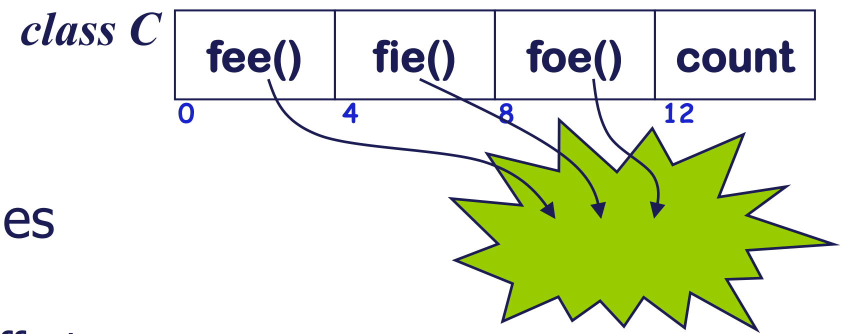
Programming Language & Compiler

Object Oriented Language Implementation

Hwansoo Han

Issues in Implementing OOLs

- **Two critical issues in OOL implementation:**
  - Object representation
  - Mapping a method invocation name to a method implementation
  - Both are intimately related to the OOL's name space

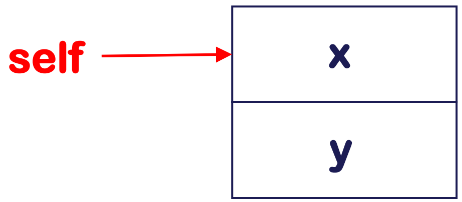


- **Object Representation**
  - Private storage for instance variables
    - Objects (or instances) allocated in heap
    - Need consistent, fast access : constant offsets
  - Static class storage for class variables accessible by global names
    - Accessible via linkage symbol &_C.count (e.g. *class C::count*)
    - Nested classes are handled like blocks in Algol-Like-Languages
  - Method code put at fixed offset from start of class area
    - Maintain pointers to method codes

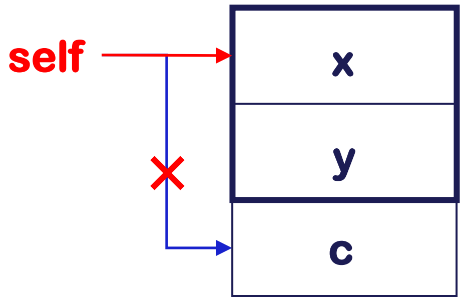
Dealing with Single Inheritance

- **Use prefixing of storage**

```
Class Point {
        int x, y;
}
```




```
Class ColorPoint extends Point {
        Color c;
}
```



Does casting work properly?

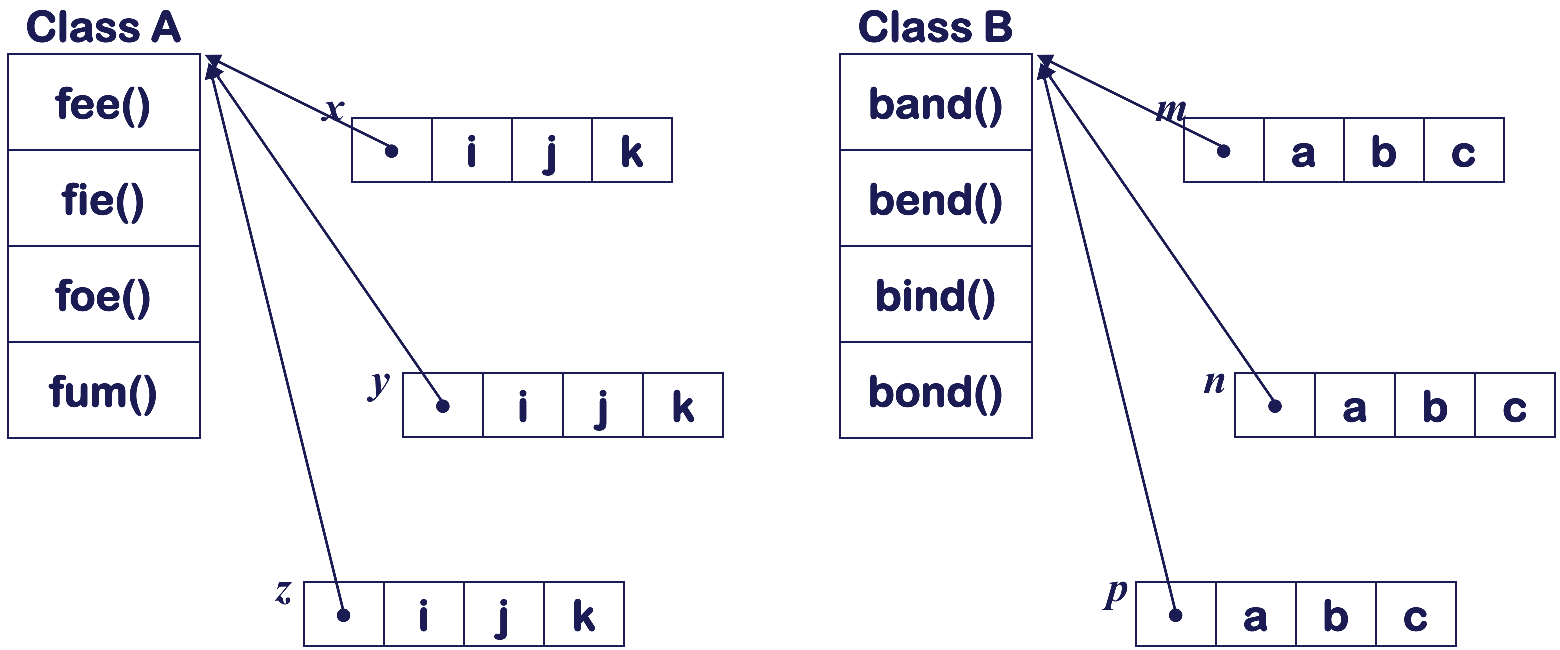
Resolving Method Names

- **Mapping names to methods**
  - <class, method> ⇒ method implementation
  - Static mapping, known at compile-time (Java, C++)
    - Fixed offsets & indirect calls
    - Static mapping for <class, method>, but dynamic binding for method name
  - Dynamic mapping, unknown until run-time (Smalltalk)
    - Look up name in class's table of methods at runtime
    - Dynamic class hierarchy changes class's method table

- **Use a method table per class**
  - Build a table of function pointers (method table for each class)
  - Use a standard invocation sequence
    - Read function address from the entry of method table
    - Invoke indirect call

Per-Class Method Table

- **With static, compile-time mapped classes**



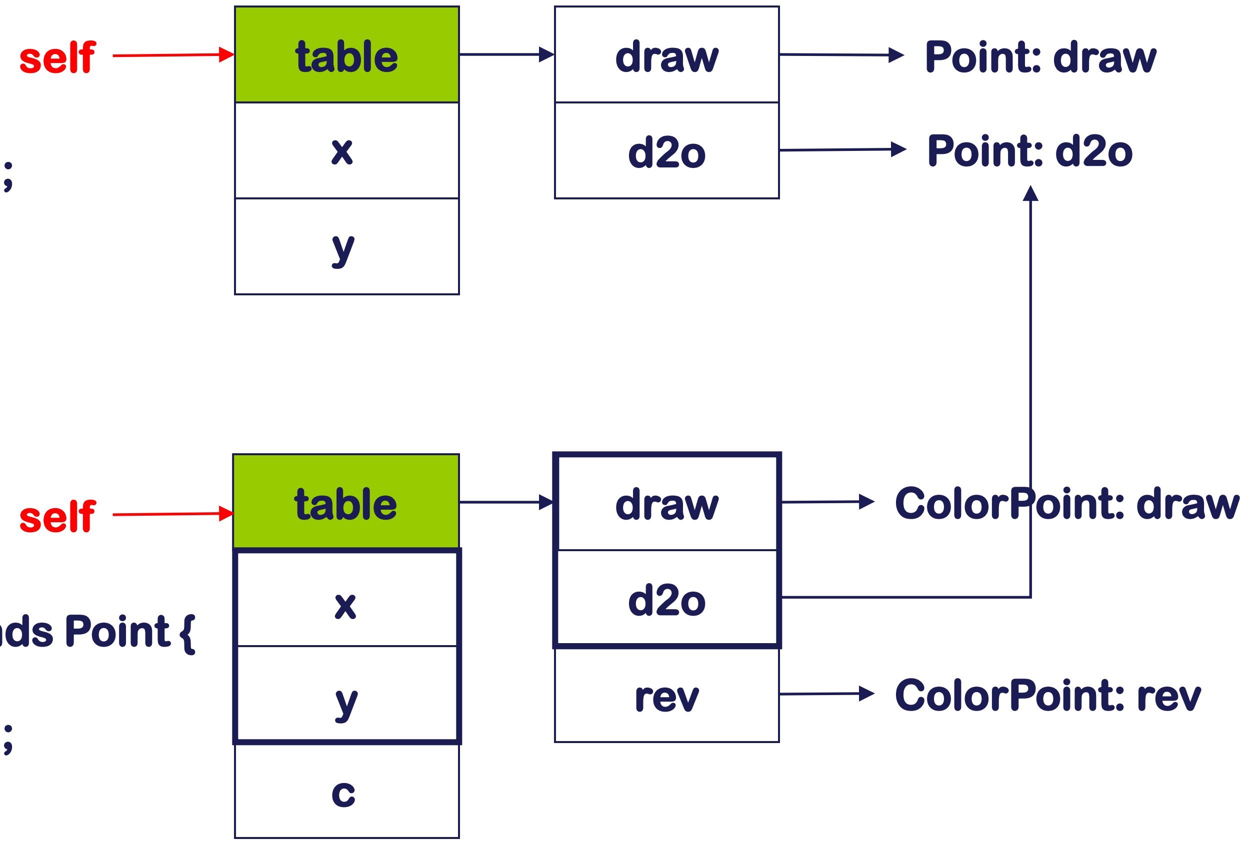
Method dispatch becomes an indirect call through a method table

Dispatching in Single Inheritance

- **Use prefixing of tables : fixed entry for same name**

```
Class Point {
        int x, y;
        public void draw();
        public void d2o();
}
```

```
Class ColorPoint extends Point {
        Color c;
        public void draw();
        public void rev();
}
```

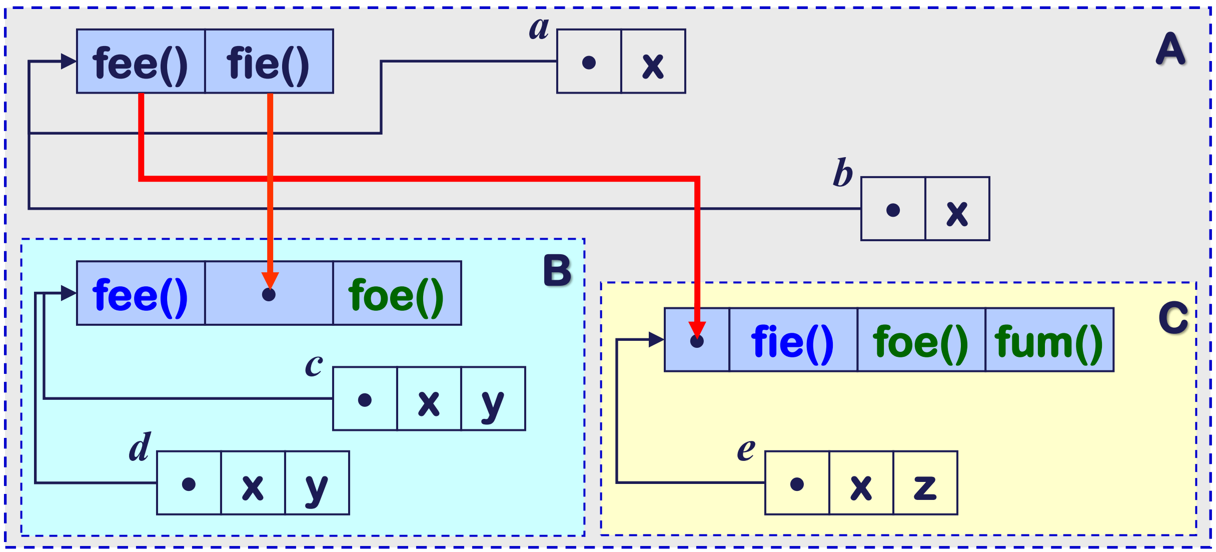


Inheritance Hierarchy

- **To simplify object creation,**
  - We allow descendant class to inherit methods from *superclass*.
    - descendant class: *subclass* of its ancestor

The Concept:

Method tables of B & C are extensions of the table from A



copy from the superclass

fn() override base class's methods

fn() extend base class's methods

Multiple Inheritance

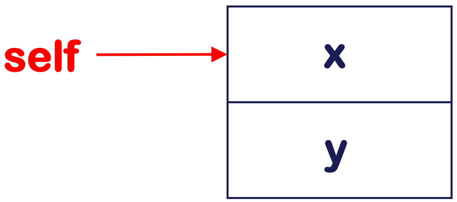
- **The idea**
  - Allow more flexible sharing of methods & attributes
  - Relax the inclusion requirement
  - Need a linguistic mechanism for specifying partial inheritance

- **Problems when C inherits from both A & B**
  - C's method table can extend A or B, but not both
    - Layout of an object instance for C becomes tricky
  - Other classes, say D, can inherit from C & B
    - Adjustments to offsets become complex
  - Both A & B might provide fum() with the same name
    - which is seen in C ?
    - C++ produces a "syntax error" when fum() is used

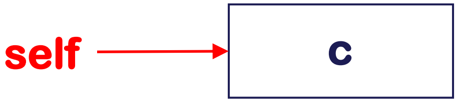
Multiple Inheritance - fields

- **Use prefixing of storage**

```
Class Point {
        int x, y;
}
```

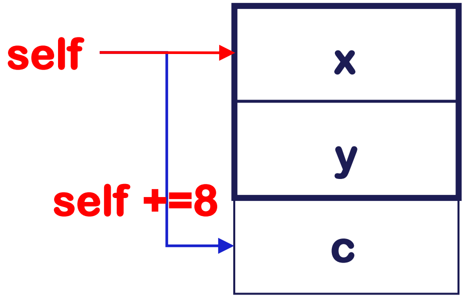



```
Class ColoredThing {
        Color c;
}
```




```
Class ColorPoint extends
        Point,  ColoredThing {

}
```



Does casting work properly?

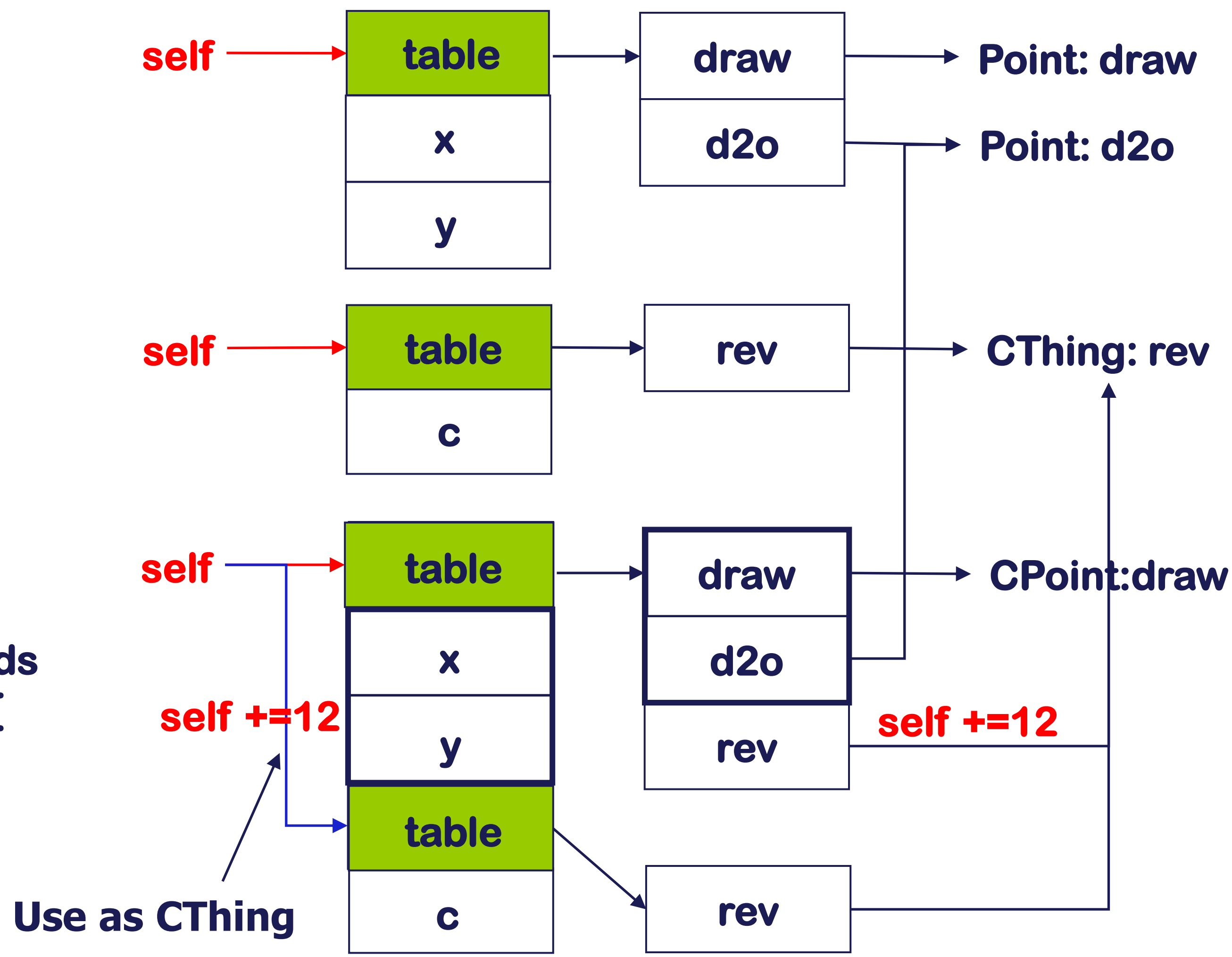
Multiple Inheritance – fields & methods

- **Use prefixing of storage**

```
Class Point {
        int x, y;
        void draw();
        void d2o();
}

Class CThing {
        Color c;
        void rev();
}

Class CPoint extends
        Point, CThing {
        void draw()
}
```

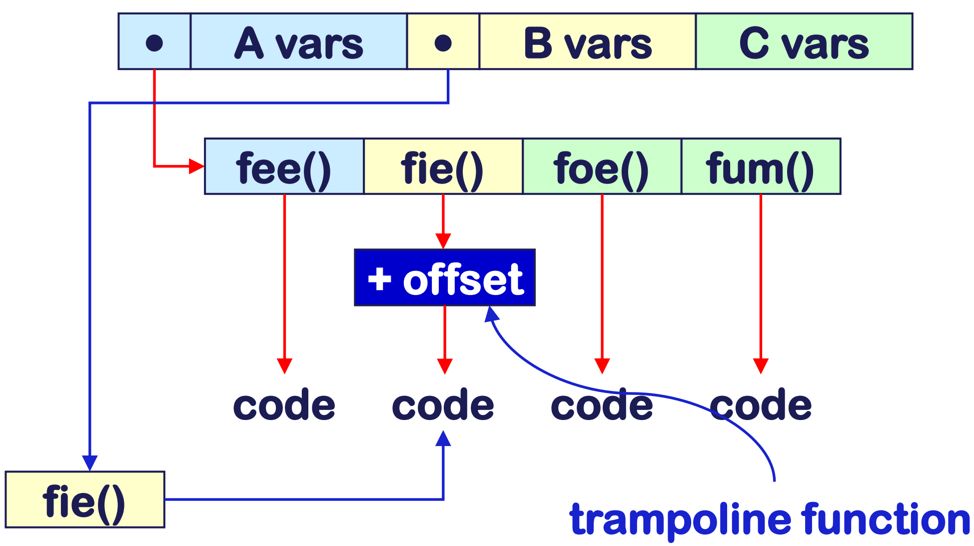


Multiple Inheritance (casting & method call)

- **Usage as Point:**
  - No extra action (prefixing does everything)
- **Usage as CThing:**
  - Increment self by 12
- **Usage as CPoint:**
  - Lay out Cthing's class pointer and Cthing's data at self + 12
  - When calling rev()
    - All methods has a pointer self as an implicit parameter
    - Two possible options
      - Add 12 to self in pre-call and restore self in post-call sequences
      - The call in class table points to a *trampoline function* that adds 12 to self and calls rev()
    - Ensures that rev(), which assumes that self points to a CThing data area, gets the right data

Multiple Inheritance (trampoline function)

- **Assume C has multiple inheritance from A and B**
  - C inherits fee() from A, fie() from B
  - C add definitions of foe() and fum()
- **Object record for an instance of C**
  - Method table entry for fie() contains a point to a trampoline function instead of real pointer to B::fie()
  - Trampoline function increases self pointer and call B::fie()



Static vs. Dynamic Inheritance

- **Two distinct philosophies**

<u>**Static class hierarchy**</u>	<u>**Dynamic class hierarchy**</u>
• **Can map <class:method> to code at compile time**	• **Cannot map <class:method> to code at compile time**
• **Leads to 1-level jump vector**	• **Multiple jump vector (*one per class*)**
• **Copy superclass methods**	• **Must search method tables**
• **Fixed offsets & indirect calls**	• **Run-time lookups & caching**
• **Less flexible & expressive**	• **Much more expensive to run**

- **Visibility in name space**
  - Method can see instance variables of self class & superclasses
  - Many different levels where a value can reside

- **In essence, OOL differs from ALL (Algol-like-language) in**
  - shape of its name space *AND*
  - mechanism used to bind names to implementations

What About Calls in an OOL (Dispatch)?

- **In an OOL, most calls are indirect calls**
  - Compiled code does not contain address of callee
    - Finds it by indirection through class's method table
    - Required to make subclass calls find right methods
    - Code compiled in class *C* cannot know of subclass methods that override methods in *C* and *C*'s superclasses

- **In a general case, need dynamic dispatch**
  - Map method name to a search key
  - Perform a run-time search through hierarchy
    - Start with object's class, search for 1st occurrence of key
    - This can be expensive, when search up the hierarchy
  - Use a method cache to speed up the search
    - Cache holds < ***key, class, method pointer*** >

How big cache?
Bigger $\Rightarrow$ more hits, longer search
Smaller $\Rightarrow$ fewer hits, faster search

What About Calls in an OOL (Dispatch)?

Improvements are possible in special cases

- If class has no subclasses, can generate a direct call
  - Class structure must be static, or class must be **FINAL**
- If class hierarchy is static
  - Can generate complete method table for each class
  - Single indirection through class pointer (*1 or 2 operations*)
  - Keeps overhead at a low level
- If class hierarchy changes infrequently
  - Build complete method tables at run time
  - Initialization & any time class hierarchy changes
- If running program can create new classes, …
  - Well, not all things can be done quickly

Summary

- **OOLs support inheritance**
  - Single vs. multiple inheritance
  - Casting to superclasses
- **Issues in implementing OOLs**
  - Data layout
  - Method mapping
- **Optimization for method invocation**
  - Direct call based on class hierarchy analysis