Polymorphism

Subtyping

- First, we had:

```
void addCD(CD &theCD);
void addDVD(DVD &theDVD);
```

- Now, we have:

```
void addItem(Item &theItem);
```

- We call this method with:

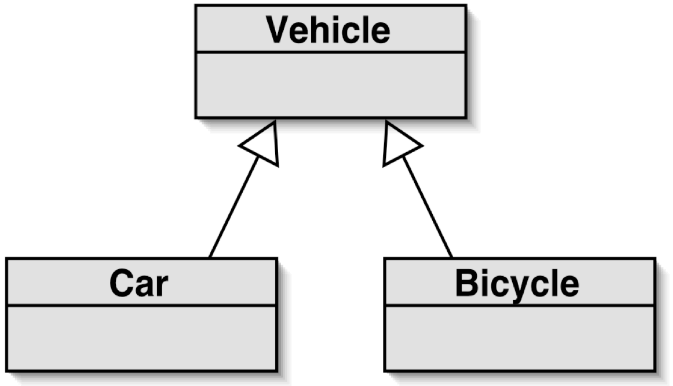
```
DVD myDVD;
database.addItem(myDVD);
```

Subclasses and subtyping

- Classes define types.
- Subclasses define subtypes.
- Objects of subclasses can be used where objects of supertypes are required. (This is called substitution)

Subtyping and assignment

- Subclass object may be assigned to superclass pointr variables




```
Vehicle *v1 = new Vehicle();
Vehicle *v2 = new Car();
Vehicle *v3 = new Bicycle();
```

Subtyping and parameter passing

```
public class Database
{
    public void addItem(const Item &theItem)
    {
        ...
    }
}

DVD dvd;
CD cd;

database.addItem(dvd);
database.addItem(cd);
```

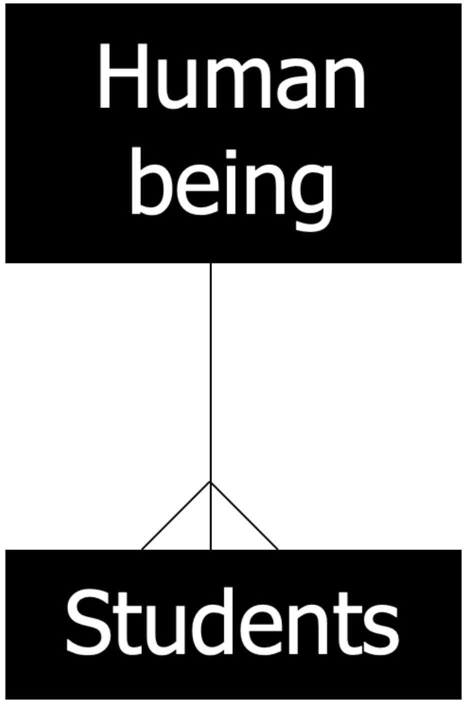
- Subclass objects may be passed to superclass parameters

Conversions

- Public Inheritance should imply substitution
  - If B isa A,you can use a B any where an A can be used.
  - if B isa A, then everything that is true for A is also true of B.
  - Be careful if the substitution is not valid!
- Given D is derived from B
  - `D -> B`
  - `D* -> B*`
  - `D& -> B&`

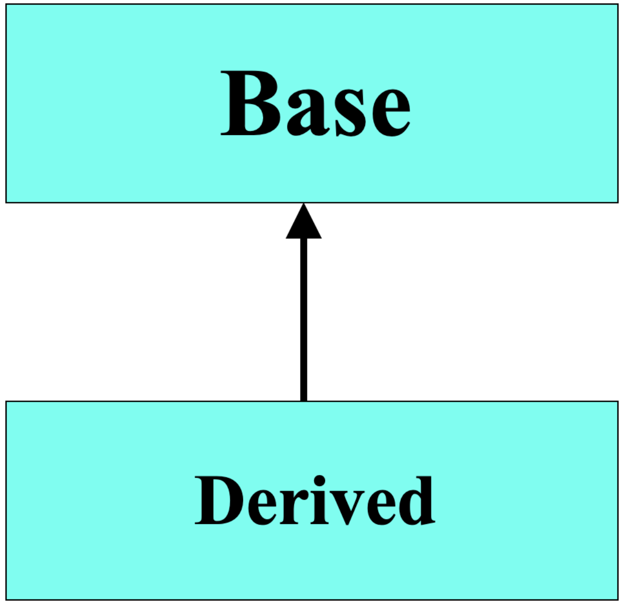
Up-casting

- Is to regard an object of the derived class as an object of the base class.
- It is to say: Students are human beings. You are students. So you are human being.



Upcasting

- Upcasting is the act of converting from a Derived reference or pointer to a base class reference or pointer.



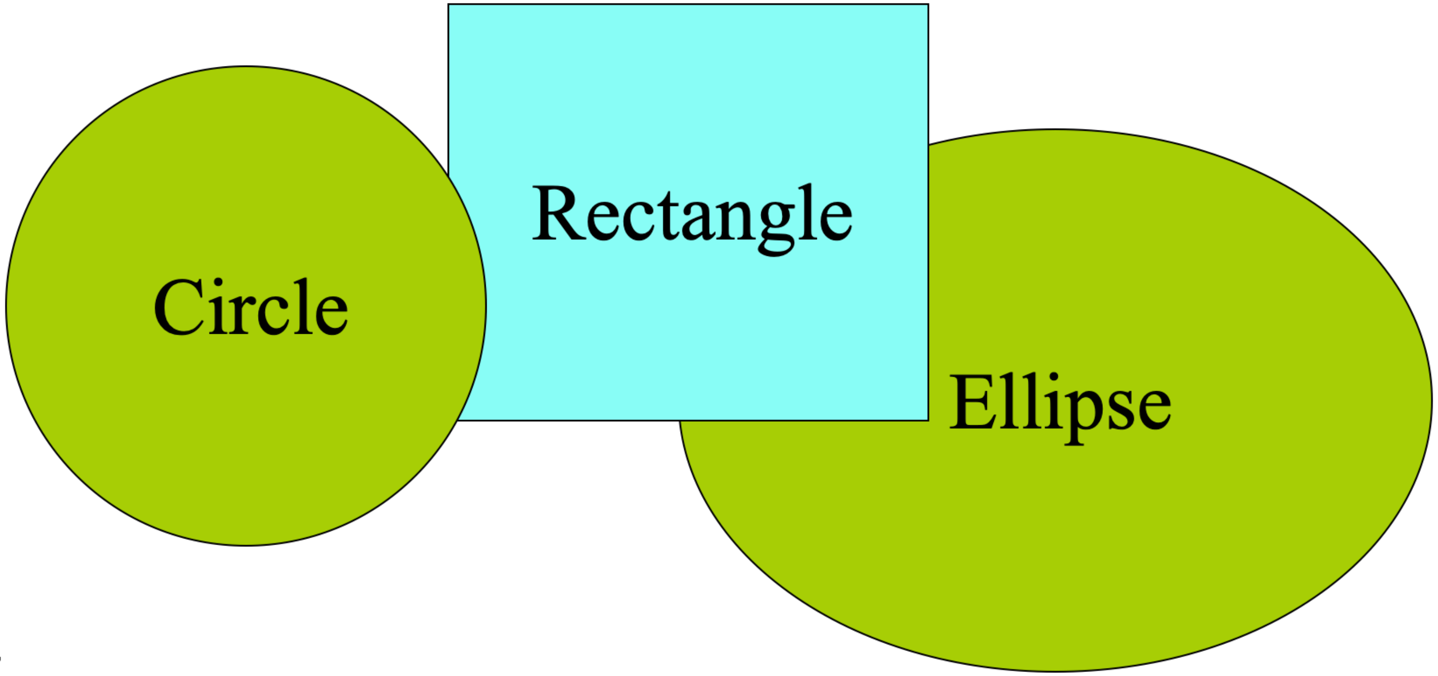
Upcasting examples

```
Manager pete( "Pete", "444-55-6666", "Bakery");
Employee* ep = &pete; // Upcast
Employee& er = pete; // Upcast
```

- Lose type information about the object:

```
ep->print( cout ); // prints base class version
```

A drawing program



<u>Operations</u>

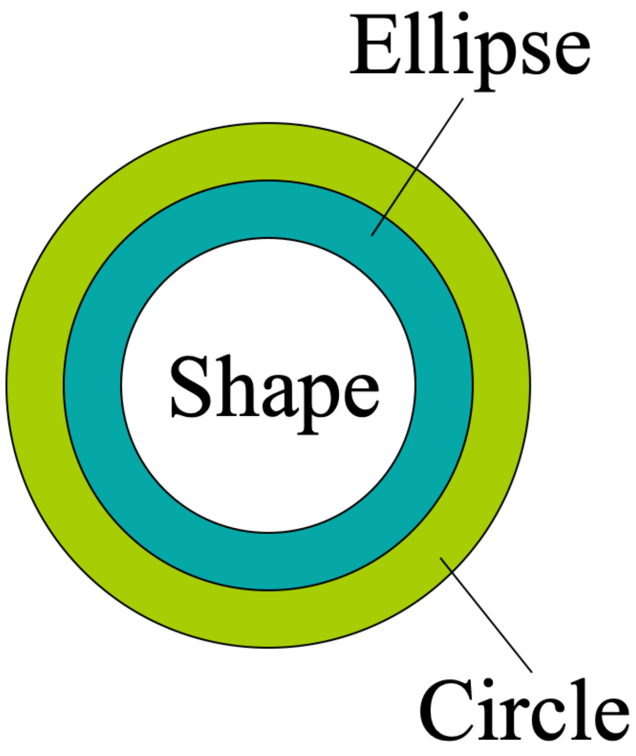
- render
- move
- resize

<u>Data</u>

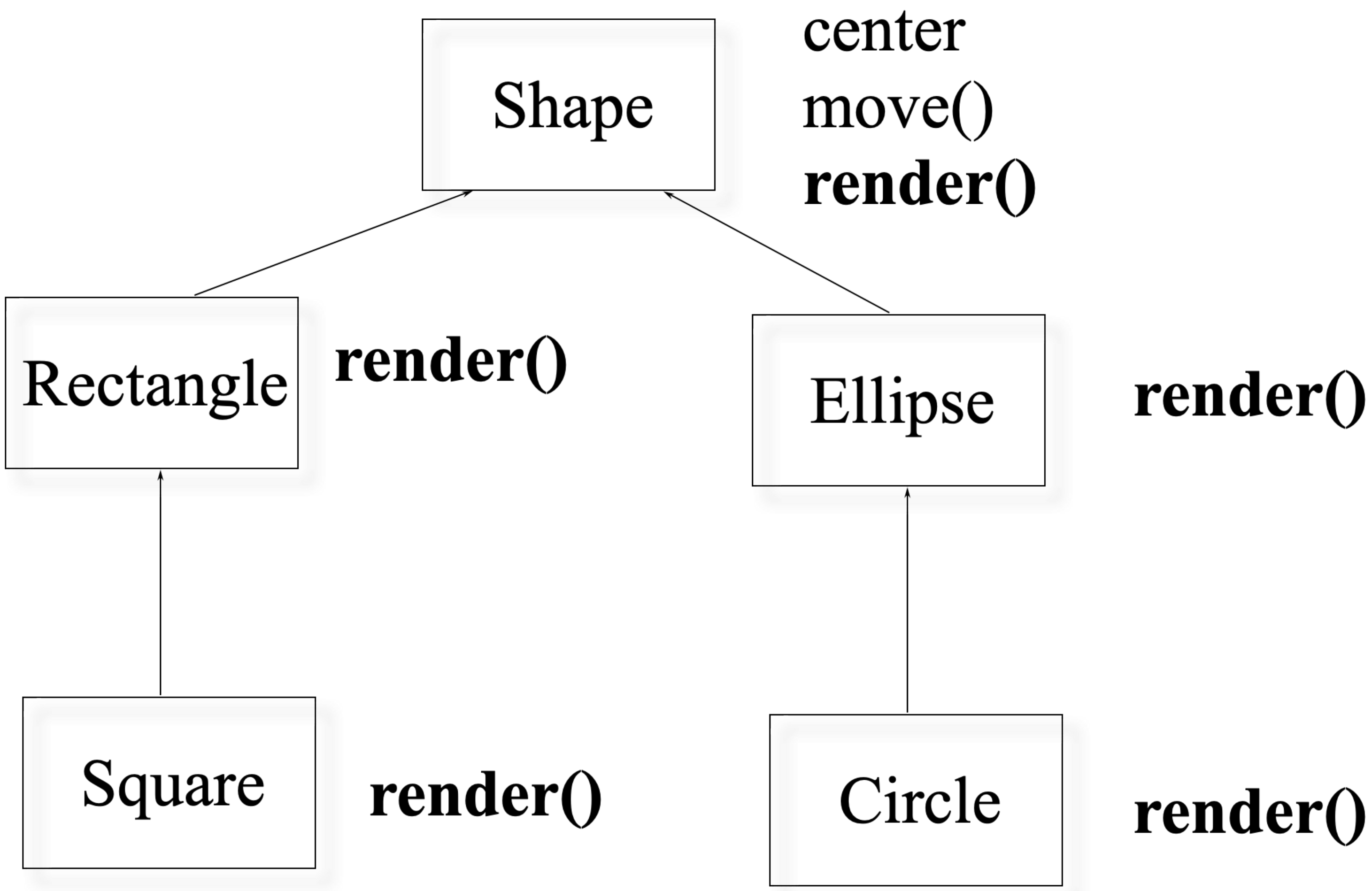
+ center

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 is a poor design choice!

In C++

- Define the general properties of a Shape

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

Add new shapes

```
class Ellipse : public Shape {
public:
    Ellipse(float maj, float minr);
    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();
};
```

Example

```
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()
```

Static type and dynamic type

- A more complex type hierarchy requires further concepts to describe it.
- Some new terminology:
  - static type
  - dynamic type
  - method dispatch/lookup

Static and dynamic type

```
Car *c1 = new Car();
Vehicle *v1 = new Car();
```

Static and dynamic type

- The declared type of a variable is its static type.
- The type of the object a variable refers to is its dynamic type.
- The compiler's job is to check for static-type violations.

```
for(Item item : items) {
    item.print(); // Compile-time error, given no print() defined in Item
}
```

Polymorphic variables

- Pointers or reference variables of objects are polymorphic variables
- They can hold objects of the declared type, or of subtypes of the declared type.

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 code
        - Dynamic binding: call the function of the object

You are a shape. You know how to draw yourself. So do it by yourself!

Virtual functions

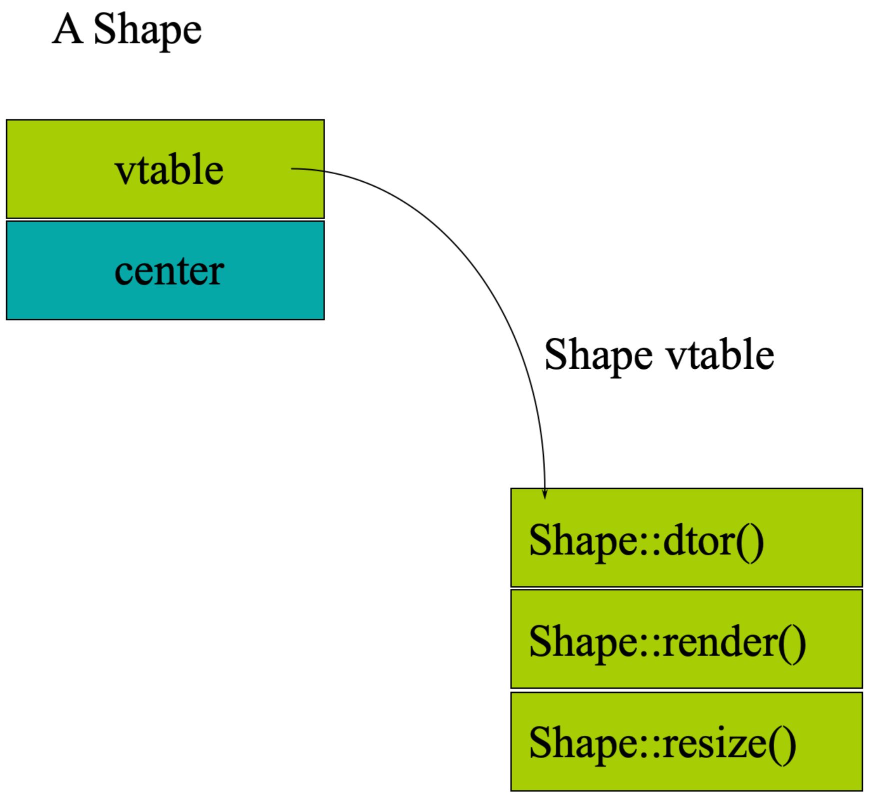
- Non-virtual functions
  - Compiler generates *static*, or direct call to stated type – Faster to execute
- Virtual functions
  - Can be *transparently* overridden in a derived class
  - Objects carry a pack of their virtual functions
  - Compiler checks pack and *dynamically* calls the right function
  - If compiler knows the function at compile-time, it can generate a static call

How virtuals work in C++

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

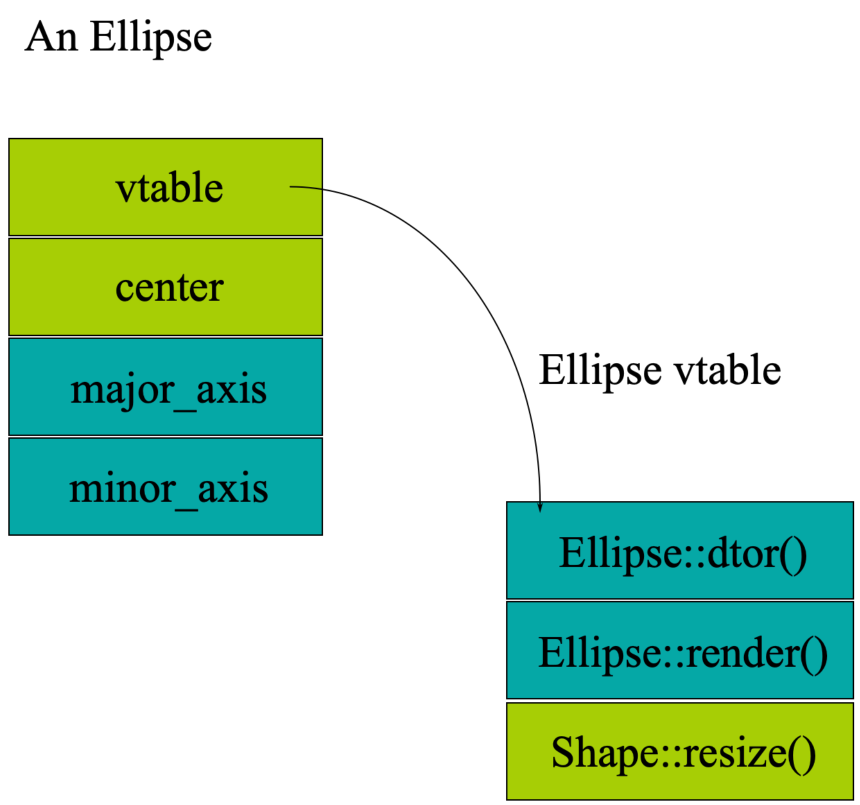
see: Virtual.cpp

```
Rectangle r;
long long **vptr = (long long **)(&r);
void (*fp)() = (void (*)())vptr[0][0];
fp();
```

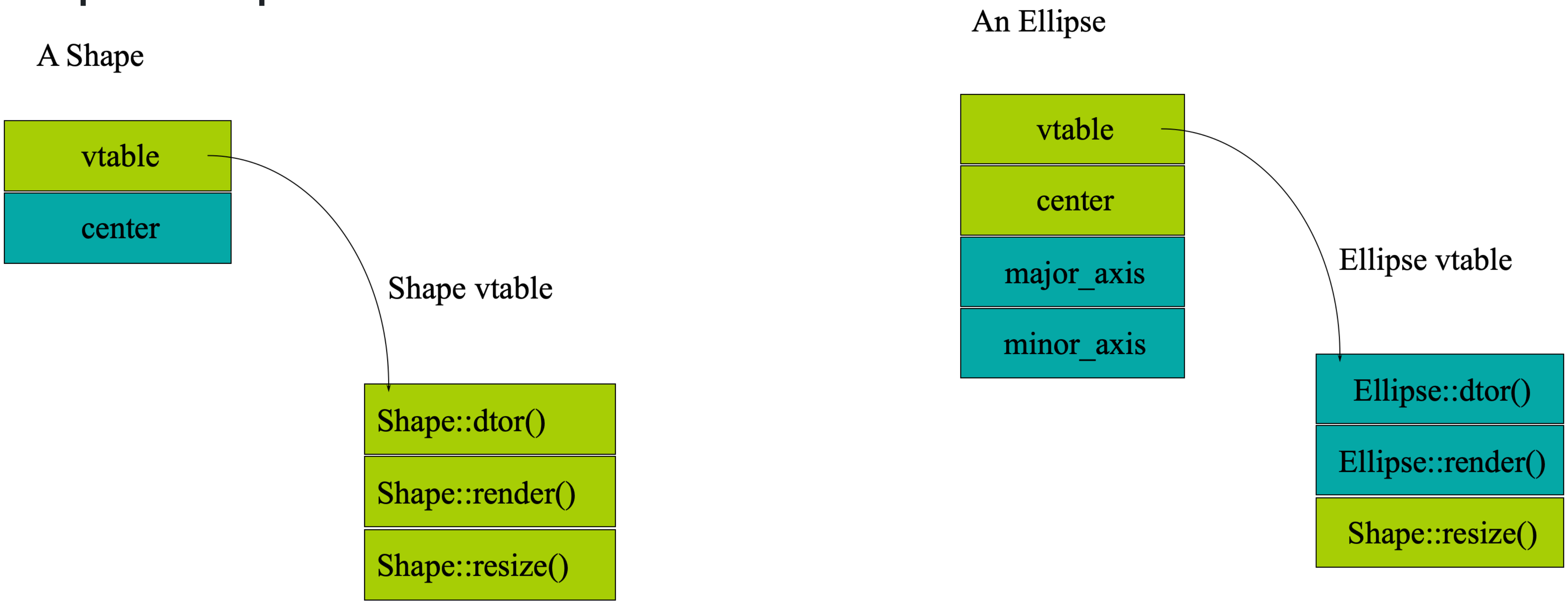


Ellipse

```cpp
class Ellipse : public Shape {
public:
    Ellipse(float majr, float minr);
    virtual void render();
protected:
    float major_axis;
    float minor_axis;
};
```

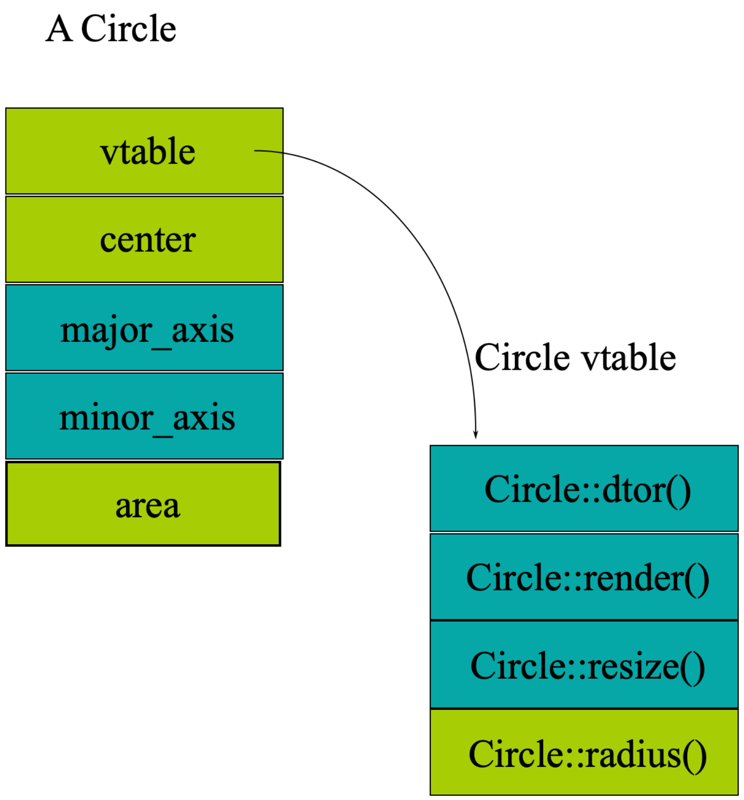


Shape vs Ellipse



Circle

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



What happens if

```
Ellipse elly(20F, 40F);
Circle  circ(60F);
elly = circ; // 10 in 5?
```

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

Virtuals and reference arguments

```cpp
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;
```

- Want `Ellipse::~Ellipse()` to be called
  - Must declare `Shape::~Shape()` virtual
  - It will call `Shape::~Shape()` automatically
- If `Shape::~Shape()` were not virtual, only `Shape::~Shape()` will be invoked!

Overriding

- Overriding redefines the body of a virtual function

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

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

Overriding

- Superclass and subclass define methods with the same signature.
- Each has access to the fields of its class.
- Superclass satisfies static type check.
- Subclass method is called at runtime – it overrides the superclass version.
- What becomes of the superclass version?

Calls up the chain

- You can still call the overridden function:

```cpp
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*`

Relaxation example

```cpp
class Expr {
public:
    virtual Expr* newExpr();
    virtual Expr& clone();
    virtual Expr  self();
};
class BinaryExpr : public Expr {
public:
    virtual BinaryExpr* newExpr();  // Ok
    virtual BinaryExpr& clone();    // Ok
    virtual BinaryExpr self();      // Error!
};
```

Overloading and virtual

- Overloading adds multiple signatures

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

- If you override an overloaded function, you must override all of the variants!
  - Can't override just one
  - If you don't override all, some will be hidden

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

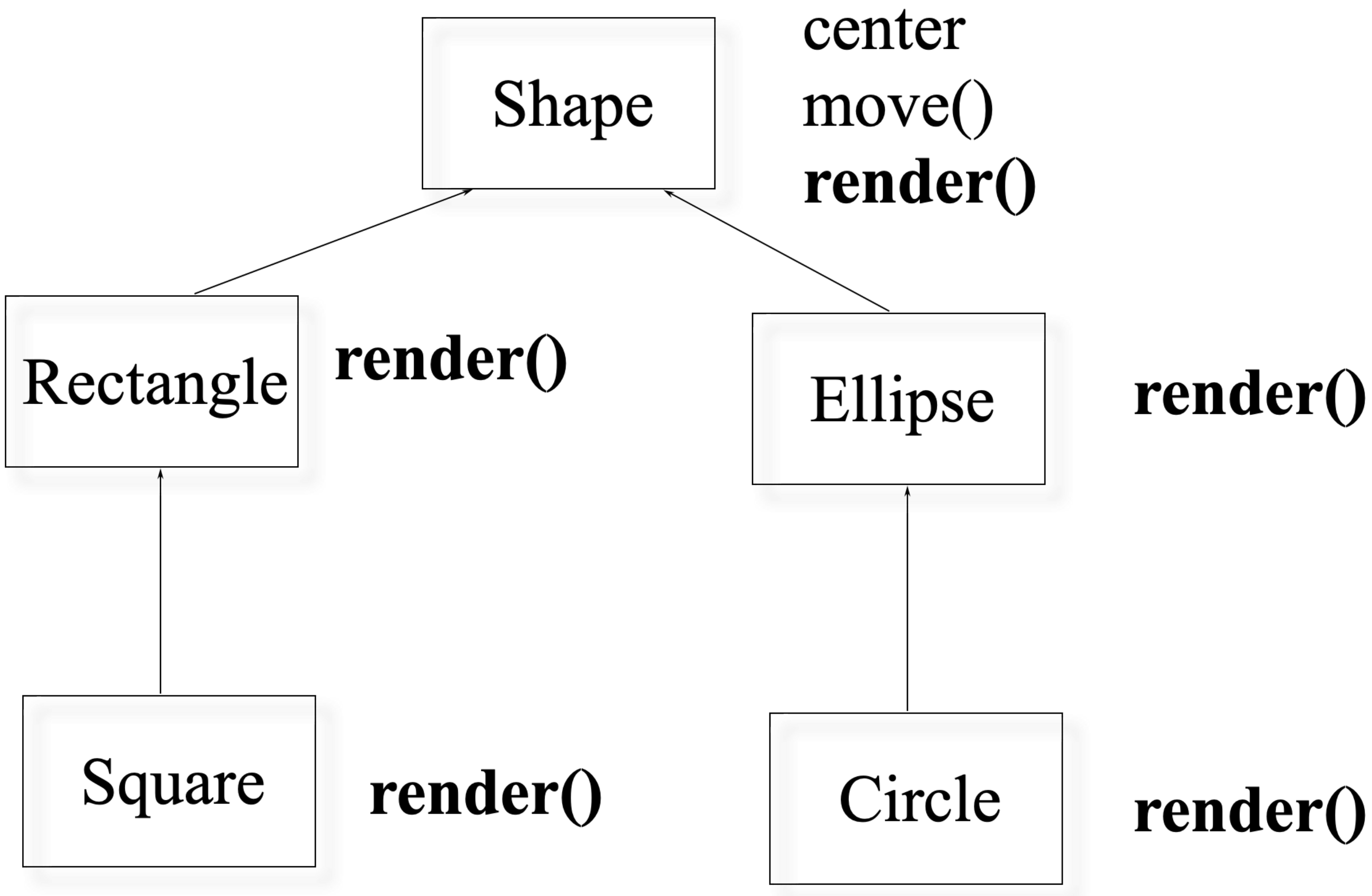
- Never redefine an inherited non-virtual function
  - Non-virtuals are statically bound
  - No dynamic dispatch!
- Never redefine an inherited default parameter value
  - They're statically bound too!
  - And what would it mean?

Virtual in Ctor?

```
class A {
public:
    A() { f(); }
    virtual void f() { cout << “A::f()”; }
};

class B : public A {
public:
    B() { f(); }
    void f() { cout << “B::f()”; }
};
```

Conceptual model



Abstract classes and methods

- Some class is to create a common interface for all the classes derived from it.
- An abstract method is incomplete. It has only a declaration and no method body.
- A class containing abstract methods is called an abstract class.

In C++

- Define the general properties of a Shape

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

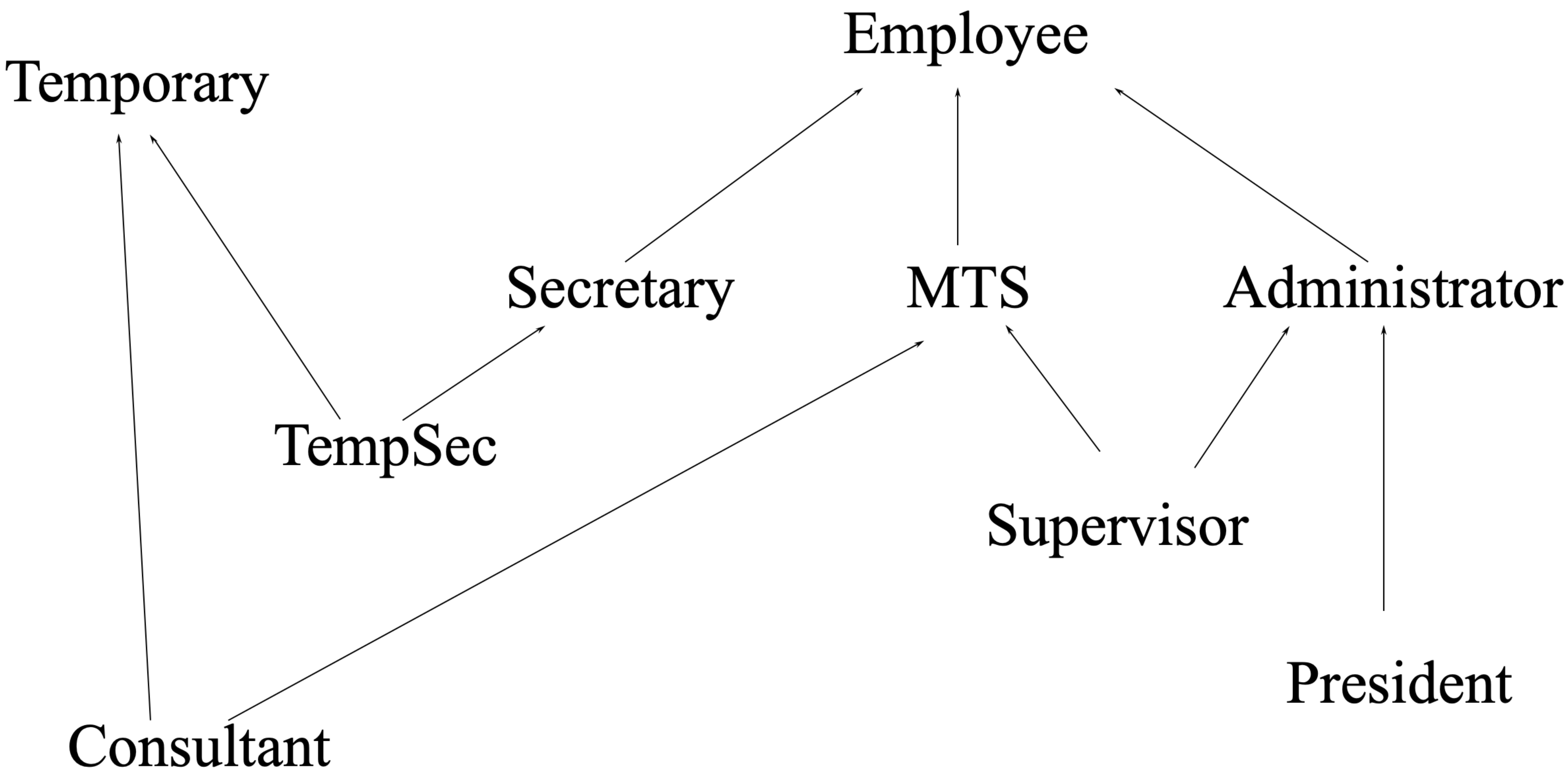
Abstract base classes

- 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

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

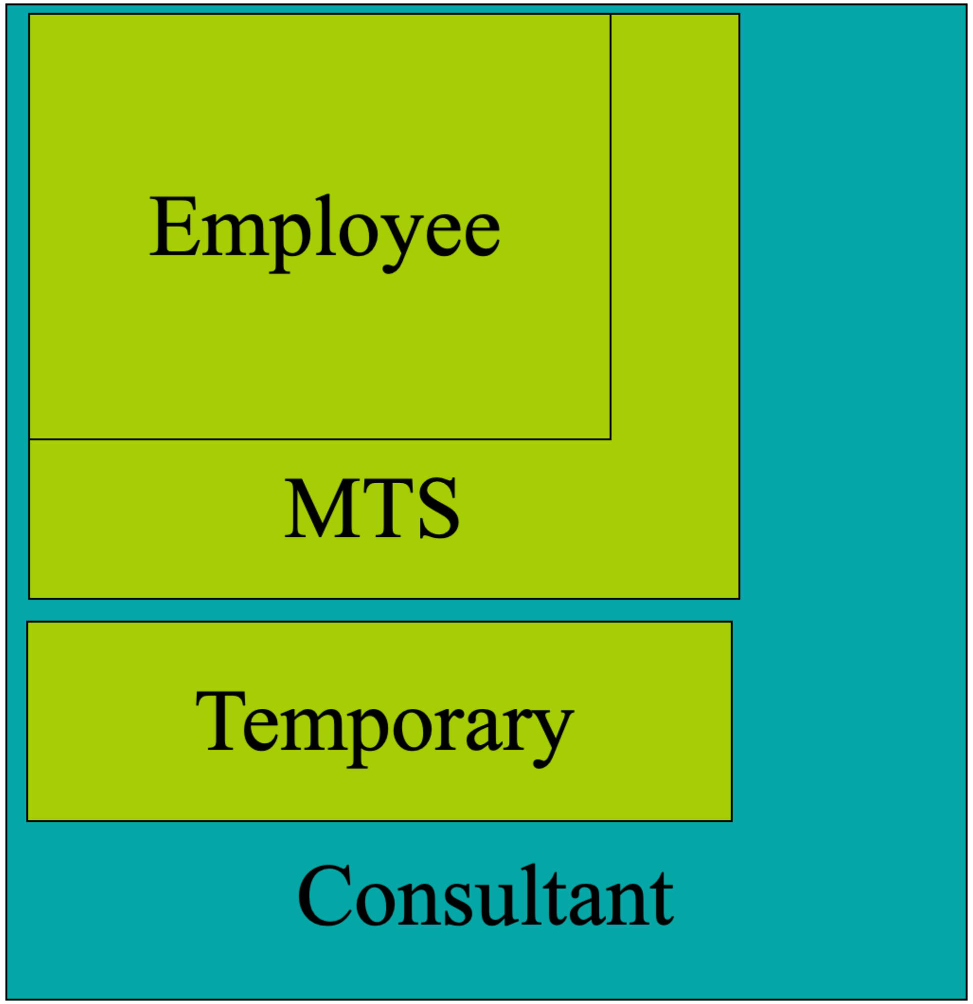
Multiple Inheritance



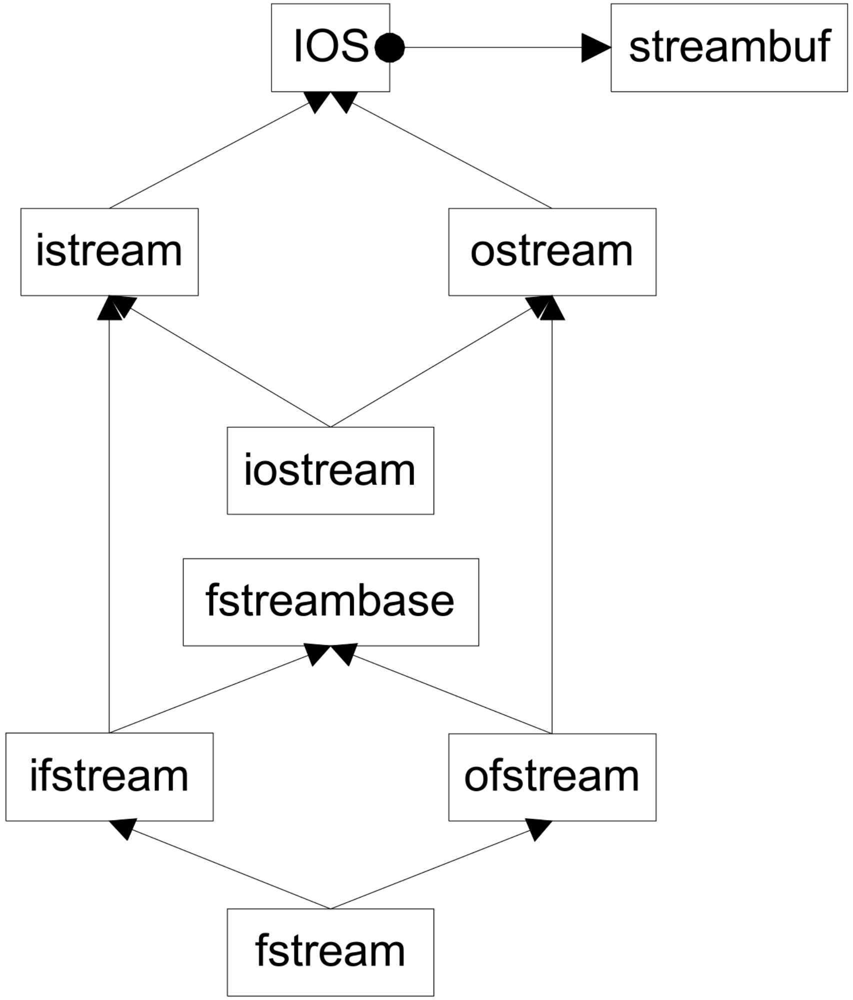
Mix and match

```
class Employee {
protected:
    String name;
    EmpID id;
};
class MTS : public Employee {
protected:
    Degrees degree_info;
};
class Temporary {
protected:
    Company employer;
};
class Consultant: public MTS,public Temporary {
...
};
```

MI Complicates Data Layouts

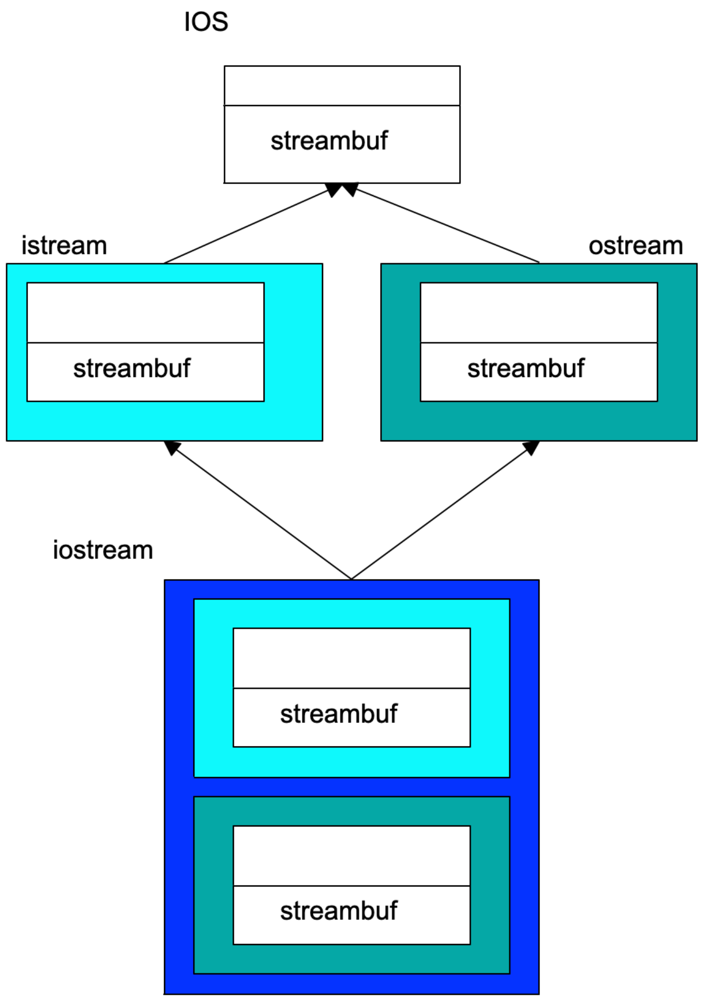


IOStreams package



Vanilla MI

- Members are duplicated
- Derived class has access to full copies of each base class
- This can be useful!
    - Multiple links for lists
    - Multiple streambufs for input and output



More on MI...

```
class B1 { int m_i; };
class D1 : public B1 {};
class D2 : public B1 {};
class M : public D1, public D2 {};

void main() {
    Mm; //OK
    B1* p = new M; // ERROR: which B1
    B1* p2 = dynamic_cast<D1*>(new M); // OK
}
```

- B1 is a replicated sub-object of M.

Replicated bases

- Normally replicated bases aren't a problem (usage of B1 by D1 and D2 is an implementation detail).
- Replication becomes a problem if replicated data makes for confusing logic:

```
M m;
m.m_i++; // ERROR: D1::B1.m_i or D2::B1.m_i?
```

Safe uses

- Protocol classes

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

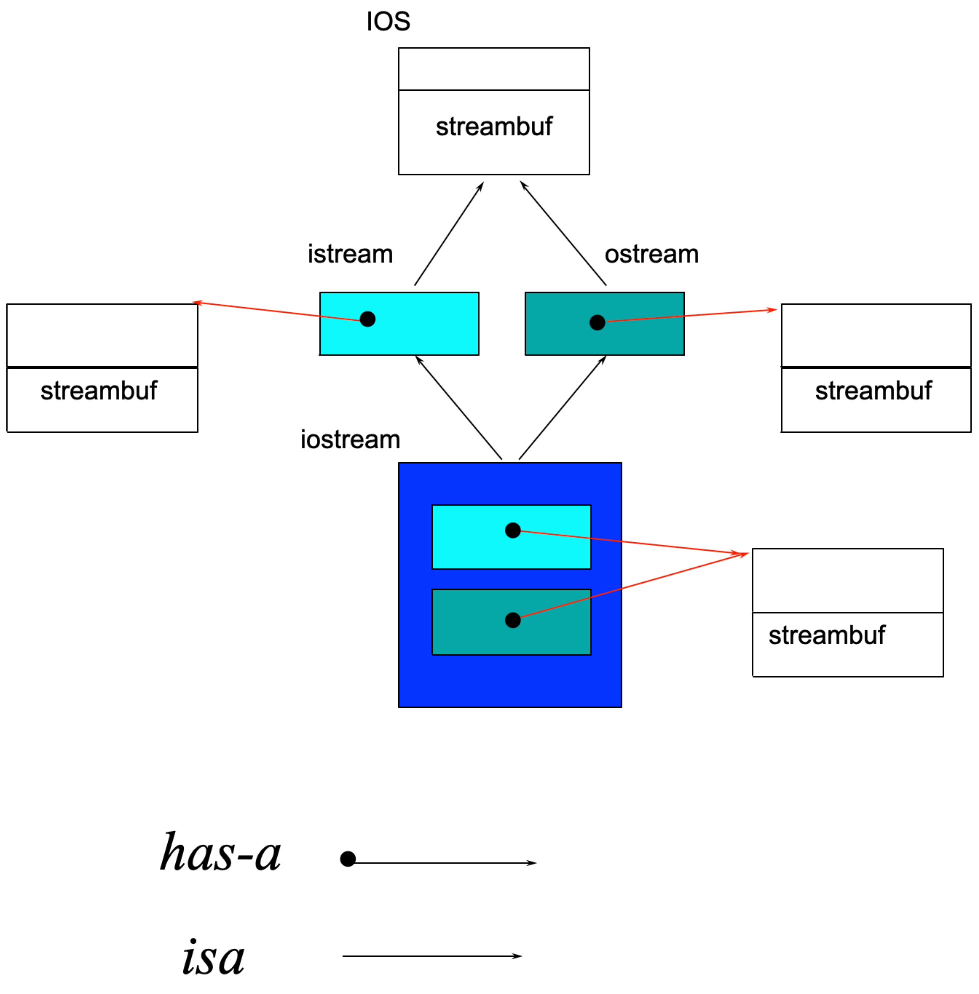
```
class CDevice {
public:
    virtual ~CDevice();
    virtual int read(...) =0;
    virtual int write(...) = 0;
    virtual int open(...) =0;
    virtual int close(...) = 0;
    virtual int ioctl(...) = 0;
};
```

What about sharing?

- How do you avoid having two streambufs?
- Base classes can be virtual
  - To C++ people, “virtual” means “indirect”
- Virtual member functions have dynamic binding
  - They use pointer indirection
- Virtual base classes are represented indirectly
  - They use pointer indirection

Using virtual base classes

- Virtual base classes are shared
- Derived classes have a single copy of the virtual base
- Full control over sharing
    - Up to you to choose
- Cost is in complications

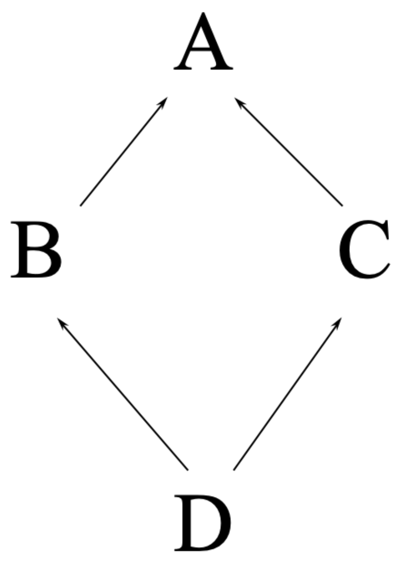


Virtual bases

```
class B1 { int m_i; };
class D1 : virtual public B1 {};
class D2 : virtual public B1 {};
class M : public D1, public D2 {};
void main() {
    M m;            //OK
    m.m_i++;        // OK, there is only one B1 in m.
    B1* p = new M;  // OK
}
```

Complications of MI

- Name conflicts
  - Dominance rule
- Order of construction
  - Who constructs virtual base?
- Virtual bases not declared when you need them
- Code in virtual bases called more than once
- Compilers are still iffy
- Moral:
  - Use sparingly
  - Avoid diamond patterns
    - expensive and/or hard



Virtual bases

- Use of virtual base imposes some runtime and space overhead.
- If replication isn't a problem then you don't need to make bases virtual.
- Abstract base classes (that hold no data except for a vptr) can be replicated with no problem - virtual base can be eliminated.

TIPS for MI

- SAY NO

What we've learned today?

- Polymorphism
    - virtual functions and override
    - abstract functions and classes
- Multiple Inheritance