# CSE 401 – 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

(As before, more generality than we actually need for the project)

# 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());

   }
```


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# Your Answer Here


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# 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 somewhere…
  - Methods declared in its class and 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 really don't want to copy all those methods, do we?)


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# Actual representation

- Each object contains
  - An entry for each field (instance 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


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# 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


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# 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 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.)


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# 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


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# 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


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# 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());

}
```


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# Implementation


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# 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
  - 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


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# 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
```


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# 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


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# 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
    - One possibility: push or save in method prologue
    - Following examples aren’t careful about this


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# 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
```


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# x86 Method Tables (vtbls)

- Generate these as initialized data in the assembly language source program
- Need to pick a naming convention for method labels; suggest:
  - 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)


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# Method Tables For Perverse Example (Intel/Microsoft asm)

```
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
```


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# 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 pointer *regardless of whether that method is overridden* and regardless of the actual (dynamic) type of the object


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# 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

```
push   nBytesNeeded               ; obj size + 4
call   mallocEquiv                ; addr of bits returned in eax
add    esp,4                      ; pop nBytesNeeded argument
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
```

# Constructor

- Only special issue here is generating call to superclass constructor
  - Same issues as super.method(…) calls – we know the superclass name, so just generate a direct call to the appropriate method.


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# Method Calls

- Steps needed
  - Push arguments as usual
  - Load pointer to object in ecx (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 after method returns)
    - Useful hack: push ecx in the function prologue so it is always in the stack frame at a known location & reload when needed if it might be clobbered


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# 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)
```


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# 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 pointer to superclass method table 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 by the top of the chain, result is "false"
- Same test as 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, and scheduling
- Survey of code optimization