CSE P 501 – Compilers

Code Shape II – Objects & Classes

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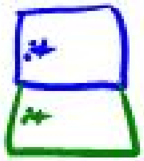
Agenda

- Object representation and layout
- Field access
- What is `this`?
- Object creation - `new`
- Method calls
  - Dynamic dispatch
  - Method tables
  - Super
- Runtime type information

4±1 a) 2 3 3 42 42
12 b) 2 17 3 42 3
6 c) 1 17 3 42 3
8 d) 3 17 42 42 —

What does this program print?



```
class One {
    int tag;
    int it;
    void setTag()        { tag = 1; }
    int getTag()         { return tag; }
    void setIt(int it)   { this.it = it; }
    int getIt()          { return it; }
}
class Two extends One {
    int it;
    void setTag() {
        tag = 2;  it = 3;
    }
    int getThat()        { return it; }
    void resetIt()       { super.setIt(42); }
}
```

```
public static void main(String[] args) {
        Two two = new Two();
        One one = two;

        one.setTag();
        System.out.println(one.getTag());

        one.setIt(17);
        two.setTag();
        System.out.println(two.getIt());
        System.out.println(two.getThat());
        two.resetIt();
        System.out.println(two.getIt());
        System.out.println(two.getThat());

    }
```

Your Answer Here

state
+
behavior

Object Representation

- The naïve explanation is that an object contains
  - Fields declared in its class and in all superclasses
    - Redeclaration of a field hides superclass instance – but the superclass field is still there somehow…
  - Methods declared in its class and in all superclasses
    - Redeclaration of a method overrides (replaces) – but overridden methods can still be accessed by super….
- When a method is called, the method "inside" that particular object is called
- But we don't want to really implement it this way – we only want one copy of each method's code

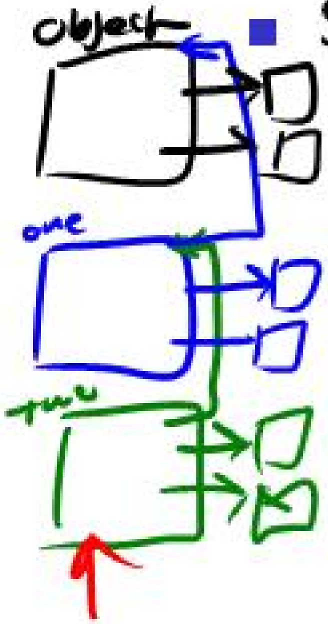
Actual representation

- Each object contains
  - An entry for each field (variable)
  - A pointer to a runtime data structure describing the class
    - Key component: method dispatch table
- Basically a C struct
- Fields hidden by declarations in extended classes are *still* allocated in the object and are accessible from superclass methods

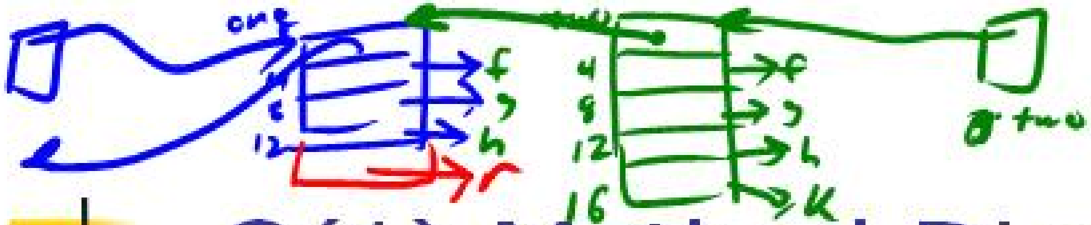
Method Dispatch Tables

- One of these per class, not per object
- Often known as "vtables"
- One pointer per method – points to beginning of method code
- Dispatch table offsets fixed at compile time

Method Tables and Inheritance



- Simple implementation
  - Method table for extended class has pointers to methods declared in it
  - Method table also contains a pointer to parent class method table
  - Method dispatch
    - Look in current table and use it if method declared locally
    - Look in parent class table if not local
    - Repeat
  - Actually used in typical implementations of some dynamic languages (e.g. SmallTalk, Ruby, etc.)



O(1) Method Dispatch

- Idea: First part of method table for extended class has pointers for same methods in same order as parent class
  - BUT pointers actually refer to overriding methods if these exist
  - ∴ Method dispatch is indirect using fixed offsets known at compile time – O(1)
    - In C: `*(object->vtbl[offset])(parameters)`
- Pointers to additional new methods in extended class are included in the table following inherited / overridden ones

Method Dispatch Footnotes

- Still want pointer to parent class method table for other purposes
  - Casts and instanceof
- Multiple inheritance requires more complex mechanisms *
  - Also true for multiple interfaces

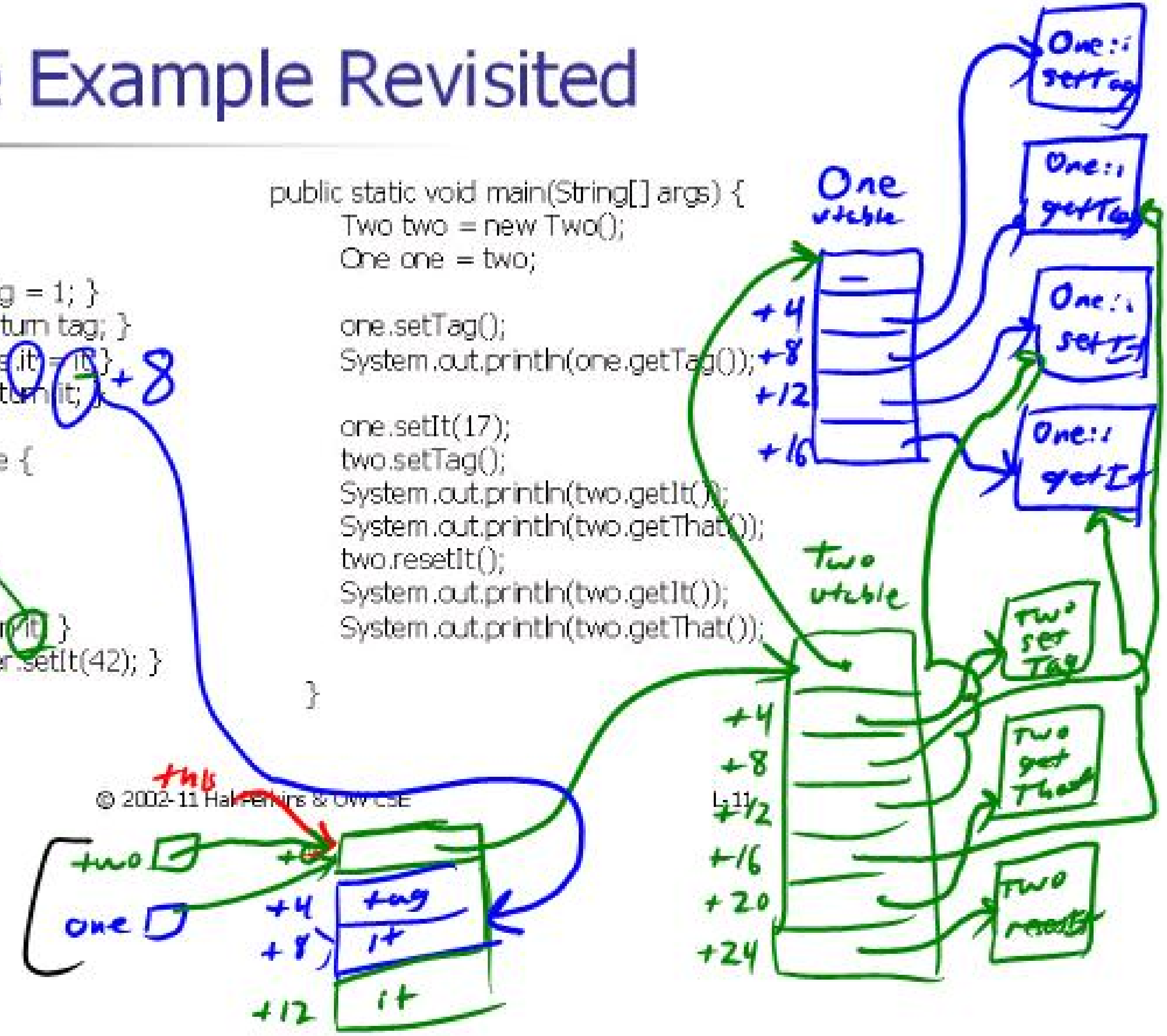
Perverse Example Revisited

```
class One {
   int tag;
   int it;
   void setTag()    { tag = 1; }
   int getTag()     { return tag; }
   void setIt(int it) {this.it = it;}
   int getIt()      { return it; }
}
class Two extends One {
   int it;
   void setTag() {
     tag = 2;  it = 3;
   }
   int getThat() { return it; }
   void resetIt() { super.setIt(42); }
}
```

```
public static void main(String[] args) {
      Two two = new Two();
      One one = two;

      one.setTag();
      System.out.println(one.getTag());

      one.setIt(17);
      two.setTag();
      System.out.println(two.getIt());
      System.out.println(two.getThat());
      two.resetIt();
      System.out.println(two.getIt());
      System.out.println(two.getThat());
}
```



Implementation

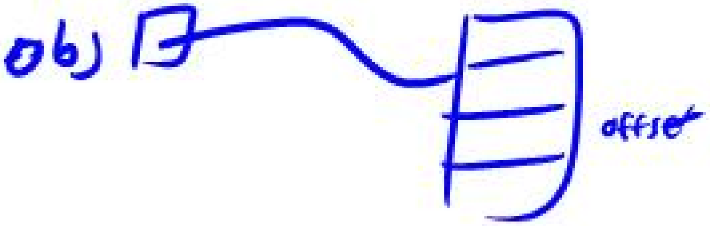
Now What?

- Need to explore
    - Object layout in memory
    - Compiling field references
        - Implicit and explicit use of "this"
    - Representation of vtables
    - Object creation: new
    - Code for dynamic dispatch
        - Including implementing "super.f"
    - Runtime type information – instanceof and casts

Object Layout

- Typically, allocate fields sequentially
- Follow processor/OS struct/object alignment conventions when appropriate / available
- Use first word of object for pointer to method table/class information
- Objects are allocated on the heap
  - No actual bits in the generated code

Local Variable Field Access



- Source

  int n = obj.fld;

- x86
  - Assuming that obj is a local variable in the current method

    ✓ mov eax,[ebp+$\text{offset}_{\text{obj}}$] ; load obj ptr

    ✓ mov eax,[eax+$\text{offset}_{\text{fld}}$] ; load fld

    mov [ebp+offset_{n}],eax ; store n

Local Fields

- A method can refer to fields in the receiving object either explicitly as "this.f" or implicitly as "f"
    - Both compile to the same code – an implicit "this." is assumed if not present explicitly
- Mechanism: a reference to the current object is an implicit parameter to every method
    - Can be in a register or on the stack

Source Level View

- When you write

```
void setIt(int it) {

  this.it = it;
}
...
obj.setIt(42);
```

- You really get

```
void setIt(ObjType this,
                    int it) {
  this.it = it;
}
...
setIt(obj,42);
```

x86 Conventions (C++)

- ecx is traditionally used as "this"
- Add to method call

```
mov ecx,receivingObject       ; ptr to object
```

  - Do this after arguments are evaluated and pushed, right before dynamic dispatch code that actually calls the method
  - Need to save ecx in a temporary or on the stack in methods that call other non-static methods
    - Following examples aren't always careful about this

x86 Local Field Access

- Source

```
int n = fld;  or  int n = this.fld;
```

- x86

```
mov   eax,[ecx+offset_fld]        ; load fld
mov   [ebp+offset_n],eax          ; store n
```

x86 Method Tables (vtbls)

- We'll generate these in the assembly language source program
- Need to pick a naming convention for method labels; suggestion:
  - For methods, classname$methodname
    - Would need something more sophisticated for overloading
  - For the vtables themselves, classname$$
- First method table entry points to superclass table
- Also useful: second entry points to default (0-argument) constructor (if you have constructors)
  - Makes implementation of super() particularly simple

Method Tables For Perverse Example

.long

```
class One {
   void setTag()    { … }
   int getTag()     { … }
   void setIt(int it) {…}
   int getIt()      { … }
}

class Two extends One {
   int getThat() { … }
   void setTag() { … }
   void resetIt() { … }
}
```

```
              .data
One$$    dd  0            ; no superclass
         dd  One$One      ; ctr
         dd  One$setTag
         dd  One$getTag
         dd  One$setIt
         dd  One$getIt
Two$$    dd  One$$        ; parent
         dd  Two$Two      ; ctr
         dd  Two$setTag
         dd  One$getTag
         dd  One$setIt
         dd  One$getIt
         dd  Two$getThat
         dd  Two$resetIt
```

Method Table Footnotes

- Key point: First four non-constructor method entries in Two's method table are pointers to methods declared in One in *exactly the same order*
  - ∴ Compiler knows correct offset for a particular method *regardless of whether that method is overridden*

Object Creation – new

- Steps needed
  - ① Call storage manager (malloc or similar) to get the raw bits
  - ② Store pointer to method table in the first 4 bytes of the object
  - ③ Call a constructor (with pointer to the new object, `this`, in ecx)
  - ④ Result of new is pointer to the constructed object

Object Creation

- Source

```
One one = new One(...);
```

- x86

```
   push   nBytesNeeded              ; obj size + 4
①  call   mallocEquiv               ; addr of bits returned in eax
   add    esp,4                     ; pop nBytesNeeded
②  lea    edx,One$$                 ; get method table address
   mov    [eax],edx                 ; store vtab ptr at beginning of object
   mov    ecx,eax   this            ; set up "this" for constructor
③  push   ecx                       ; save ecx (constructor might clobber it)
   <push constructor arguments>     ; arguments (if needed)
   call   One$One                   ; call constructor (no vtab lookup needed)
   <pop constructor arguments>      ; (if needed)
   pop    eax                       ; recover ptr to object
   mov    [ebp+offset_one],eax      ; store object reference in variable one
```

Constructor

- Only special issue here is generating call to superclass constructor
  - Same issues as super.method(…) calls – we'll defer for now

Method Calls

- Steps needed
  - ① Push arguments as usual
  - ② Put pointer to object in ecx (this)
  - ③ Get pointer to method table from first 4 bytes of object
  - Jump indirectly through method table
  - ④ Restore ecx to point to current object (if needed)
    - Useful hack: push it in the function prologue so it is always in the stack frame at a known location

Method Call

- Source

```
obj.meth(...);
```

- x86

```
① <push arguments from right to left>   ; (as needed)
② mov   ecx,[ebp+offset_obj]          ; get pointer to object
③ mov   eax,[ecx]                     ; get pointer to method table
  call  dword ptr [eax+offset_meth]   ; call indirect via method tbl
  <pop arguments>                     ; (if needed)
④ mov   ecx,[ebp+offset_ecxtemp]      ; (restore if needed)
```

Handling super

- Almost the same as a regular method call with one extra level of indirection
- Source

```
super.meth(…);
```

- x86

```
①  <push arguments from right to left>   ; (if needed)
②  mov    ecx,[ebp+offset_obj]           ; get pointer to object
③  mov    eax,[ecx]                      ; get method tbl pointer
   mov    eax,[eax]                      ; get parent's method tbl pointer
   call   dword ptr [eax+offset_meth]    ; indirect call
   <pop arguments>                       ; (if needed)
```

Runtime Type Checking

- Use the method table for the class as a "runtime representation" of the class
- The test for "o instanceof C" is
  - Is o's method table pointer == &C$$?
    - If so, result is "true"
  - Recursively, get the superclass's method table pointer from the method table and check that
  - Stop when you reach Object (or a null pointer, depending on how you represent things)
    - If no match when you reach the top of the chain, result is "false"
- Same test is part of check for legal downcast

Coming Attractions

- x86-64 – what changes, what doesn't
- Simple code generation for project
- Industrial-strength register allocation, instruction selection & scheduling
- Optimization