CSE P 501 – Compilers

Code Shape II – Objects & Classes

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Autumn 2009

Agenda

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

1 7 3 42 3   2 17 3 2 3 42 42 3

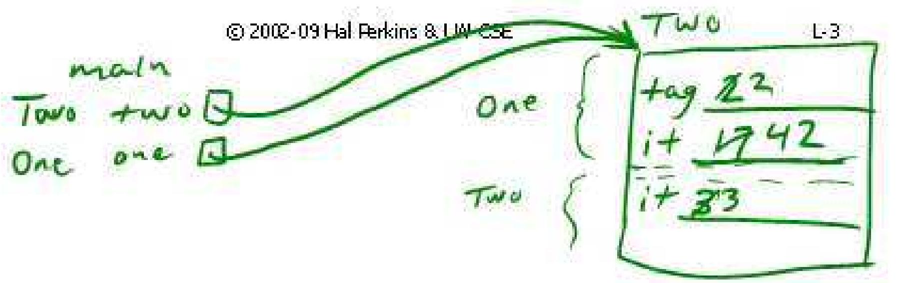
What does this program print?

```
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); }
}
```

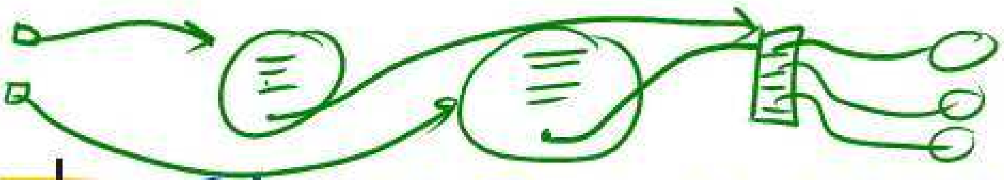
```
public static void main(String[] args) {
  Two two = new Two();
  One one = two;

  one.setTag();
  System.out.println(one.getTag());        2

  one.setIt(17);
  two.setTag();
  System.out.println(two.getIt());         17
  System.out.println(two.getThat());       3
  two.resetIt();
  System.out.println(two.getIt());         42
  System.out.println(two.getThat());       3
}
```



Your Answer Here



Object Representation

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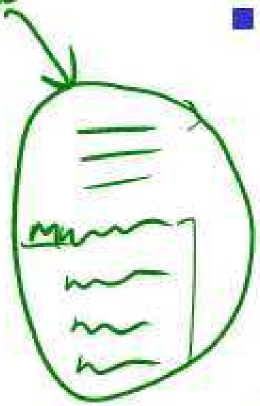
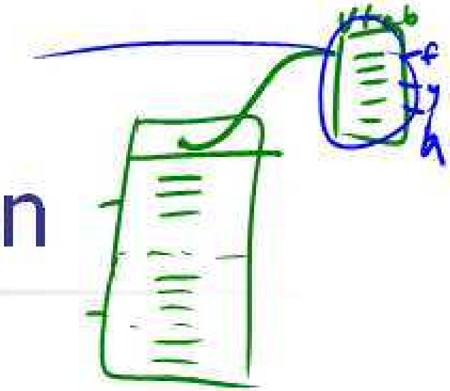


- The naïve explanation is that an object contains
  - Fields declared in its class and in all superclasses
    - Redeclaration of a field hides superclass instance
  - Methods declared in its class and in all superclasses
    - Redeclaration of a method overrides (replaces)
      - But overridden methods can still be accessed by super….

ob.m(- - -)

- 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

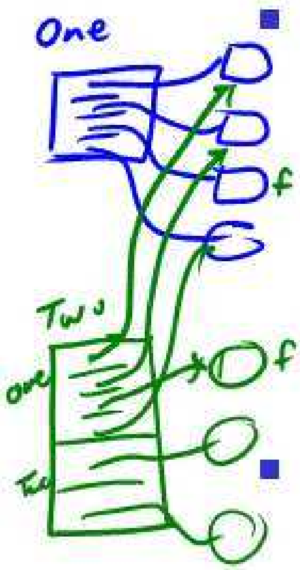
Method Dispatch Tables

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

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 some dynamic systems (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 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

2 7 6 4 8

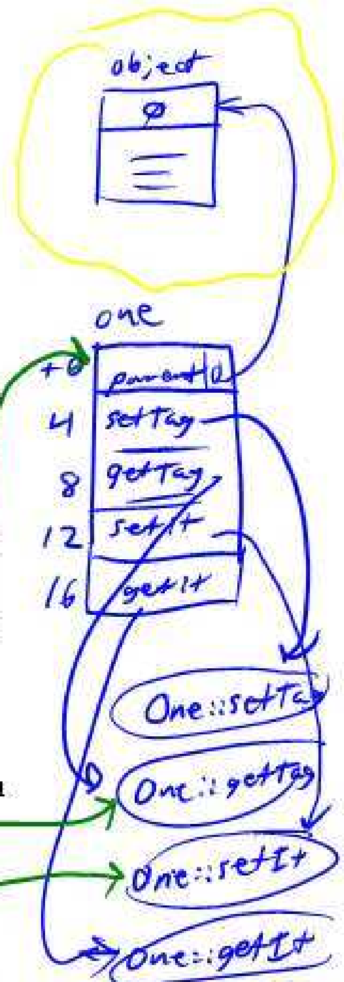
Perverse Example Revisited

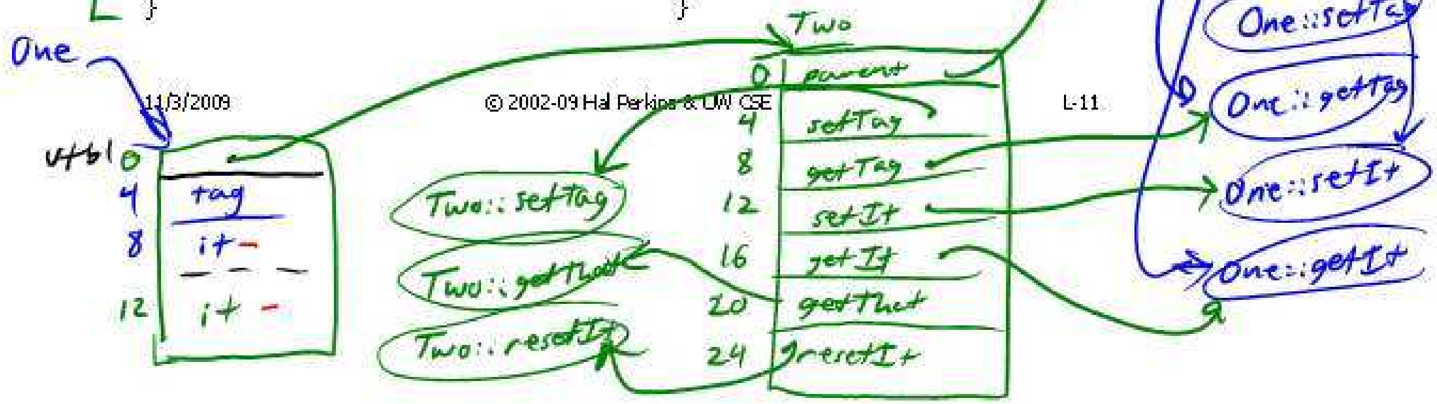
```
class One {
  int tag;
  int it;
  void setTag()    { tag = 1; }
  int getTag()     { return tag; }
  void setIt(int it) {this.it = it;}
  int getIt()      { return it; }
}
class Two extends One {
  int it;
  void setTag() {
    tag = 2; it = 3;
  }
  int getThat() { return it; }
  void resetIt()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



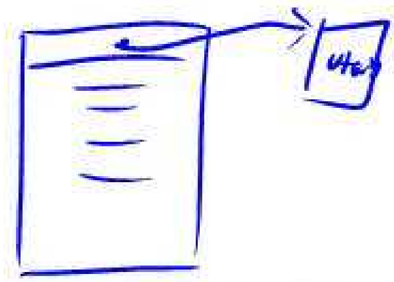


Implementation

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 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+offset_obj]     ; load obj ptr
mov   eax,[eax+offset_fld]     ; load fld
mov   [ebp+offset_n],eax       ; store n
```


```
void m() {
      f
    this.f
}
```

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

this. _v = 17

Source Level View

- When you write

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

- You really get

```
void setIt(ObjType this,
  this.tag = 42          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
      - One possibility: add to prologue
      - Following examples aren't 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

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

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

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

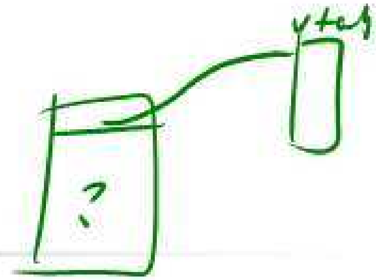
Method Table Footnotes

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

Object Creation



- Source

  One one = new One(...);

- X86

get bytes

```
push   nBytesNeeded                  ; obj size + 4
call   mallocEquiv                   ; addr of bits returned in eax
add    esp,4                         ; pop nBytesNeeded
lea    edx,One$$                     ; get method table address
mov    [eax],edx                     ; store vtab ptr at beginning of object
mov    ecx,eax                       ; set up "this" for constructor
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
```

set vtab ptr

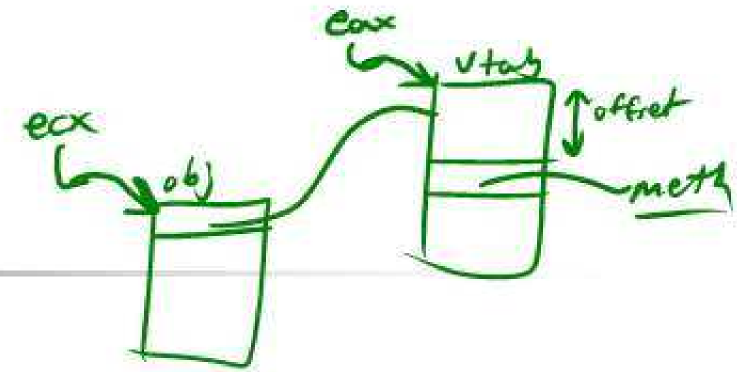
Constructor

- 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
  - ✓ Push arguments as usual
  - ✓ Put pointer to object in ecx (new this)
  - ✓ Get pointer to method table from first 4 bytes of object
  - ✓ Jump indirectly through method table
  - ✓ 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

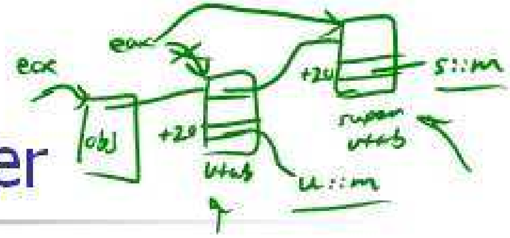


- Source

  obj.meth(...);

- X86

  <push arguments from right to left> ; (as needed)
  mov ecx,[ebp+offset$_{obj}$] ; get pointer to object
  mov eax,[ecx] ; get pointer to method table
  call dword ptr [eax+offset$_{meth}$] ; call indirect via method tbl
  <pop arguments> ; (if needed)
  mov ecx,[ebp+offset$_{ecxtemp}$] ; (if needed)



Handling super

- Almost the same as a regular method call with one extra level of indirection
- Source
  - super.meth(...);
- X86

```
<push arguments from right to left>  ; (if needed)
mov   ecx,[ebp+offset_obj]    ; get pointer to object
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)
```

class A {
  f()
}

class B extends A {
  this.g()
  super.f()
}

class C extends B {
  f()
}

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 as part of check for legal downcast

Coming Attractions

- Code generation: register allocation, instruction selection & scheduling
  - Industrial-strength versions plus a simpler "get it to work" scheme for our project
- Code optimization