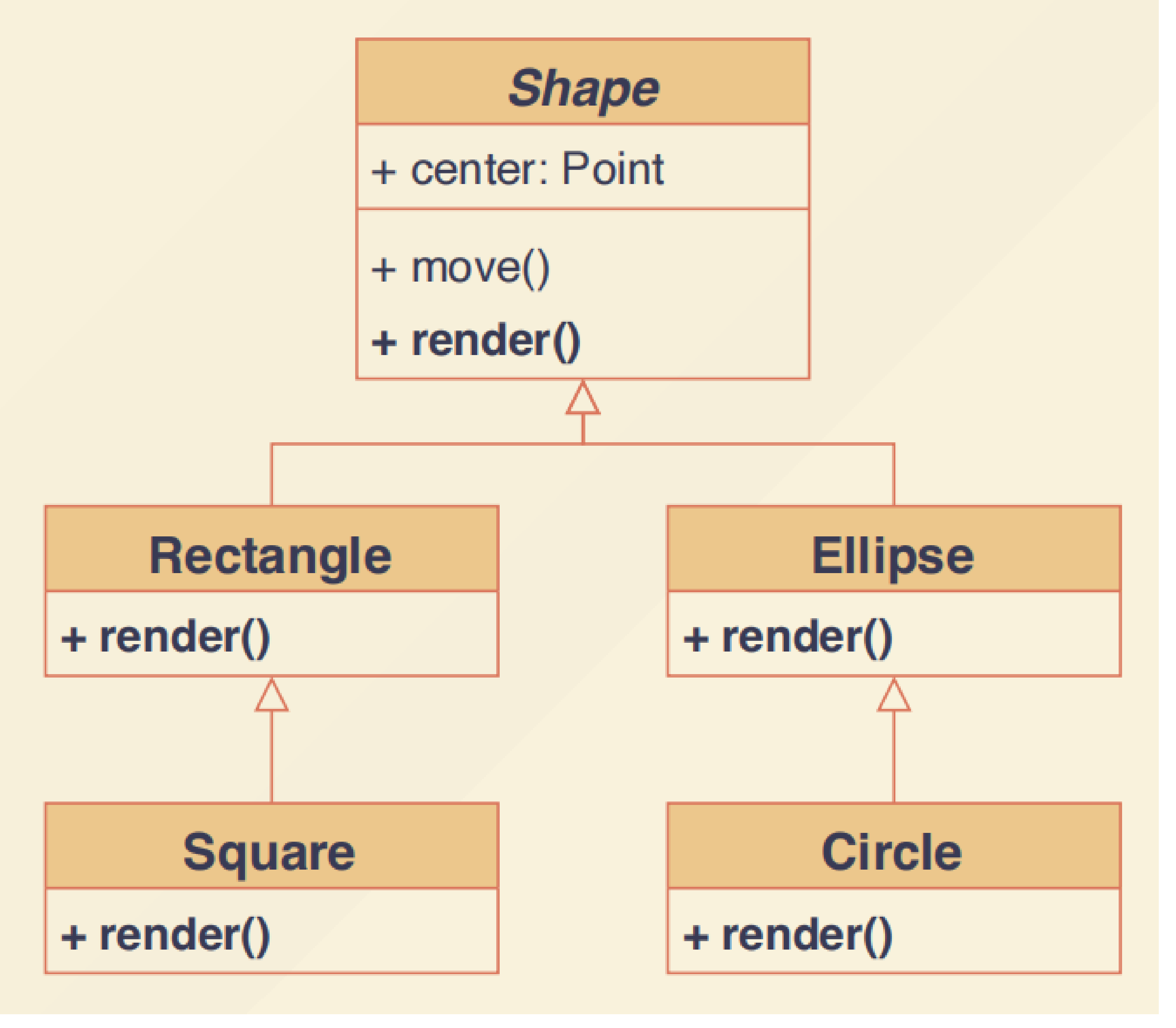
+ center

Inheritance in C++

- Can define one class in terms of another
- Can capture the notion that
  - –An ellipse is a shape
  - –A circle is a special kind of ellipse
  - –A rectangle is a different shape
  - –Circles, ellipses, and rectangles share common
    - attributes
    - services
  - –Circles, ellipses, and rectangles are not identical



Conceptual model



Note: Deriving Circle from Ellipse may be a poor design choice!

Shape

- Define the general properties of a Shape

```
class Point {...};    // (x,y) point
class Shape {
public:
    Shape();
    void move(const Point&);
    virtual void render();
    virtual void resize();
    virtual ~Shape();
protected:
    Point center;
}
```

Add new shapes

```
class Ellipse: public Shape {
public:
    Ellipse(float major, float minor);
    virtual void render();  // will define own
protected:
    float major_axis, minor_axis;
};

class Circle: public Ellipse {
public:
    Circle(float radius) : Ellipse(radius, radius) {}
    virtual void render();
};
```

Usage

```
void render(Shape* p) {
    p->render(); // calls correct render function
} // for given Shape!

void func() {
    Ellipse ell(10, 20);
    ell.render(); // static -- Ellipse::render();

    Circle circ(40);
    circ.render(); // static -- Circle::render();

    render(&ell); // dynamic -- Ellipse::render();
    render(&circ); // dynamic -- Circle::render()
}
```

Polymorphism

- Upcast: take an object of the derived class as an object of the base one.
  – Ellipse can be treated as a Shape

- Dynamic binding:
  – Binding: which function to be called
    - Static binding: call the function as the declared type
    - Dynamic binding: call the function according to the "real" type of the object

Virtual functions

- Non-virtual functions
  - Compiler generates ***static***, or direct call to stated type
  - Faster to execute

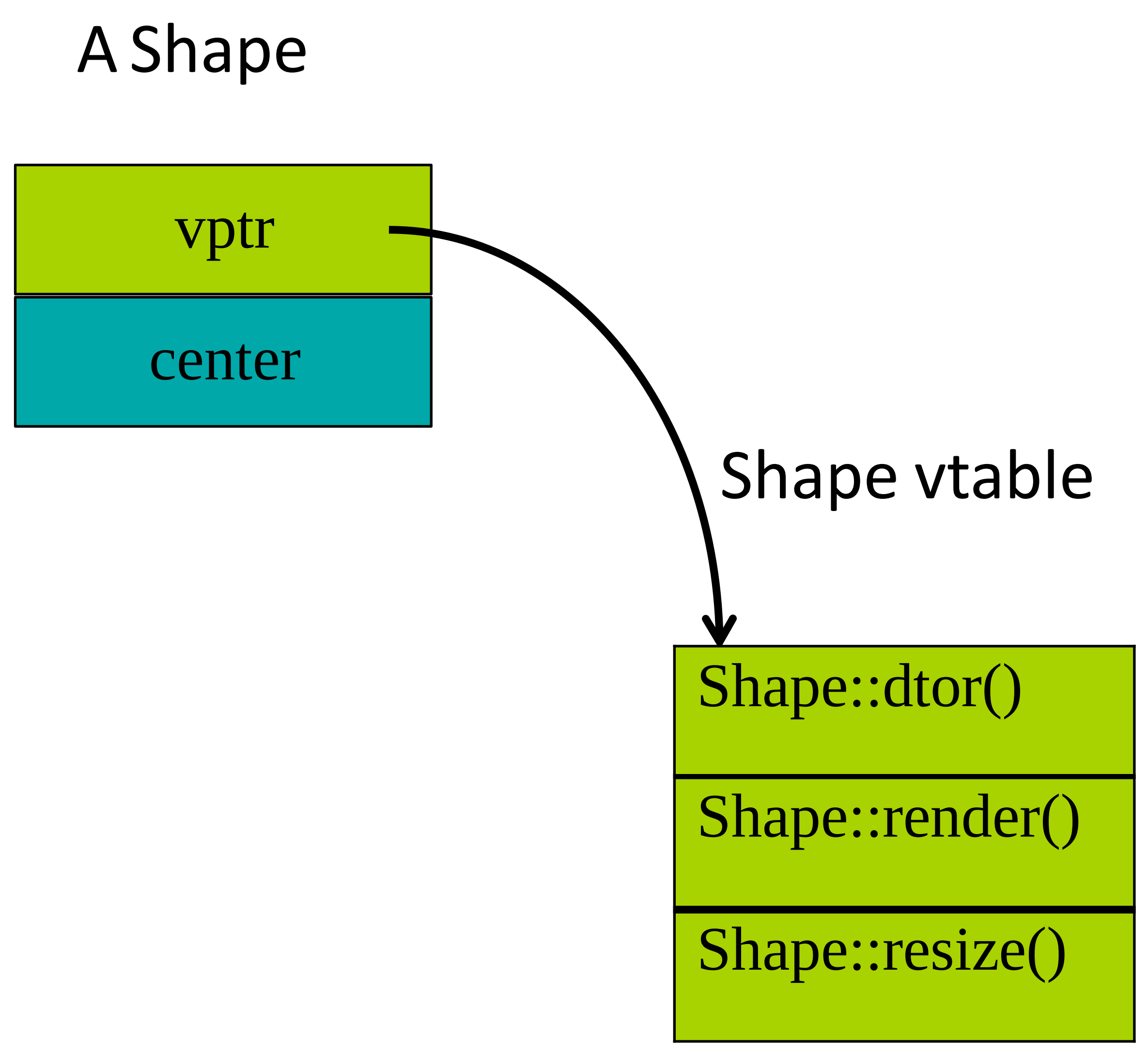
- Virtual functions
  - Can be ***transparently*** overridden in a derived class
  - Objects carry a pack of their virtual functions
  - Compiler checks pack and ***dynamically*** calls the right function
  - If compiler knows the function at compile-time, it can generate a static call

How virtual works in C++

```
class Point {...};

class Shape {
public:
 Shape();
 virtual ~Shape();
 virtual void render();
 virtual void resize();
 void move(
 const Point&);
protected:
 Point center;
};
```

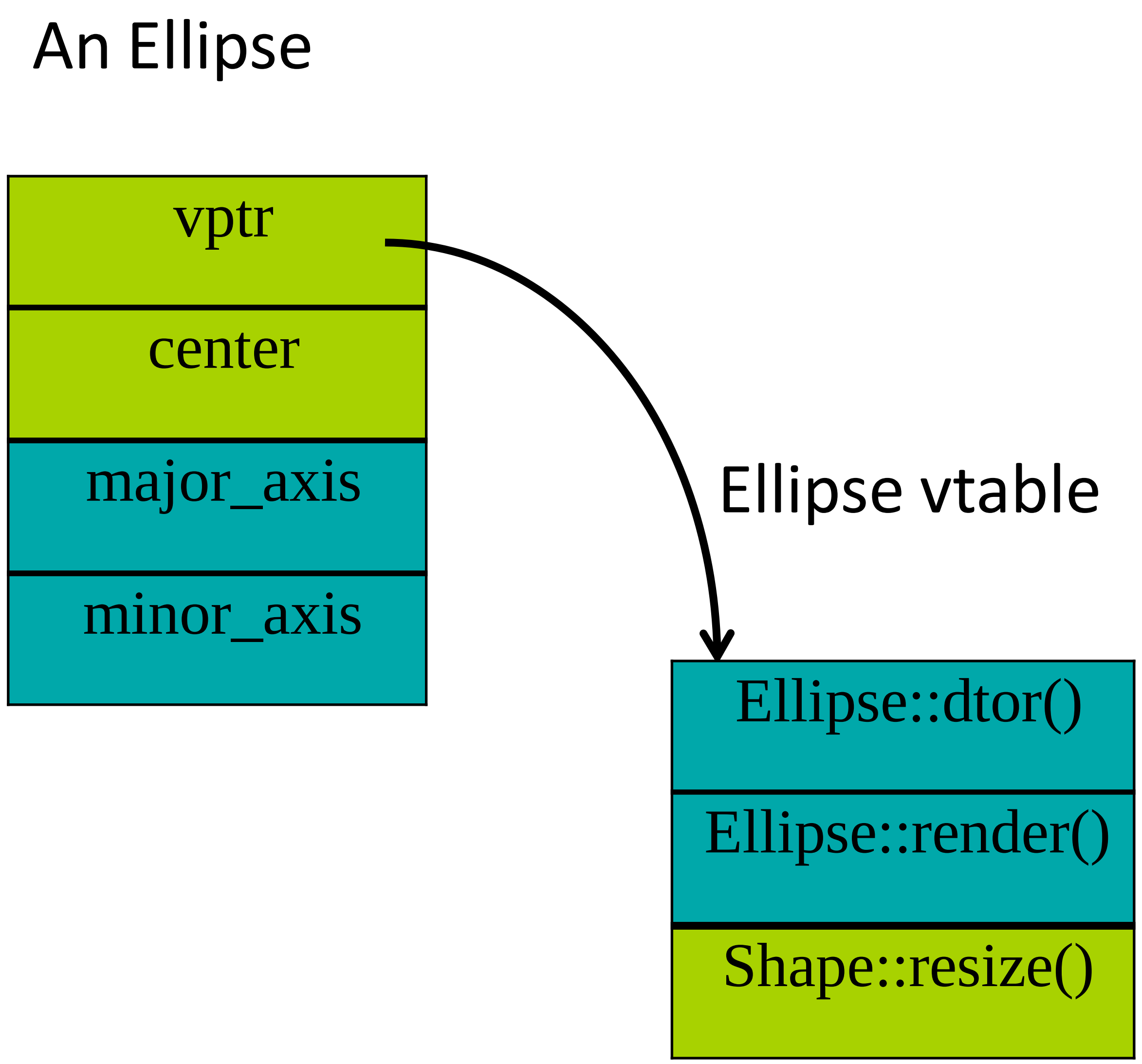
How virtual works in C++

```
class Point {...};

class Shape {
public:
 Shape();
 virtual ~Shape();
 virtual void render();
 virtual void resize();
 void move(
 const Point&);
protected:
 Point center;
};
```

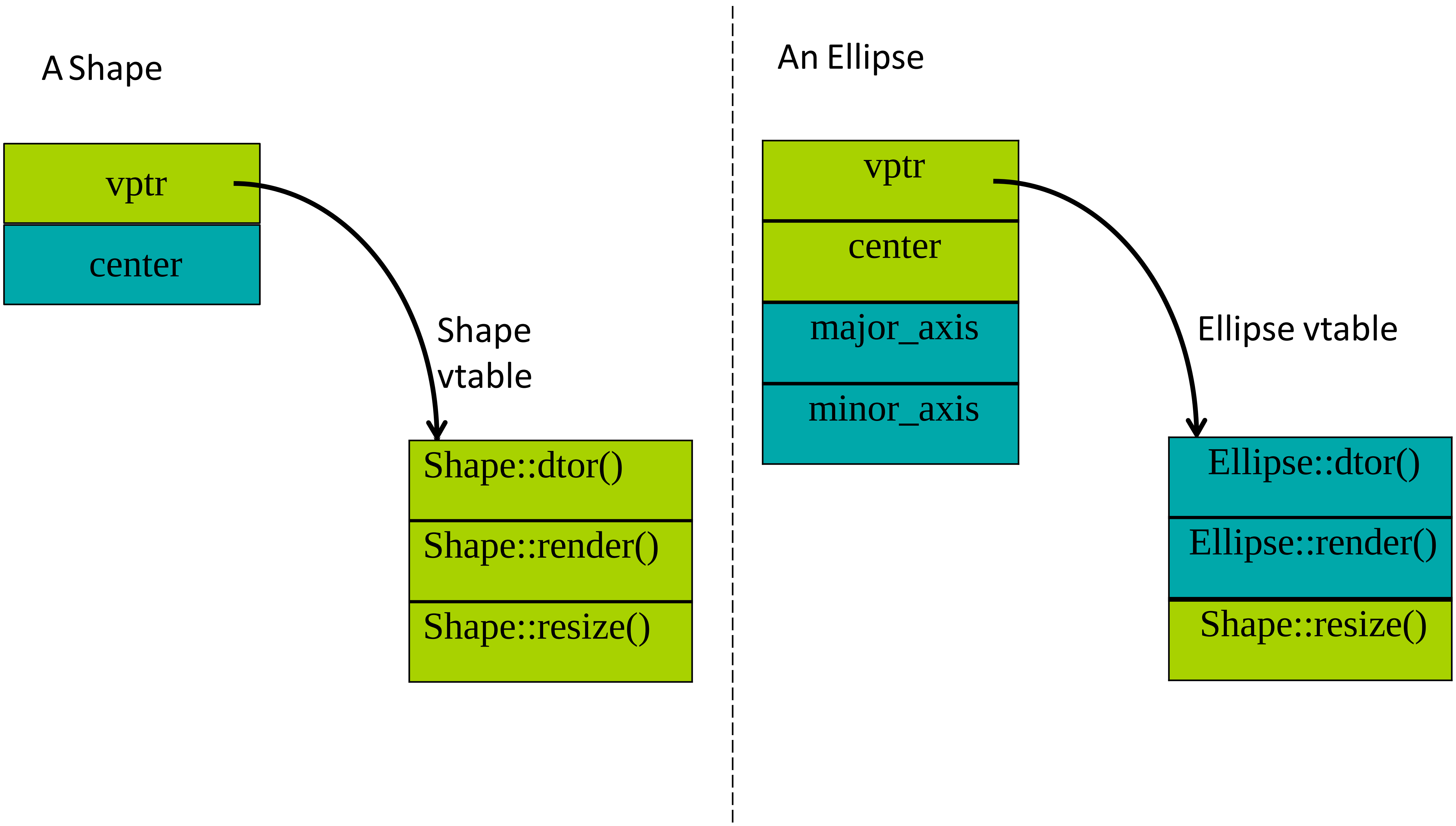


Ellipse

```
class Ellipse: public Shape{
public:
    Ellipse(float major,
            float minor);
    ~Ellipse();
    virtual void render();

protected:
    float major_axis,;
    float minor_axis;
};
```

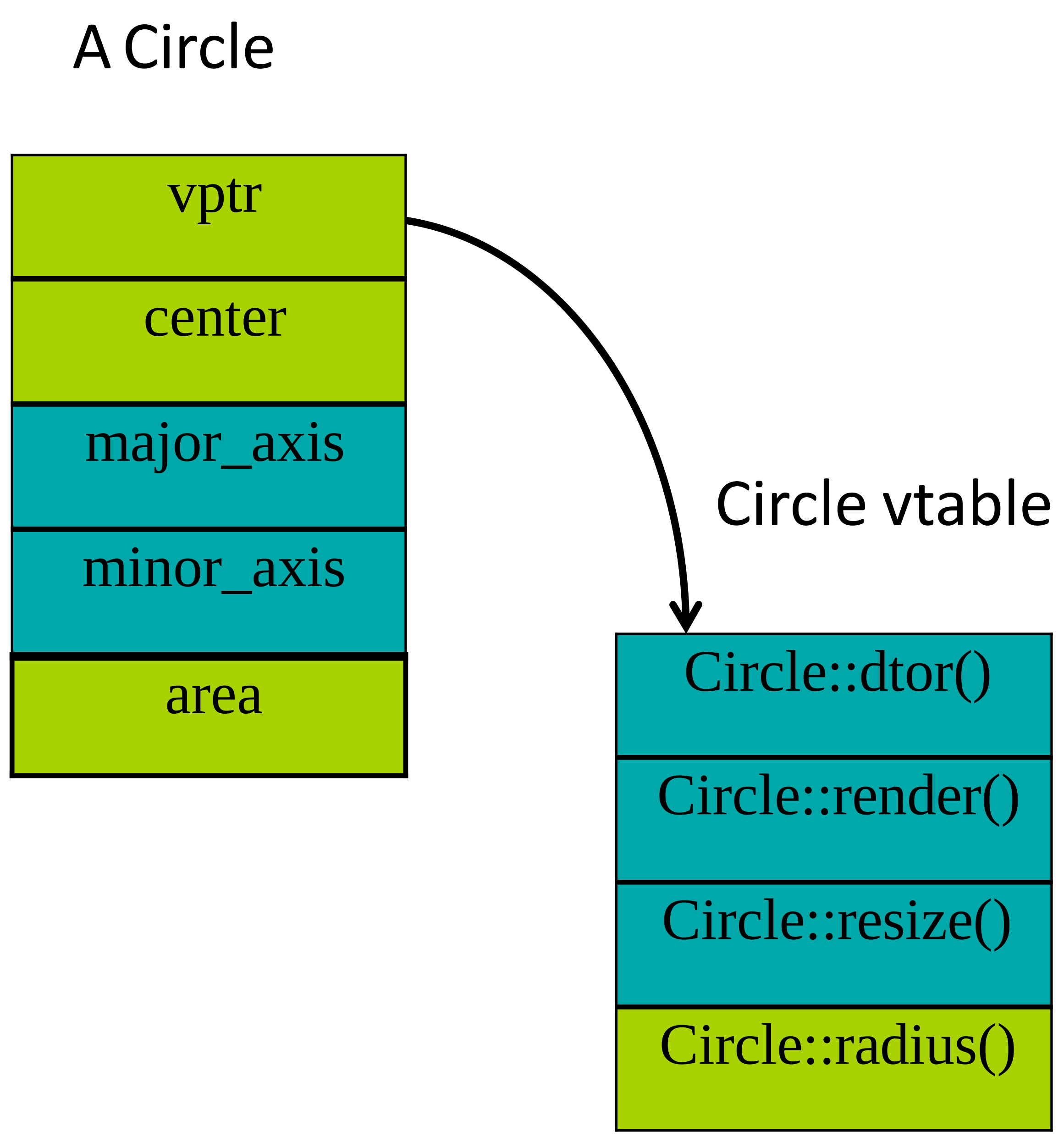


Shape vs. Ellipse



Circle

```cpp
class Circle: public Ellipse{
public:
    Circle(float radius);
    ~Circle();
    virtual void render();
    virtual void resize();
    virtual float radius();

protected:
    float area;

};
```



What happens if

```
Ellipse elly(20f, 40f);
Circle circ(60f);
elly = circ; // ???
```

- Area of `circ` is sliced off
  - (Only the part of `circ` that fits in `elly` gets copied)

- The vptr from `circ` is ignored; the vptr in `elly` points to the Ellipse vtable

```
(&elly)->render(); // Ellipse::render()
```

What happens with pointers?

```
Ellipse *elly = new Ellipse(20f, 40f);
Circle *circ = new Circle(60f);
elly = circ;
```

- Well, the original Ellipse for `elly` is lost....
- `elly` and `circ` point to the same Circle object!

```
elly->render(); // Circle::render()
```

Virtual and reference arguments

```
void func(Ellipse& elly) {
    elly.render();
}

Circle circ(60F);
func(circ);
```

- References act like pointers
- `Circle::render()` is called

Virtual destructors

- Make destructors ***virtual*** if they might be inherited

```
Shape *p = new Ellipse(100.0F, 200.0F);
...
delete p; // which dtor?
```

- If `Shape::~Shape()` is not virtual, only `Shape::~Shape()` will be invoked!

- Want `Ellipse::~Ellipse()` to be called
  - Must declare `Shape::~Shape()` virtual, and it will call `Ellipse::~Ellipse()` implicitly

Overriding

- **override** redefines the body of a virtual function

```
class Base {
public:
 virtual void func();
}
class Derived : public Base {
public:
 void func() override; // overrides Base::func()
}
```

Calls up the chain

- You can still call the overridden function for *reuse*:

```
void Derived::func() {
 cout << "In Derived::func()!";
 Base::func(); // call to base class
}
```

- This is a common way to add new functionality
- No need to copy the old stuff!

Return types relaxation (current)

- Suppose `D` is publicly derived from `B`
- `D::f()` can return a subclass of the return type defined in `B::f()`
- Applies to pointer and reference types
  - e.g. `D&`, `D*`
- In most compilers now

Relaxation example

```
class Expr{
public:
    virtual Expr* newExpr();
    virtual Expr& clone();
    virtual Expr self();
    Expr self2();
};

class BinaryExpr: public Expr{
public:
    virtual BinaryExpr* newExpr();  // ok
    virtual BinaryExpr& clone();  // ok
    virtual BinaryExpr self();  // Error!
    BinaryExpr self2();  // ok, since it is a new
function (name hiding)
};
```

Overloading and virtual

- Overloading adds multiple signatures

```
class Base {
public:
 virtual void func();
 virtual void func(int);
};
```

- If you *override* an *overloaded* function, you should override all of the variants!
  – Can't override just one
  – If you don't override all, some will be hidden (when static binding occurs)

Overloading example

- When you *override* an *overloaded* function, override all of the variants!

```
class Derived: public Base{
public:
    virtual void func(){
        Base::func();
    }
    virtual void func(int) { ... };
}
```

Tips

- Never redefine an inherited non-virtual function
  - Non-virtuals are statically bound
  - No dynamic dispatch!
- Never redefine an inherited default parameter value
  - They’re statically bound too!
  - And what would it mean?

Virtual in Ctor?

```cpp
class A {
public:
    A() { f(); }
    virtual void f() { cout << "A::f()"; }
};
class B : public A {
public:
    B() { f(); }
    void f() { cout << "B::f()"; }
};
```

Abstract base classes

- An *abstract base class* has **pure** virtual functions
  - Only interface defined
  - No function body given

- *Abstract base classes cannot be instantiated*
  - Must derive a new class (or classes)
  - Must supply definitions for all pure virtuals before class can be instantiated

In C++

- Define the general properties of a Shape

```
class Point{ ... }; // x,y point
class Shape {
public:
    Shape();
    virtual void render() = 0; // mark render()
pure
    void move(const Point&);
    virtual void resize();
protected:
    Point center;
};
```

Abstract classes

- Why use them?
  - Modeling
  - Force correct behavior
  - Define interface without defining an implementation
- When to use them?
  - Not enough information is available
  - When designing for interface inheritance

Protocol / Interface classes

- Abstract base class with
  - All non-static member functions are *pure* virtual except destructor
  - Virtual destructor with empty body
  - No non-static member variables, inherited or otherwise
  - May contain static members

Example interface

- Unix character device

```
class CDevice {
public:
    virtual ~CDevice() {}

    virtual int read(...) = 0;
    virtual int write(...) = 0;
    virtual int open(...) = 0;
    virtual int close(...) = 0;
    virtual int ioctl(...) = 0;
};
```