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
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.getTag());
    System.out.println(two.getIt());
    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
    - Redefinition of a field hides superclass instance – but the superclass field is still there somehow...
  - Methods declared in its class and in all superclasses
    - Redefinition 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

```java
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.getTag());
    System.out.println(two.getIt());
    two.resetIt();
    System.out.println(two.getTag());
    System.out.println(two.getIt());
}
```

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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**
  \[ \text{int } n = \text{obj.fld;} \]

- **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`
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

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

- You really get

```java
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+offs_fld] ; load fld
  mov [ebp+offs_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 {
    int getThat() { ... }
    void setTag() { ... }
    void 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

1. push nBytesNeeded
   call mallocEquiv
   add esp, 4
   lea edx, One$$
   mov [eax], edx
   mov ecx, eax
   push ecx

2. <push constructor arguments>
   call One$One
   <pop constructor arguments>
   pop eax
   mov [ebp+offset_one], eax

3. ; obj size + 4
   ; addr of bits returned in eax
   ; pop nBytesNeeded
   ; get method table address
   ; store vtab ptr at beginning of object
   ; set up "this" for constructor
   ; save ecx (constructor might clobber it)
   ; arguments (if needed)
   ; call constructor (no vtab lookup needed)
   ; (if needed)
   ; recover ptr to object
   ; 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**
  
  \texttt{obj.meth(...)};

- **x86**
  
  1. <push arguments from right to left> \quad ; \text{as needed}
  2. \texttt{mov ecx,[ebp+offset_{obj}]} \quad ; \text{get pointer to object}
  3. \texttt{mov eax,[ecx]} \quad ; \text{get pointer to method table}
  4. \texttt{call dword ptr [eax+offset_{method}]} \quad ; \text{call indirect via method tbl}
  5. <pop arguments> \quad ; \text{if needed}
  6. \texttt{mov ecx,[ebp+offset_{ecx\_temp}]} \quad ; \text{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
  4. mov eax,[eax] ; get parent’s method tbl pointer
  5. call dword ptr [eax+offset_method] ; indirect call
  6. <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