A little bit on Class-Based OO Languages

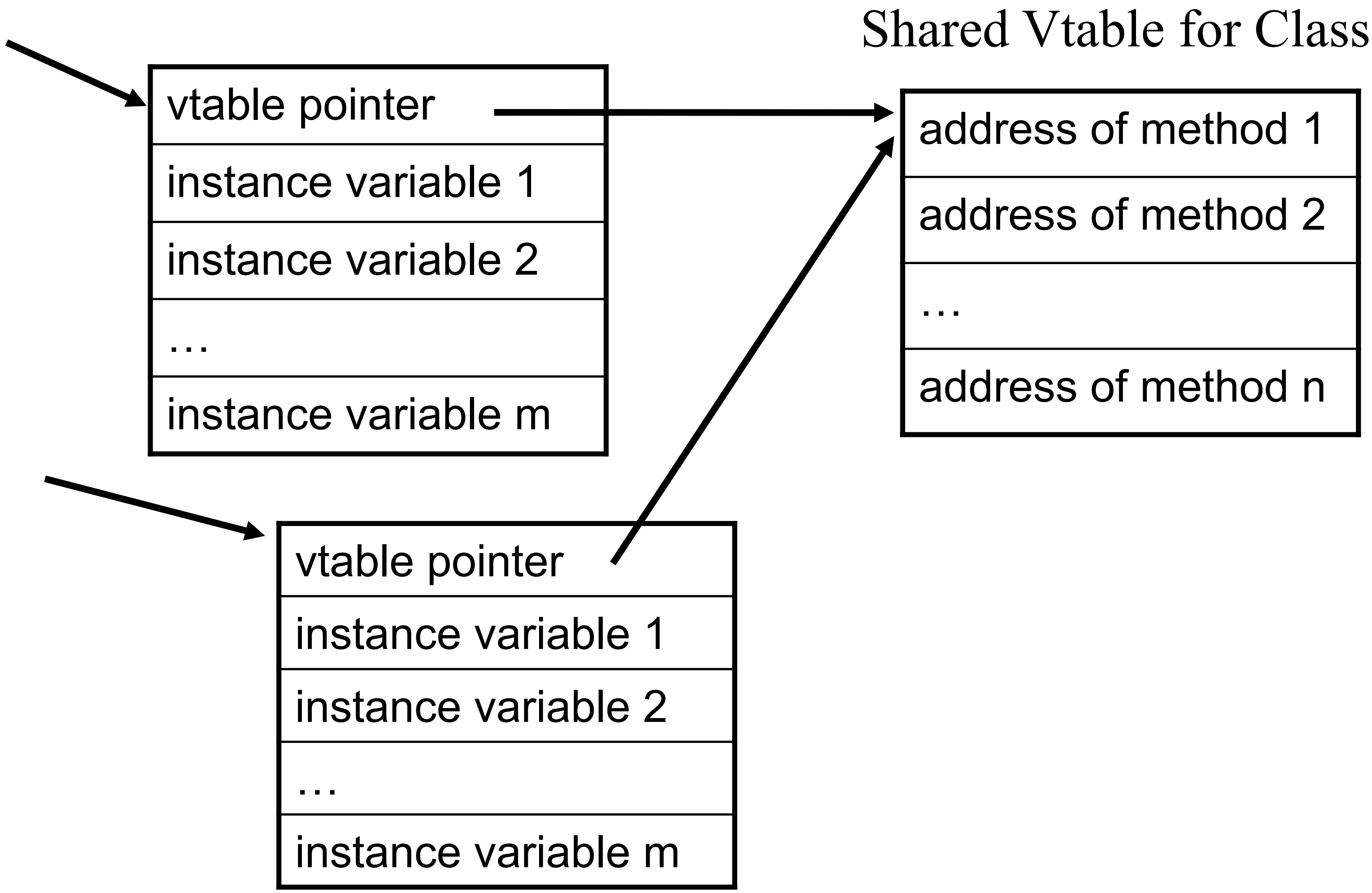
CS4410: Spring 2013

Java Objects

Representing Objects

- 1st field is a pointer to a vtable
  - vtable: virtual method table.
  - each method is a procedure that takes an extra (implicit) argument corresponding to self.
- Remaining fields are instance variables.

In Pictures:


Shared Vtable for Class
vtable pointer
instance variable 1
instance variable 2
…
instance variable m
address of method 1
address of method 2
…
address of method n
vtable pointer
instance variable 1
instance variable 2
…
instance variable m

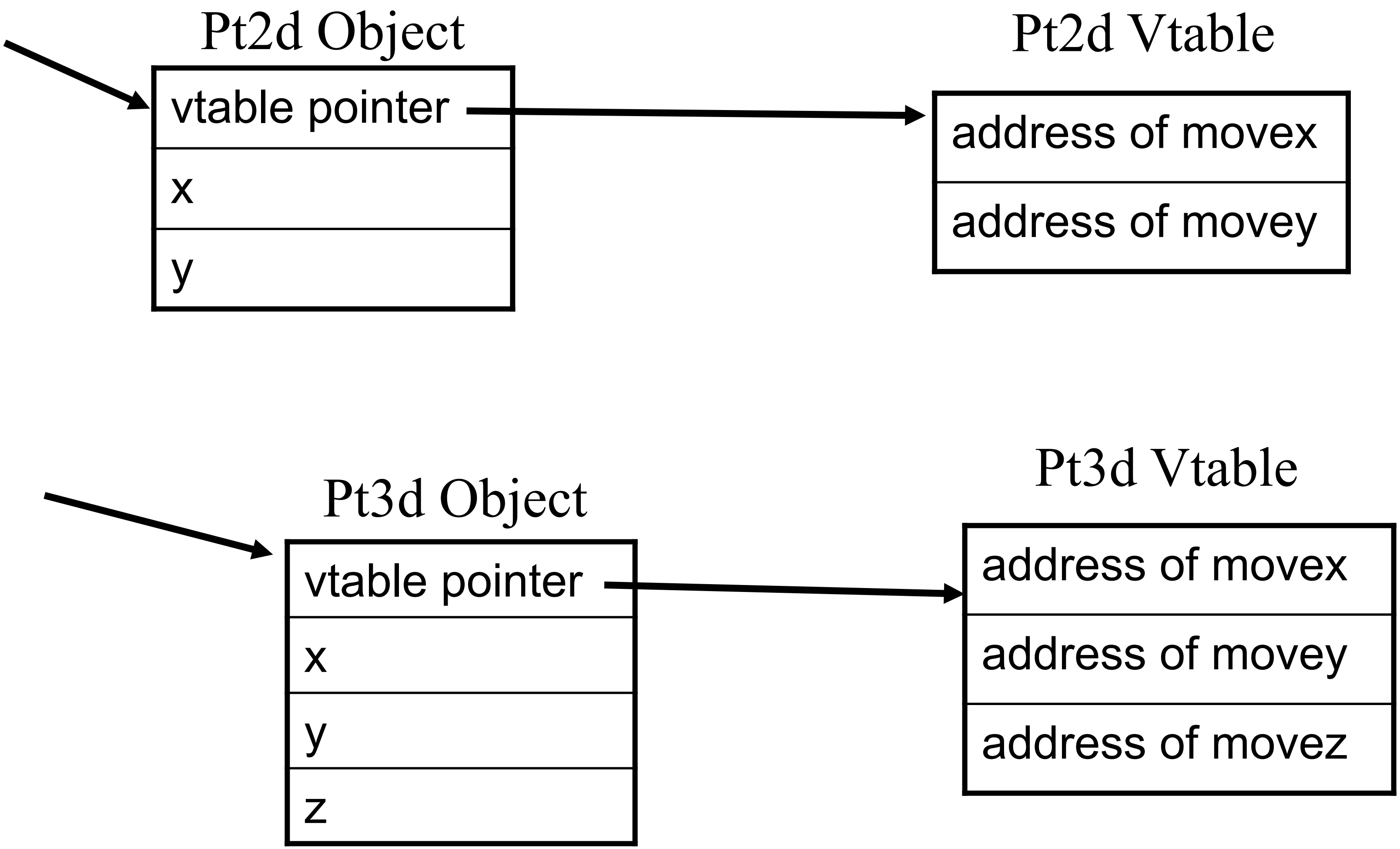
Simple Inheritance

```
class Pt2d extends Object {
  int x;
  int y;
  void movex(int i) { x = x + i; }
  void movey(int i) { y = y + i; }
}

class Pt3d extends Pt2d {
  int z;
  void movez(int i) { z = z + i; }
}
```

Same as:

```
class Pt2d {
  int x;
  int y;
  void movex(int i) { x = x + i; }
  void movey(int i) { y = y + i; }
}

class Pt3d {
  int x;
  int y;
  int z;
  void movex(int i) { x = x + i; }
  void movey(int i) { y = y + i; }
  void movez(int i) { z = z + i; }
}
```

At Run-Time:



Pt2d Object
vtable pointer
x
y
Pt2d Vtable
address of movex
address of movey
Pt3d Object
vtable pointer
x
y
z
Pt3d Vtable
address of movex
address of movey
address of movez

Jish Abstract Syntax

```
type tipe = Int_t|Bool_t |Class_t of class_name
type exp = Var of var | Int of int | Nil |
  Assign of var * exp | New of class_name |
  Invoke of exp * var * (exp list) | ...
type stmt = Exp of exp | Seq of stmt*stmt | ...
type method =
  Method of {mname:var, mret_tipe:tipe option,
             margs:var*tipe list, mbody:stmt}
type class =
  Class of {cname:class_name, csuper:class_name,
            cinstance_vars:var*tipe list,
            cmethods:method list}
```

Compiling to Cish

- For every method $m(x_1,\ldots,x_n)$, generate a Cish function $m(self,vtables,x_1,\ldots,x_n)$.
- At startup, for every class C, create a record of C's methods (the vtable.)
- Collect all of the vtables into a big record.
  - we will pass this data structure to each method as the vtables argument.
  - wouldn't need this if we had a global variable in Cish for storing the vtables.
- Create a Main object and invoke its main() method.

Operations:

- new C
  - create a record big enough to hold a C object
  - initialize the object's vtable pointer using vtables.
  - initialize instance variables with default values
    - 0 is default for int, false for bool, nil for classes.
  - return pointer to object as result
- $e.m(e_1,\ldots,e_n)$
  - evaluate e to an object.
  - extract a pointer to the m method from e's vtable
  - invoke m, passing to it e,vtables,$e_1,\ldots,e_n$
    - e is passed as self.
    - vtables is threaded through to every method.
  - in a real system, must check that e isn't nil!

Operations Continued:

- x, x := e
  - read or write a variable.
  - the variable could be a local or an instance variable.
  - if it's an instance variable, we must use the "self" pointer to access the value.
  - Real Java provides e.x. Do we need this?
- (C)e -- type casts
  - if e has type D and D ≤ C, succeeds.
  - if e has type D and C ≤ D, performs a run-time check to make sure the object is actually (at least) a C.
  - if e has type D, and C is unrelated to D, then generates a compile-time error.

Subtleties in Type-Checking:

- Every object has a *run-time* type.
  - essentially, its vtable
- The type-checker tracks a *static* type.
  - some super-type of the object.
  - NB: Java confuses super-types and super-classes.
- In reality, if e is of type C, then e could be nil or a C object.
  - Java "C" = ML "C option"

Subtyping vs. Inheritance

- Inheritance is a way to assemble classes
- Simple inheritance:
  - D extends C implies D ≤ C
  - a read of instance variable x defined in C?
    - okay because D has it too.
  - an invocation of method m defined in C?
    - okay because D has it too.
  - m : (C self, $T_1, \ldots, T_n$) → T
    - What can m do to self?
    - Read C instance variables, invoke C methods.

Overriding:

```
class List {
  int hd;  List tl;
  void append(List y) {
    if (tl == Nil) tl := y;
    else tl.append(y);
  }
}
class DList extends List {
  DList prev;
  void append(DList y) {
    if (tl == Nil) {
      tl := y;
      if (y != Nil) y.prev := self;
    } else {
      tl.append(y);
  }
}
```

Java won't let you say this…

Best you can do:

```
class List {
  int hd;  List tl;
  void append(List y) {
    if (tl == Nil) tl := y;
    else tl.append(y);
  }
}
class DList extends List {
  DList prev;
  void append(List y) {
    if (tl == Nil) {
      tl := y;
      if (y != Nil) ((DList)y).prev := self;
    } else {
      tl.append(y);
  }
}
```

Run-time type-check

What We Wish we Had…

- Don't just "copy" when inheriting:
  - Also replace super-class name with sub-class name.
  - That is, we need a "self" type as much as a self value.
  - But this will not, in general, give you that the sub-class is a sub-type of the super-class.
  - why?

Run-time Type Checks:

- Given an object x, how do we (quickly) determine if it has a run-time type D that is a sub-class of C?
- option 1: Have a link to the parent's vtable in the child's vtable.
  - crawl up the chain until you reach the parent (or Object).
  - disadvantage?
- other options?

Displays:

address of method 1
address of method 2
…
address of method n
num ancestors
parent @ level 0
parent @ level 1
…
parent @ level m

Just have a pointer to all ancestors.

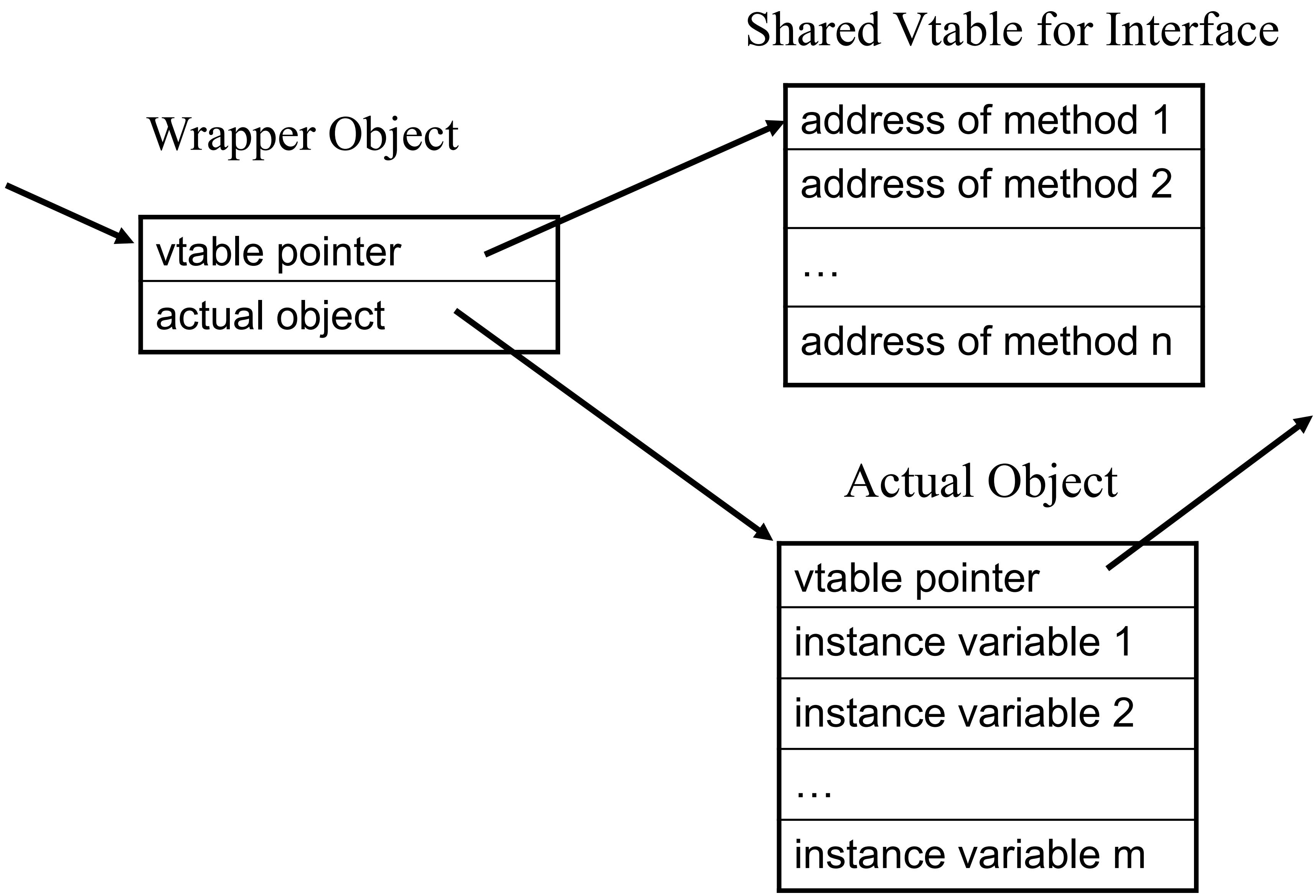
To check if C is a super-class:

- statically calculate depth of C
- check that num ancestors is at least that depth.
- check that this ancestor is C.

Interfaces

- Consider an interface
- **`I = { void foo(); void bar(); }`**
- Any object of a class C that implements methods named **`foo`** and **`bar`** can be treated as if it has interface type **`I`**.
- Can we use C's vtable?
  - no.
  - In general, C may have defined methods before, between, or after foo and bar or may have defined them in a different order.
- So to support interfaces, we need a level of indirection…

Interfaces:


Shared Vtable for Interface
Wrapper Object
address of method 1
address of method 2
…
address of method n
vtable pointer
actual object
Actual Object
vtable pointer
instance variable 1
instance variable 2
…
instance variable m