Implementing Object-Oriented Languages - Part 1

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NPTEL Course on Compiler Design

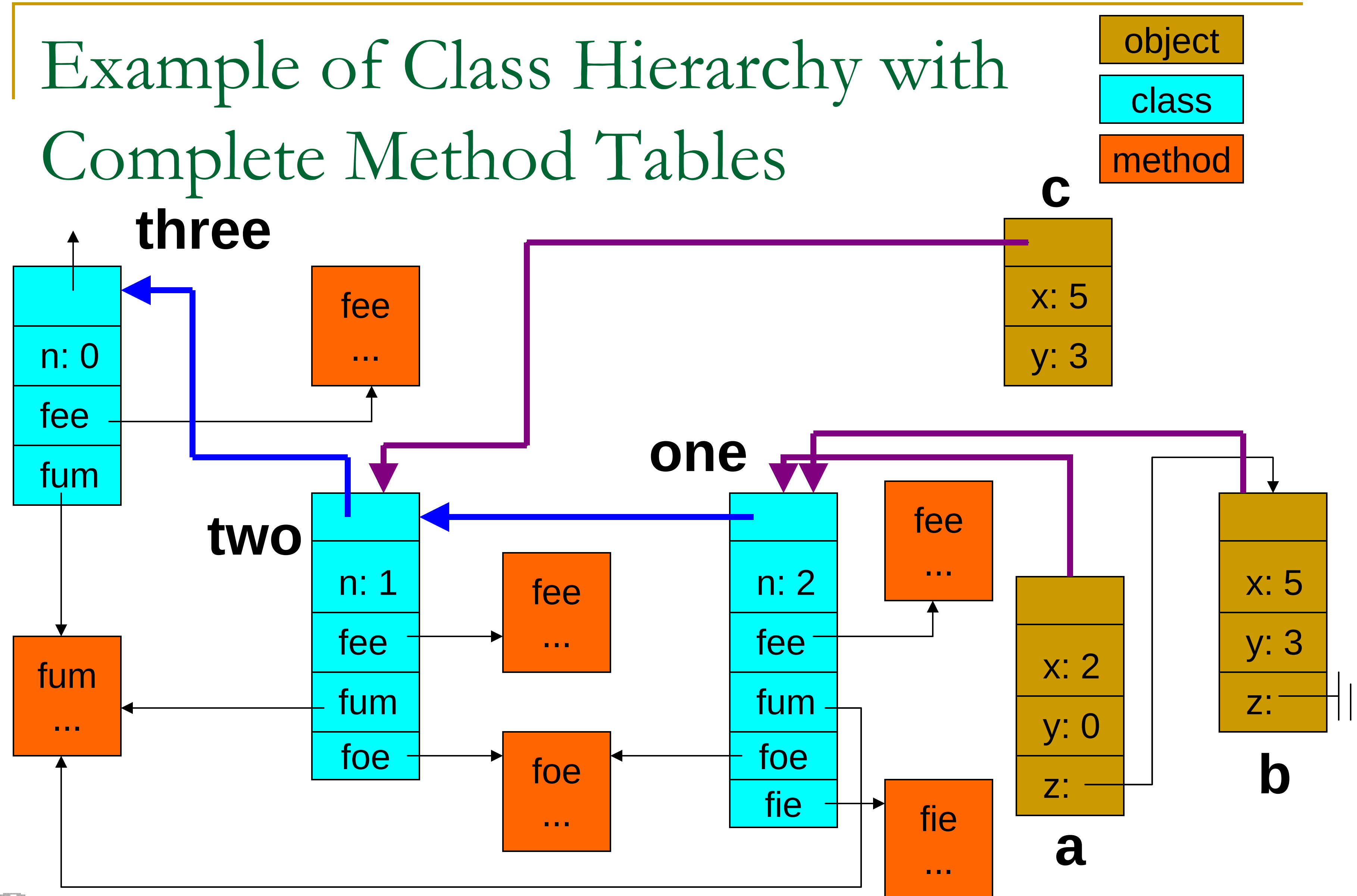
Outline of the Lecture

- Language requirements
- Mapping names to methods
- Variable name visibility
- Code generation for methods
- Simple optimizations
- **Parts of this lecture are based on the book, "Engineering a Compiler", by Keith Cooper and Linda Torczon, Morgan Kaufmann, 2004, sections 6.3.3 and 7.10.**

Language Requirements

- Objects and Classes
- Inheritance, subclasses and superclasses
- Inheritance requires that a subclass have all the instance variables specified by its superclass
  - Necessary for superclass methods to work with subclass objects
- If A is B’s superclass, then some or all of A’s methods/instance variables may be redefined in B

Example of Class Hierarchy with Complete Method Tables



Mapping Names to Methods

- Method invocations are not static calls
- *a.fee*() invokes *one.fee()*, *b.foe*() invokes *two.foe()*, and *c.fum*() invokes *three.fum()*
- Conceptually, method lookup behaves as if it performs a search for each procedure call
  - These are called virtual calls
  - Search for the method in the receiver's class; if it fails, move up to the receiver's superclass, and further
  - To make this search efficient, an implementation places a complete method table in each class
  - Or, a pointer to the method table is included (virtual tbl ptr)

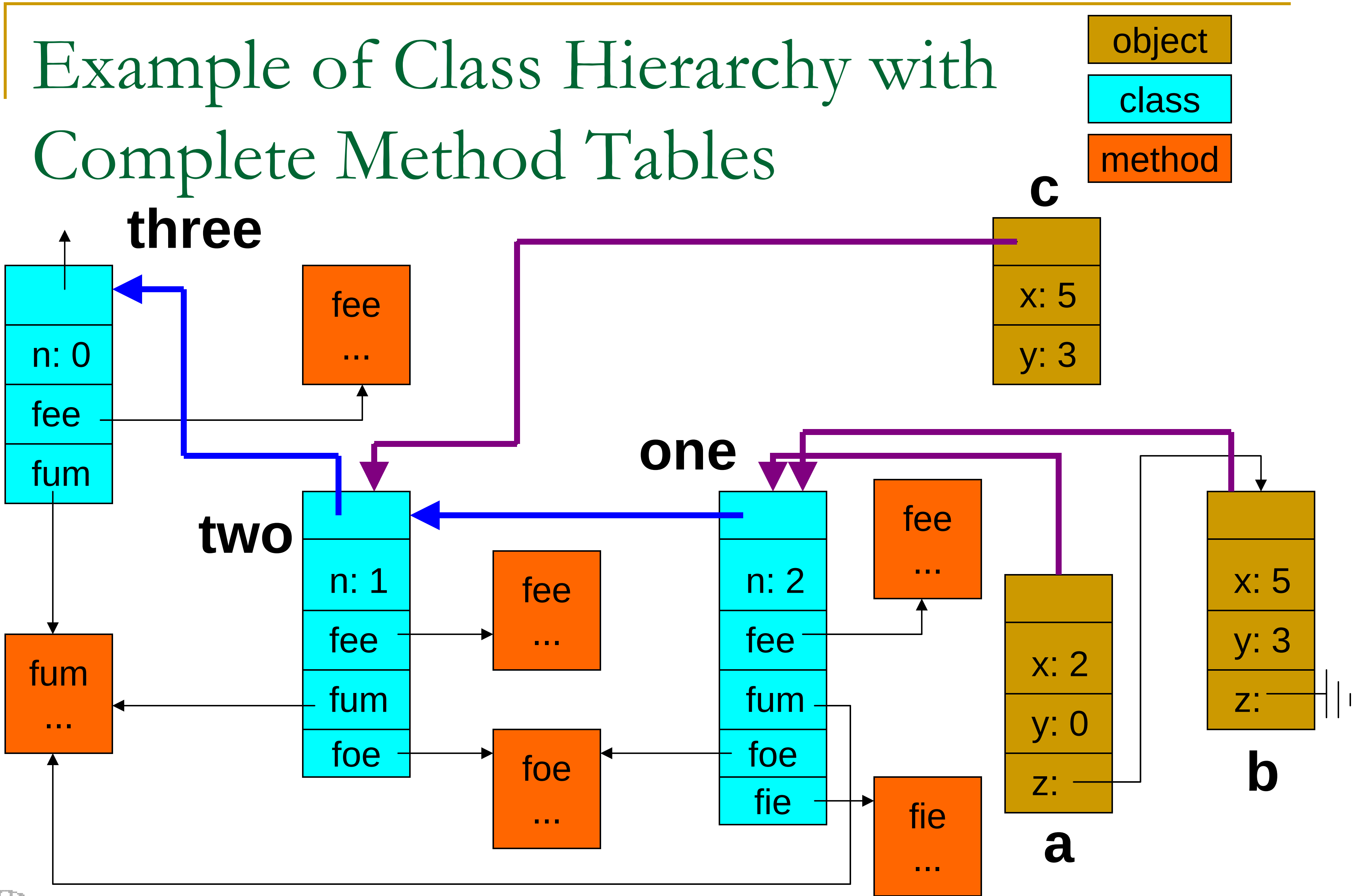
Mapping Names to Methods

- If the class structure can be determined wholly at compile time, then the method tables can be statically built for each class
- If classes can be created at run-time or loaded dynamically (class definition can change too)
  - Full lookup in the class hierarchy can be performed at run-time or
  - Use complete method tables as before, and include a mechanism to update them when needed

Rules for Variable Name Visibility

- Invoking b.fee() allows fee() access to all of b's instance variables (x,y,z), (since fee and b are both declared by class one), and also all class variables of classes one, two, and three
- However, invoking b.foe() allows foe() access only to instance variables x and y of b (not z), since foe() is declared by class two, and b by class one
  - foe() can also access class variables of classes two and three, but not class variables of class one

Example of Class Hierarchy with Complete Method Tables



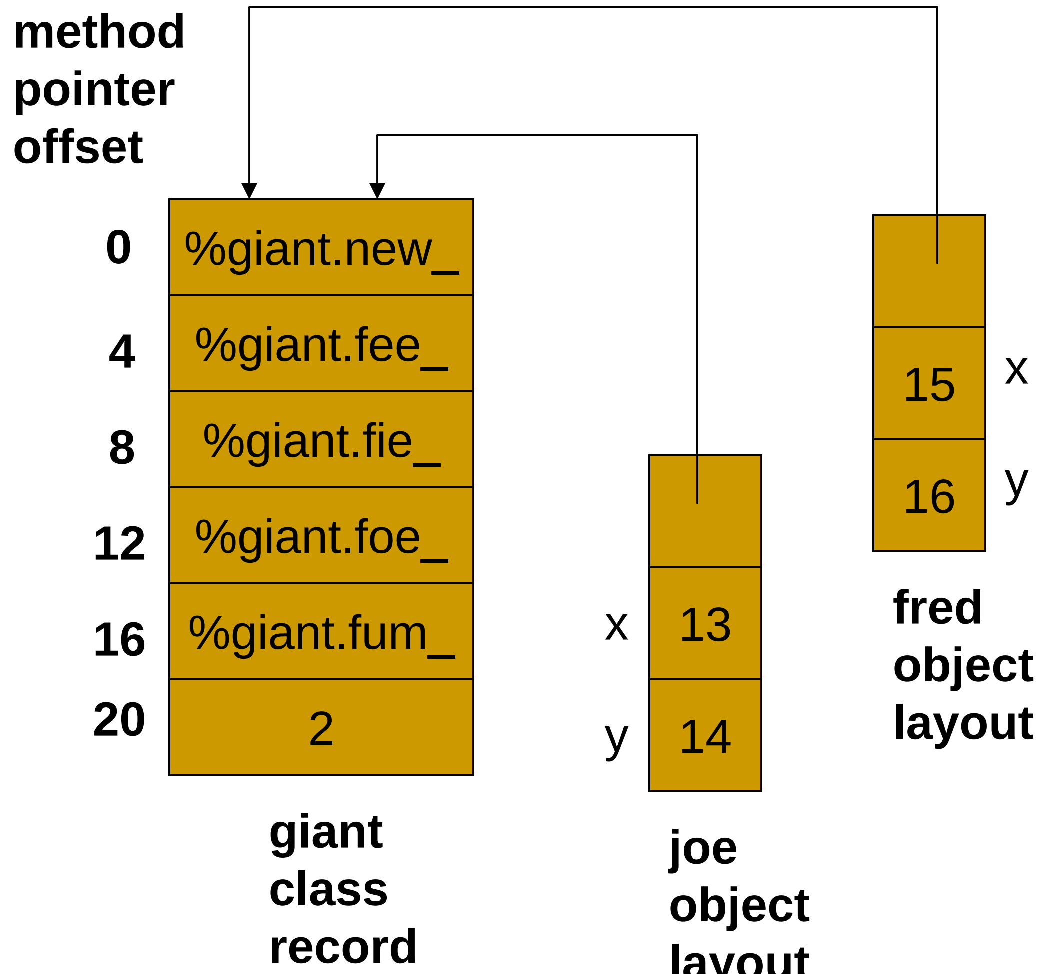
Code Generation for Methods

- Methods can access any data member of any object that becomes its receiver
  - receiver - every object that can find the method
  - subject to class hierarchy restrictions
- Compiler must establish an offset for each data member that applies uniformly to every receiver
- The compiler constructs these offsets as it processes the declarations for a class
  - Objects contain no code, only data

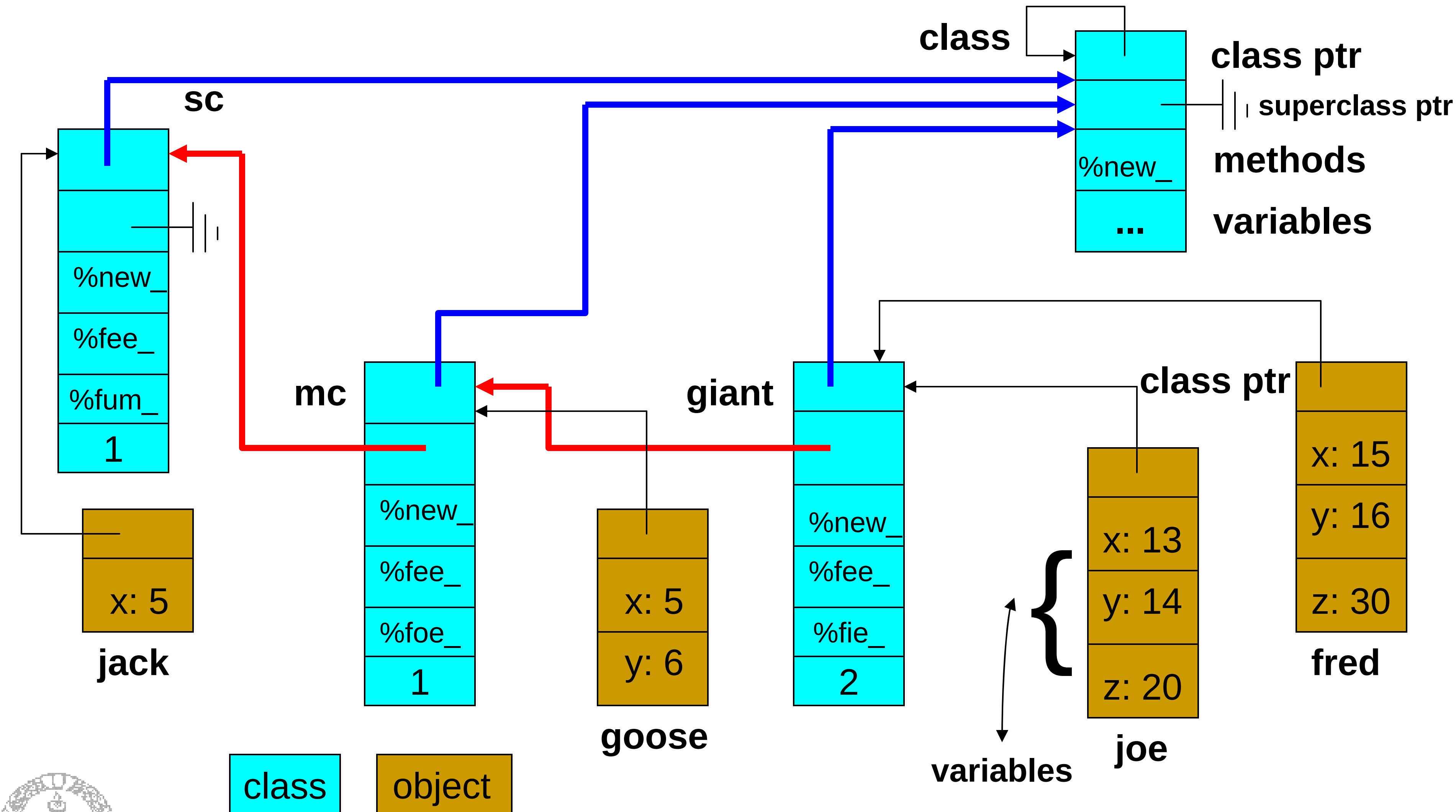
Single Class, No Inheritance

Example:

```
Class giant {
    int fee() {...}
    int fie() {...}
    int foe() {...}
    int fum() {...}
static n;
int x,y;
}
```



Implementing Single Inheritance



Single Inheritance Object Layout

Object layout for joe/fred (giant)	**class pointer**	***sc* data members (x)**	***mc* data members (y)**	***giant* data members (z)**		
class record for class giant	**class pointer**	**superclass pointer**	**%new_ pointer**	**%fee_ pointer**	**%fie_ pointer**	**2**

Object layout for goose (mc)	**class pointer**	***sc* data members (x)**	***mc* data members (y)**			
class record for class mc	**class pointer**	**superclass pointer**	**%new_ pointer**	**%fee_ pointer**	**%foe_ pointer**	**1**

Object layout for jack (sc)	**class pointer**	***sc* data members (x)**				
class record for class sc	**class pointer**	**superclass pointer**	**%new_ pointer**	**%fee_ pointer**	**%fum_ pointer**	**1**

Single Inheritance Object Layout

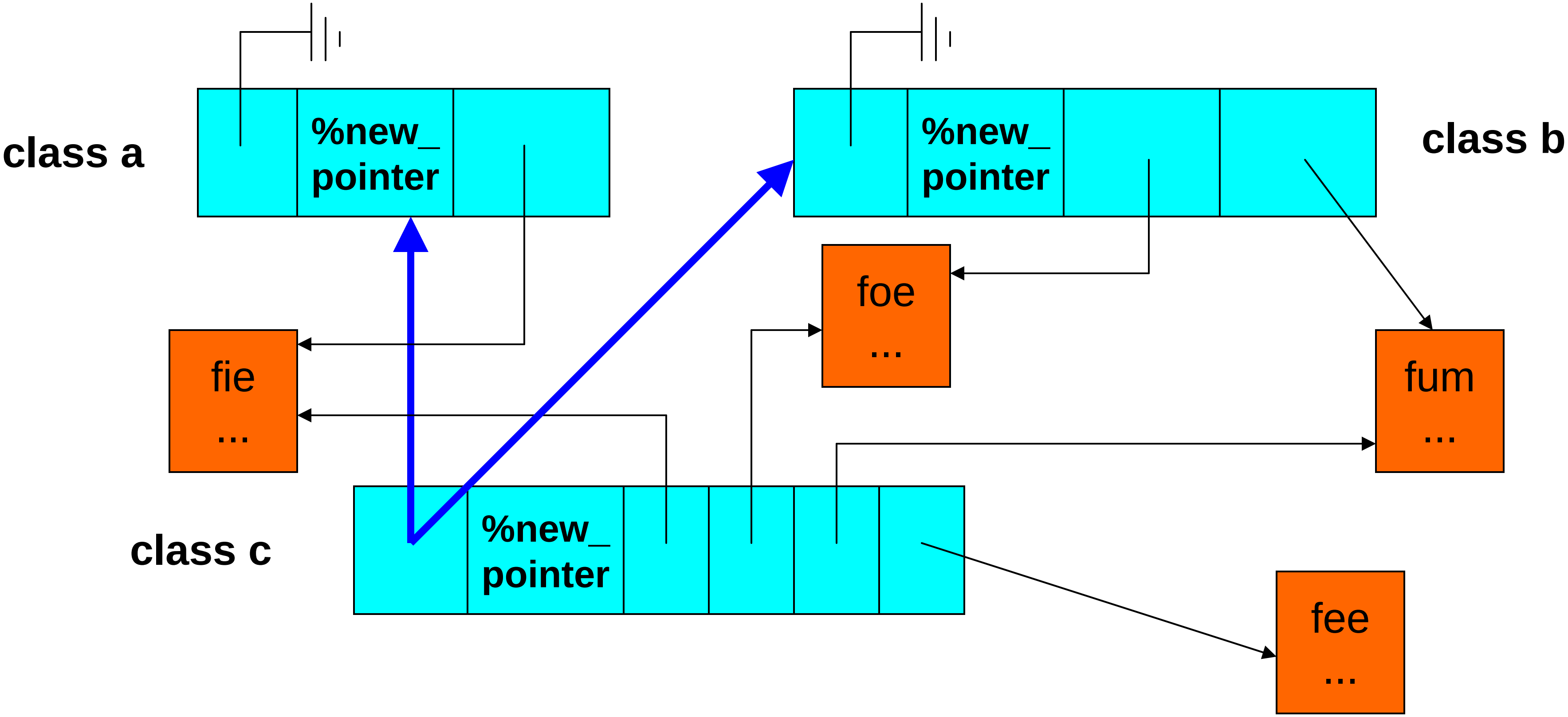
class pointer	*sc* data members	*mc* data members	*giant* data members

- Now, an instance variable has the same offset in every class where it exists up in its superclass
- Method tables also follow a similar sequence as above
- When a class redefines a method defined in one of its superclasses
  - the method pointer for that method implementation must be stored at the same offset as the previous implementation of that method in the superclasses

Implementing Multiple Inheritance

- Assume that class c inherits from classes a and b, but that a and b are unrelated in the inheritance hierarchy
- Assume that class c implements fee, inherits fie from a, and inherits foe and fum from b
- The class diagram and the object layouts are shown next

Implementing Multiple Inheritance



Implementing Multiple Inheritance

object layout for objects of class a

class pointer	***a*** data members

object layout for objects of class b

class pointer	***b*** data members

object layout for objects of class c

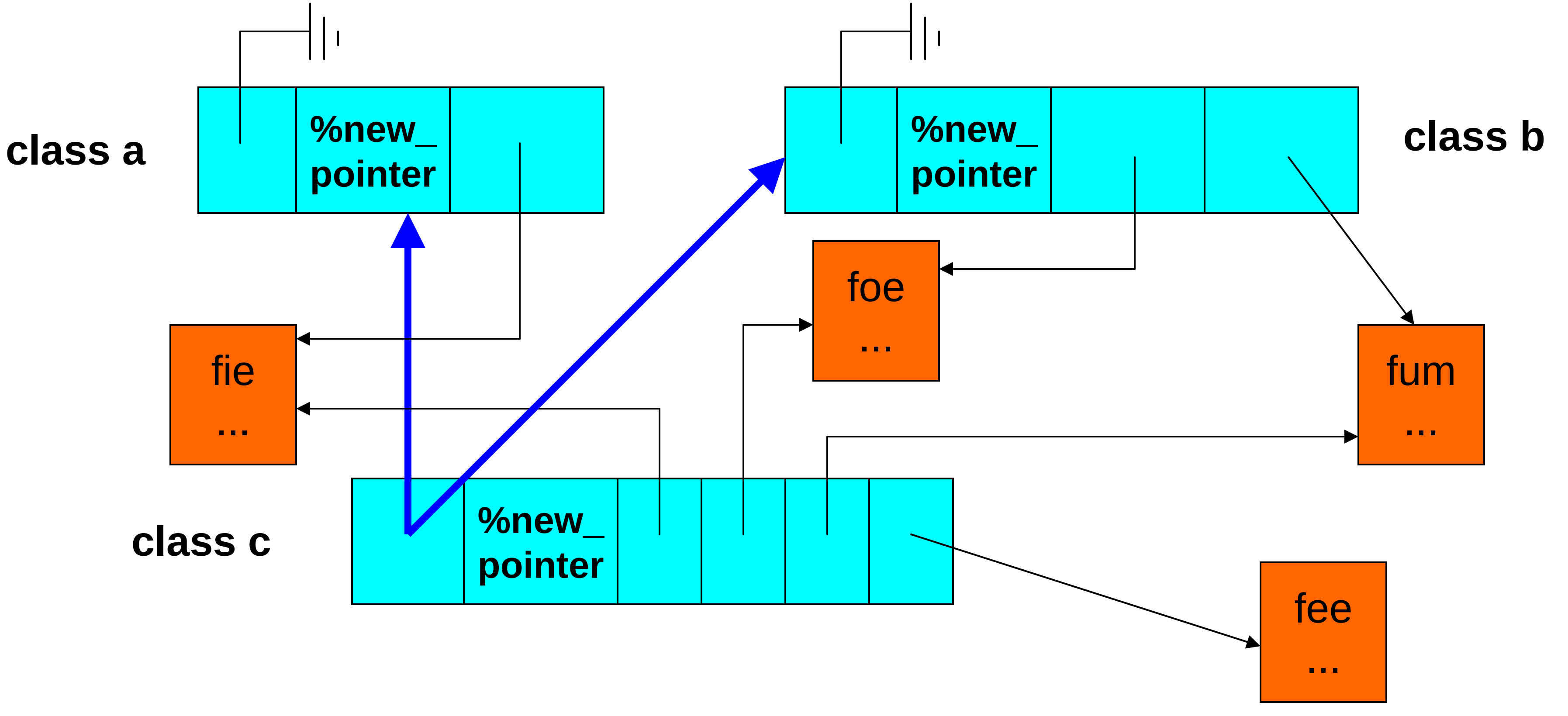
class pointer	***a*** data members	***b*** data members	***c*** data members

Implementing Multiple Inheritance

object layout for objects of class c	class pointer	*a* data members	*b* data members	*c* data members

- When c.fie() (inherited from a) is invoked with an object layout as above, it finds all of a's instance variables at the correct offsets
  - Since fie was compiled with class a, it will not (and cannot) access the other instance variables present in the object and hence works correctly
- Similarly, c.fee() also works correctly (implemented in c)
  - fee finds all the instance variables at the correct offsets since it was compiled with class c with a knowledge of the entire class hierarchy

Implementing Multiple Inheritance



Implementing Multiple Inheritance

object layout for objects of class c	class pointer	*a* data members	*b* data members	*c* data members

- However, invoking c.foe() or c.fum() creates a problem
  - foe and fum are inherited from b, but invoked from an object of class c
  - Instance variables of class b are in the wrong place in this object record – sandwiched between the instance variables of classes a and c
  - In objects of class b, the instance variables are at the start of the object record
  - Hence the offset to the instance variables of class b inside an object record of class c is unknown

Implementing Multiple Inheritance

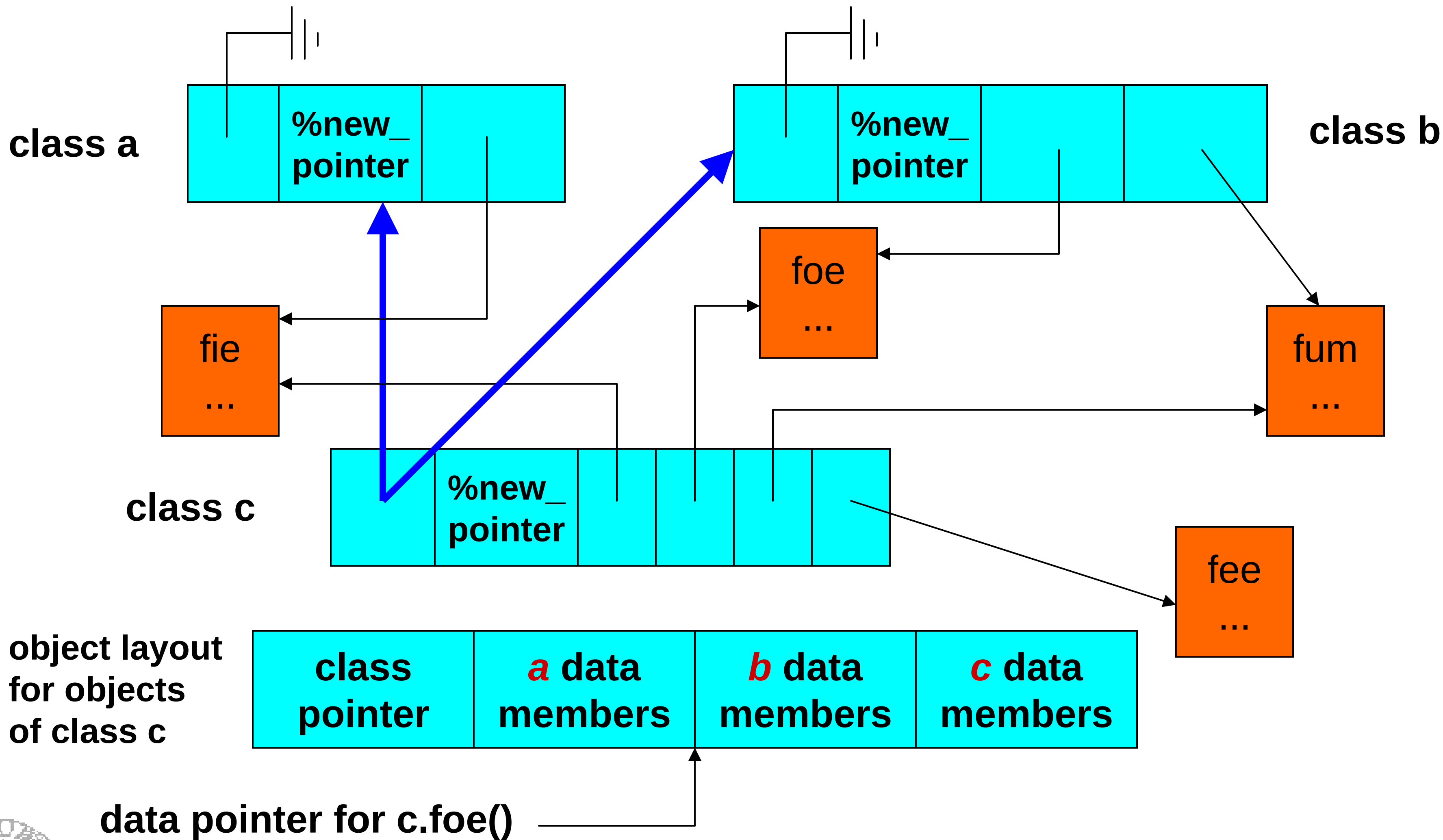
- To compensate for this, the compiler must insert code to adjust the receiver pointer so that it points into the middle of the object record – to the beginning of b's instance variables
- There are two ways of doing this

Implementing Multiple Inheritance - Fixed Offset Method

object layout for objects of class c	class pointer	*a* data members	*b* data members	*c* data members

- Record the constant offset in the method table along with the methods
  - Offsets for this example are as follows:
    - (c) fee : 0, (a) fie: 0, (b) foe : 8, (b) fum : 8, assuming that instance variables of class a take 8 bytes
  - Generated code adds this offset to the receiver's pointer address before invoking the method

Implementing Multiple Inheritance



Implementing Multiple Inheritance - Trampoline Functions

- Create trampoline functions for each method of class b
  - A function that increments this (pointer to receiver) by the required offset and then invokes the actual method from b.
  - On return, it decrements the receiver pointer, if it was passed by reference

Implementing Multiple Inheritance

- Trampolines appear to be more expensive than the fixed offset method, but not really so
  - They are used only for calls to methods inherited from b
    - In the other method, offset (possibly 0) was added for all calls
  - Method inlining will make it better than option 1, since the offset is a constant
- Finally, a duplicate class pointer (pointing to class c) may need to be inserted just before instance variables of b (for convenience)