CSE P 501 – Compilers

Code Shape II – Objects & Classes

Hal Perkins

Winter 2016

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); }
}
```

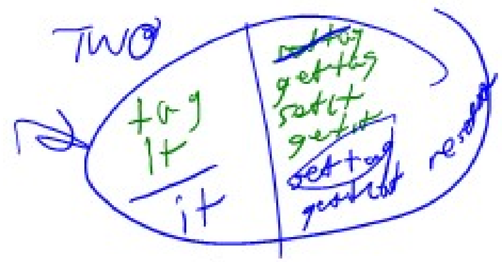
```
public static void main(String[] args) {
    Two two = new Two();
    One one = two;

    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());
}
```

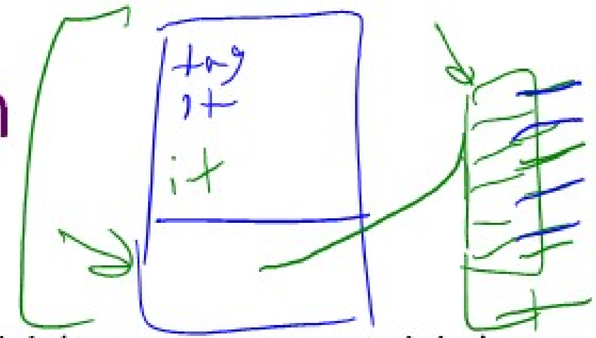
Your Answer Here

Object Representation



- The naïve explanation is that an object contains
  - Fields declared in its class and in all superclasses
    - Redeclaration of a field hides (shadows) superclass instance – but the superclass field is still there
  - 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
  - Regardless of the static (compile-time) type of the variable
    - (**But** we **really don’t** want **to copy all those methods, do** we?)

Actual representation

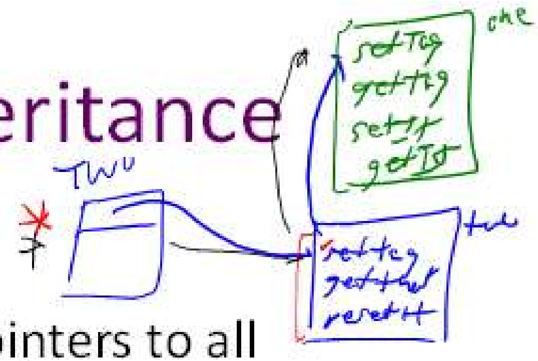


- Each object contains:
  - An entry ("slot") for each field (instance variable)
    - Including shadowed and private fields in superclasses
  - A pointer to a runtime data structure for its class
    - Key component: method dispatch table (next slide)
- Basically a C struct
- Fields hidden by declarations in subclasses are *still* allocated in the object and are accessible from superclass methods

Method Dispatch Tables

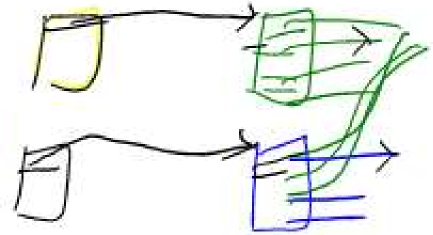
- One of these per class, not per object
- Often called “vtable”, “vtbl”, or “vtab”
  – (virtual function table – term from C++)
- One pointer per method – points to beginning of method code
- Dispatch table offsets fixed at compile time in O(1) implementations

Method Tables and Inheritance



- A really simple implementation
  - Method table for each class has pointers to all methods declared in it (a dictionary)
  - 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
    - "Message not understood" if you can't find it after search
  - Actually used/needed in typical implementations of some dynamic languages (e.g. Ruby, Smalltalk, etc.)

O(1) Method Dispatch



- Idea: First part of method table for extended class has pointers for the same methods in the same order as the parent class
  - BUT pointers actually refer to overriding methods if these exist

  ∴ Method dispatch can be done with indirect jump using fixed offsets known at compile time – O(1)
    - In C: *(object->vtbl[offset])(parameters)
- Pointers to methods added in subclass are after ptrs to inherited/overridden ones in vtable

Method Dispatch Footnotes

- Don't need vtable pointer to parent class vtable for method calls, but still useful 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); }
}
```

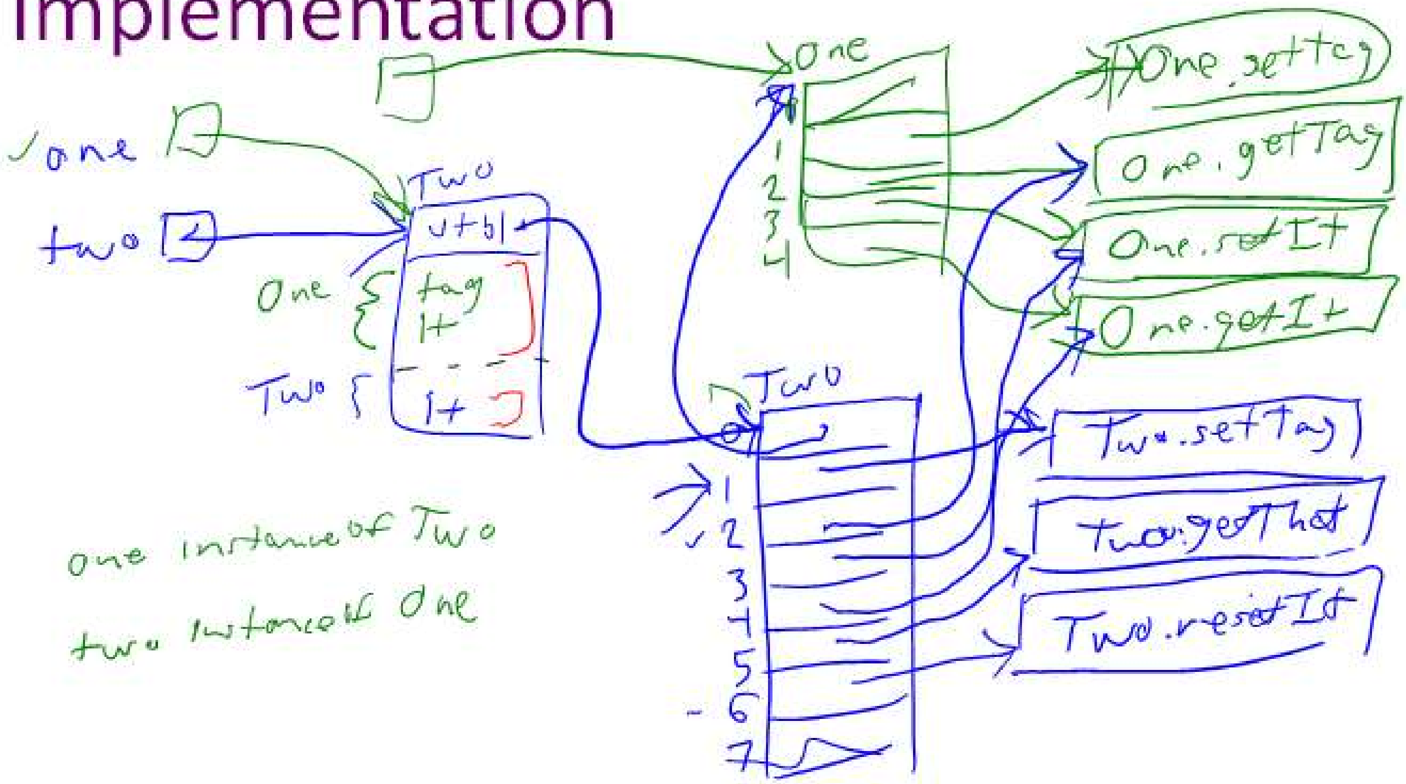
```
public static void main(String[] args) {
  Two two = new Two();
  One one = two;

  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());

}
```

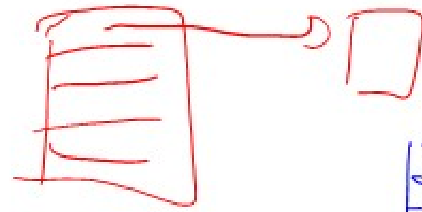
Implementation

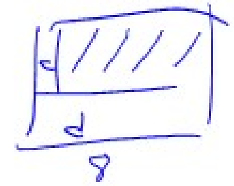


Now What?

- 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
  - Runtime type information – instanceof and casts

Object Layout





- Typically, allocate fields sequentially
- Follow processor/OS alignment conventions for struct/object when appropriate/available
  - Include padding bytes for alignment as needed
- 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

Object Field Access

- Source

  int n = obj.slot;

- x86-64
  - Assuming that obj is a local variable in the current method's stack frame

```
movq offset_obj(%rbp),%rax     # load obj ptr
movq offset_slot(%rax),%rax    # load slot
movq %rax,offset_n(%rbp)       # store n
```

  - Same idea used to reference fields of "this"
    - Use implicit "this" parameter passed to method instead of a local variable to get object address

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

Source Level View

What you write:

```
int getIt() {
  return it;
}
void setIt(int it) {
  this.it = it;
}
...
obj.setIt(42);
k = obj.getIt();
```

What you really get:

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

x86-64 “this” Convention (C++)

- “this” is an implicit first parameter to every non-static method
- Address of object placed in %rdi for every non-static method call
- Remaining parameters (if any) in %rsi, etc.

- We’ll use this convention in our project

MiniJava Method Tables (vtbls)

- Generate these as initialized data in the assembly language source program
- Need to pick a naming convention for assembly language 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 (we might not use this in our project, but is helpful if you add instanceof or type cast checks)

Method Tables For Perverse Example (gcc/as syntax)

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

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

```
        .data

One$$:  .quad 0           # no superclass
        .quad One$setTag
        .quad One$getTag
        .quad One$setIt
        .quad One$getIt

Two$$:  .quad One$$       # superclass
        .quad Two$setTag
        .quad One$getTag
        .quad One$setIt
        .quad One$getIt
        .quad Two$getThat
        .quad Two$resetIt
```

Method Table Layout

Key point: First method entries in Two's method table are pointers to methods declared in One in *exactly the same order*

– Actual pointers reference code appropriate for objects of each class (inherited or overridden)

∴ 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

Object Creation – new

Steps needed

- Call storage manager (malloc or similar) to get the raw bits
  - (and store 0's if required by the language, e.g., Java)
- Store pointer to method table in the first 8 bytes of the object
- Call a constructor with "this" pointer to the new object in %rdi and other parameters as needed
  - (Not in MiniJava since we don't have constructors)
- Result of new is a pointer to the new object

Object Creation

- Source

    One one = new One(...);
- x86-64

```
movq    $nBytesNeeded,%rdi          # obj size + 8 (include space for vtbl ptr)
call    mallocEquiv                 # addr of allocated bits returned in %rax
leaq    One$$,%rdx                  # get method table address
movq    %rdx,0(%rax)                # store vtbl ptr at beginning of object
movq    %rax,%rdi                   # set up "this" for constructor
movq    %rax,offset_temp(%rbp)      # save "this" for later
<load constructor arguments>        # arguments (if needed)
call    One$One                     # call ctr if we have one (no vtbl lookup)
movq    offset_temp(%rbp),%rax      # recover ptr to object
movq    %rax,offset_one(%rbp)       # store object reference in variable
```

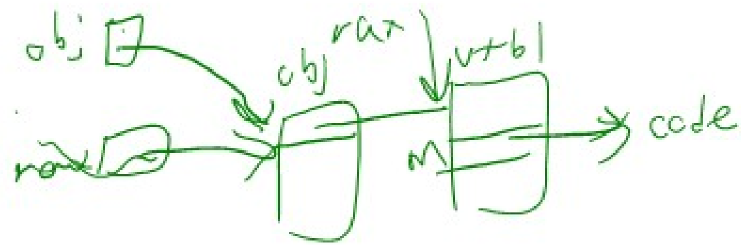
Constructor

- Why don't we need a vtable lookup to find the right constructor to call?
- Because at compile time we know the actual class (it says so right after "new"), so we can generate a call instruction to a known label
  - Same with super.method(...) or superclass constructor calls – at compile time we know all of the superclasses (need this to compile subclass and construct method tables), so we know statically what class "super.method" belongs to

Method Calls

- Steps needed
  - Parameter passing: just like an ordinary C function, except load a pointer to the object in %rdi as the first ("this") argument
  - Get a pointer to the object's method table from the first 8 bytes of the object
  - Jump indirectly through the method table

Method Call



- Source

  obj.m(…);

- x86-64

```
<load arguments in registers as usual>  # as needed
movq    offsetobj(%rbp),%rdi     # first argument is obj ptr ("this")
movq    0(%rdi),%rax             # load vtable address into %rax
call    *offsetm(%rax)           # call function whose address is at
                                 #     known offset in the vtable *
```

- * Or can use:

```
addq $offsetm,%rax
call *(%rax)
```

  or :

```
movq $offsetm(%rax),%rax
call *%rax
```

Runtime Type Checking

- We can use the method table for the class as a "runtime representation" of the class
  - Each class has one vtable at a unique address
- 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 whether there is a ultimate superclass of everything)
    - If no match by the top of the chain, result is "false"
- Same test as part of check for legal downcast (e.g., how to test for ClassCastException in (type)obj cast)

Coming (& past) Attractions

- Other IRs besides ASTs
- Code analysis and optimization
- Industrial-strength back end (register allocation, instruction selection & scheduling)
- Other topics as time allows
  - GC? Dynamic languages? JVM? What else?

- And simple code generation for the project