Lecture #28: Dynamic Method Selection and OOP

- "Interesting" language feature introduced by Simula 67, Smalltalk, C++, Java: the *virtual function* (to use C++ terminology).
- Problem:
  - Arrange classes in a hierarchy of types.
  - Instance of subtype "is an" instance of its supertype(s).
  - In particular, inherits their methods, but can override them.
  - A *dynamic* effect: Cannot in general tell from program text what body of code executed by a given call.
- Implementation difficulty (as usual) depends on details of a language's semantics.
- Some things still static:
  - Names of functions, numbers of arguments are (usually) known
  - Compiler can handle overloading by inventing new names for functions. E.g., C++ encodes a function f(int x) in class Q as `_ZN1Q1fEi`, and f(int x, int y) as `_ZN1Q1fEii`.

I. Fully Dynamic Approach

- Regular Python has a completely dynamic approach to the problem:

```
class A:
   x = 2; def f (self): return 42

a = A (); b = A ()
print a.x, a.f()   # Prints 2 42
a.x = lambda (self, z): self.w * z
a.f = 13; a.w = 5
print a.x(3), a.f, a.w  # Prints 15 13 5
print b.x(3), b.f, b.w  # Error
print A.x               # Prints 2
A.x = lambda (self): 19
A.f = 2
A.v = 1
c = A ()
print c.x (), c.f, c.v  # Prints 19, 2, 1
```

Characteristics of Dynamic Approach

- Each class instance is independent. Contents of class definition merely used for initialization.
- New attributes can be added freely to instances or to class.
- In other variants of this approach, there are no classes at all, only instances.
- Get new instances by cloning an existing object.
- Then can add new attributes.

Implementing the Dynamic Approach

- Simple strategy: just put a dictionary in every instance, and in class.
- Create an instance by making fresh copy of class's dictionary.
- All checking at runtime.
- All objects (or pointers) carry around dynamic type

Pros and Cons of Dynamic Approach

- Extremely flexible
- Conceptually simple
- Implementation easy
- Space overhead: every instance has pointers to all methods
- Time overhead: lookup on each call
- No static checking

II. Straight Single Inheritance, Dynamic Typing

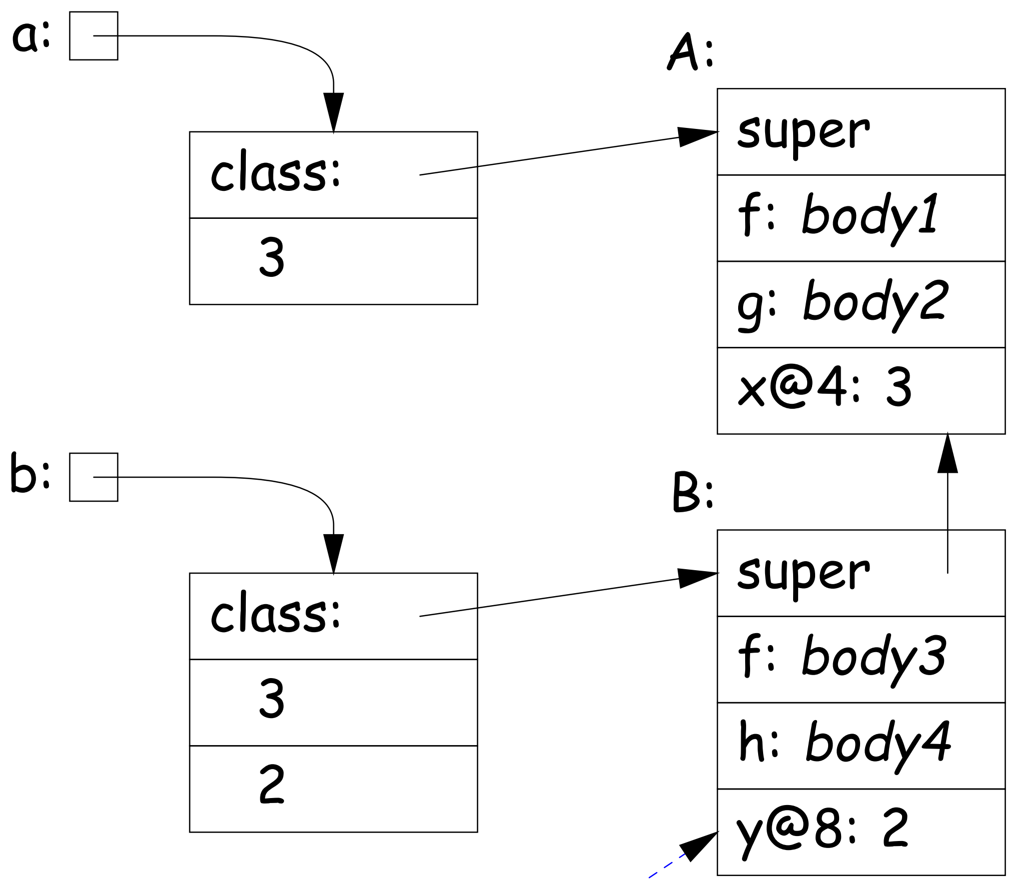
- Each class has fixed set of methods and instance variables
- Methods have fixed definition in each class.
- Classes can inherit from single superclass.
- Otherwise, types of parameters, variables, etc., still dynamic
- Basically technique in Smalltalk, Objective C.

Implementing the Smalltalk-like Approach

- Instances need not carry around copies of function pointers.
- Instead, each *class* has a data structure mapping method names to functions, and instance-variable names to offsets from the start of the object.

```
class A:
   def f (...): body1
   def g (...): body2
   x = 3
class B(A):
   def f (...): body3
   def h (...): body4
   y = 2

a = A ()
b = B ()
```



"y is stored at offset 8 from start of instance"

Pros and Cons of Smalltalk Approach

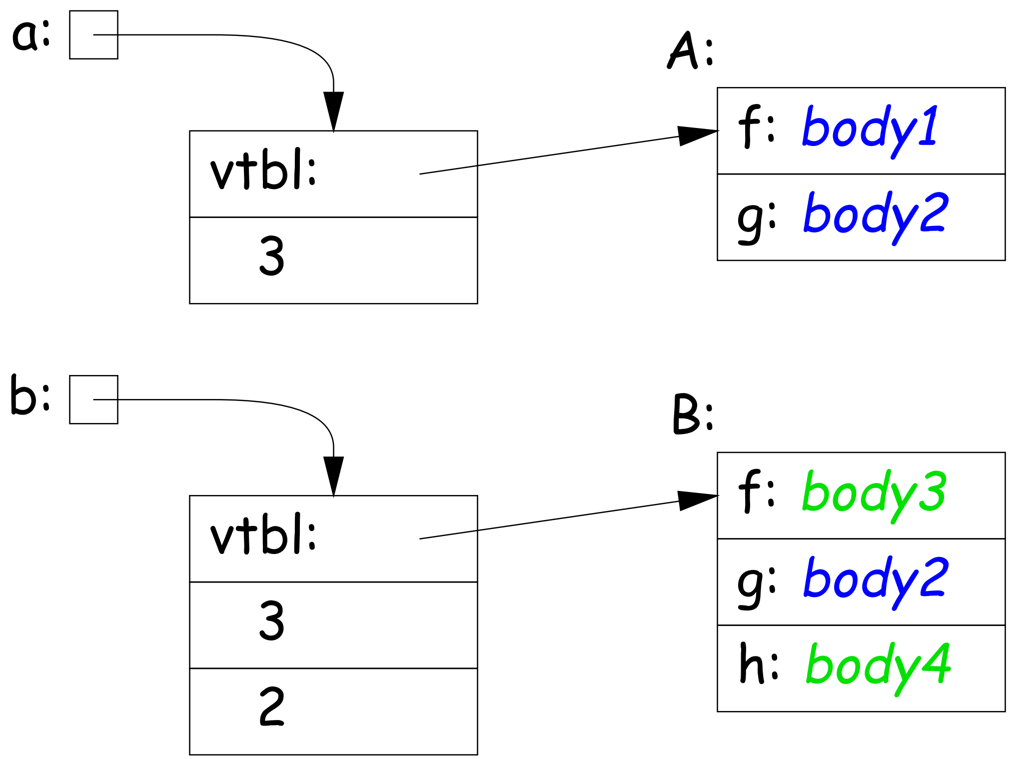
- Only need to store change things—instance variables—in instances.
- Data structure can be a bit faster at accessing than fully dynamic method
- But still, not much static checking possible, and
- Some lookup of method names required.

Single Inheritance with Static Types

- Consider Java without interfaces. Type can inherit from at most one immediate superclass.
- For an access, x.w, insist that compiler knows a supertype of x's dynamic type that defines w.
- Insist that all possible overridings of a method have compatible parameter lists and return values.
- Use a technique similar to previous one, but put entries for all methods (whether or not overridden) in each class data structure.
- Such class data structures are called "virtual tables" or "vtables" in C++ parlance.

Implementation of Simple Static Single Inheritance

```
class A {
  void f () { body1 }
  void g () { body2 }
  int x = 3
}
class B extends A {
  void f () { body3 }
  void h () { body4 }
  int y = 2
}
---------
a = new A ()
b = new B ()
```



- No need to store offsets of x and y; compiler knows where they are.
- Also, compiler knows where to find 'f', 'g', 'h' virtual tables.
- Important: offsets of variables in instances and of method pointers in virtual tables are *known constants*, the *same for all subtypes*.
- So compiler knows how to call methods of `b` even if static type is *A*!

Interfaces

- Java allows *interface inheritance* of any number of interface types (introduces no new bodies).
- This complicates life: consider

```
class A {                class B {                 interface C {
  int x;                   int y;                    f ();
  public f () { ... }      g () { ... }            }
}                          h () { ... }
                           public f () { ... }
                         }
    /*------------------------------------------------------*/
class A2 extends A            class B2 extends B
         implements C                  implements C
{...}                         { ... }
    /*------------------------------------------------------*/
            void f (C y) { y.f () }   // How can this work?
```

- We can compile A and B without knowledge of C, A2, B2.
- How can we make the virtual table of A2 and B2 compatible with each other so that `f` is at same known offset regardless of whether dynamic type of C is A2 or B2? (Above isn't hardest example!)

Interface Implementation I: Brute Force

- One approach is to have the system assign a different offset *globally* to each different function signature
  - (Functions f(int x) and f() have different function signatures)
- So in previous example, the virtual tables can be:

A:
- 0: unused
- 4: unused
- 8: pntr to A.f

B:
- 0: pntr to B.g
- 4: pntr to B.h
- 8: pntr to B.f

C:
- 0: unused
- 4: unused
- 8: unused

A2:
- 0: unused
- 4: unused
- 8: pntr to A.f

B2:
- 0: pntr to B.g
- 4: pntr to B.h
- 8: pntr to B.f

- No slowing of method calls.
- But, Total size of tables gets big (some optimization possible).
- And, must take into account all classes before laying out tables.
  - Complicates dynamic linking.

Interface Implementation II: Make Interface Values Different

- Another approach is to represent values of static type C (an interface type) differently.
- Converting value x2 of type B2 to C then causes C to point to a two-word quantity:
  - Pointer to x2
  - Pointer to a cut-down virtual table containing just the f entry from B2 (at offset 0).
- Means that converting to interface requires work and allocates storage.

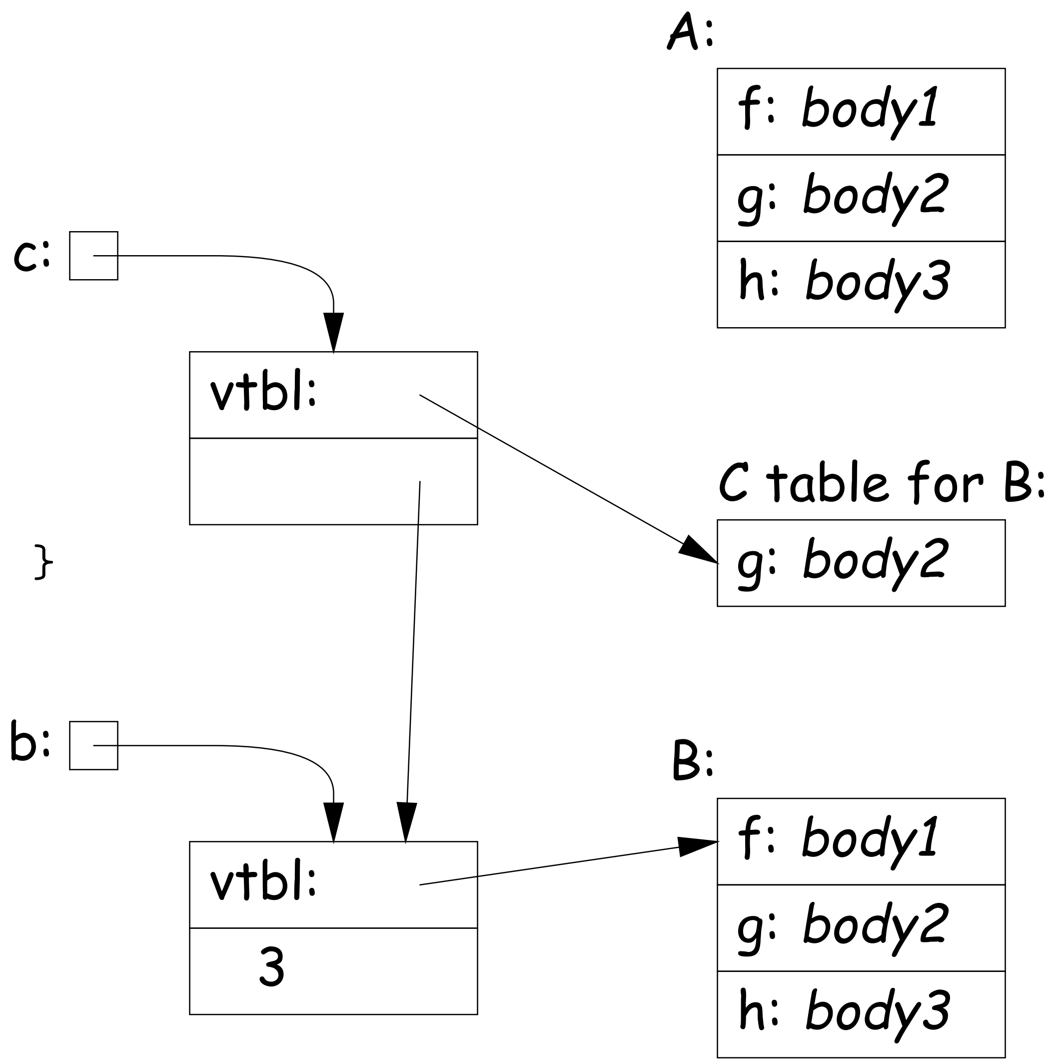
Interface Implementation II, Illustrated

```
class A {
  void f () { body1 }
  void g () { body2 }
  void h () { body3 }
  int x = 3;
}

interface C { void g (); }

class B extends A
  implements C { }

B b = new B ()
C c = b;
```



Improving Interface Implementation II

- How can we avoid doing allocation to create value of interface type *C*?
- One method: extend the virtual table of all types to include an *interface vector*.
- Each entry in this vector identifies an interface the type implements, plus the table (e.g. "C table for B" in last slide).
- How best to design the interface vector?

Full Multiple Interitance

- Java allows multiple inheritance only via interfaces.
- Important point: *interfaces don't have instance variables*.
- Instance variables basically mess everything up for multiple inheritance, assuming we want to keep constant offsets to instance variables.

```
class A {
  int x = 19;
  void f () { ... x ... h() ... }
  void h () {... }
}
```

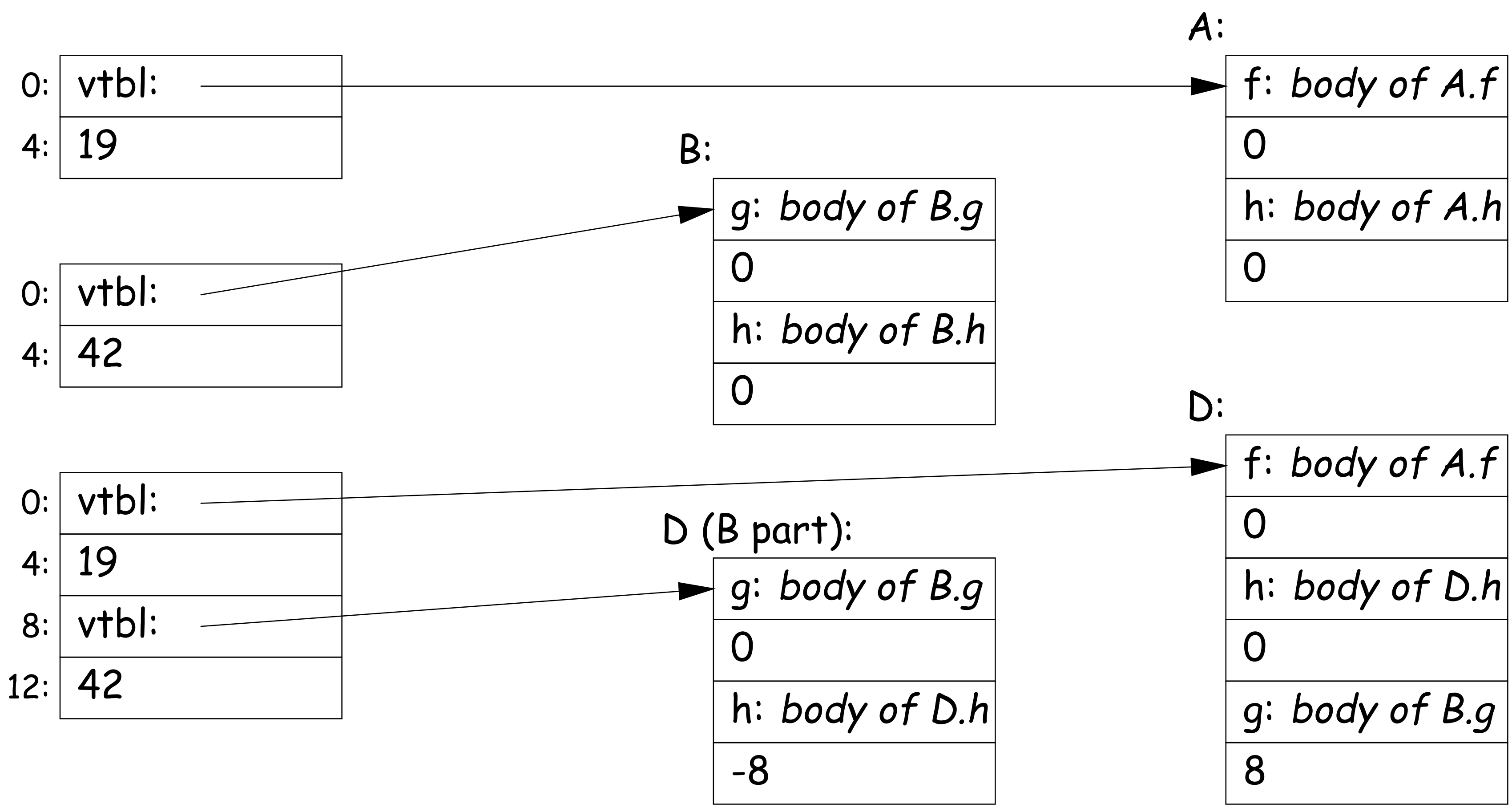
```
class B {
  int y = 42;
  void g () { ... y ... h() ... }
  void h () {... }
}
```

```
class D extends A, B {
   // Where do x and y go?
  void h () {... }
}
```

- A.f expects that this points to an A, B.g expects that it points to a B, but D.h expects it to point to a D.
- How can these all be true??

Implementing Full Multiple Inheritance I

- Idea is to extend the contents of the virtual table with an offset for each method.
- Offset tells how to adjust the 'this' pointer before calling.
- For the example from last slide:



Implementing Full Multiple Inheritance II

- First implementation slows things down in all cases to accommodate unusual case.
- Would be better if only the methods inherited from B (for example) needed extra work.
- Alternative design: use stubs to adjust the 'this' pointer.
- Define B.g_1 to add 8 to the 'this' pointer by 8 and then call B.g; and D.h_1 to subtract 8 and then call D.h.: