CSE 401 – Compilers

Lecture 18: Code Generation for Object-Oriented Constructs

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Reminders/ Announcements

- Midterms are graded!
  - I'll stop a few minutes early so you can pick them up at the end of class
- Project part 3 due Friday, March 1 (1 week)
- Part 4 will be due on Friday, March 15 (last day of class). I will put the assignment out next week – likely before part 3 is due, in case anyone wants to get a head start.

Agenda

- Finish last topic from Wednesday – 2D arrays
- Then, object-oriented code generation (may spill into Monday):
  - Object representation and layout
  - Field access
  - What is `this`?
  - Object creation - `new`
  - Method calls
    - Dynamic dispatch
    - Method tables
    - Super
  - Runtime type information

2-D Arrays

- C, etc. use row-major order
  - E.g., an array with 3 rows and 2 columns is stored in this sequence: a[0][0], a[0][1], a[1][0], a[1][1], a[2][0], a[2][1]
- Fortran uses column-major order (and indexed from 1)
  - So, a(1,1), a(2,1), a(3,1), a(1,2), a(2,2), a(3,2)
  - Can't naively pass multidimensional array references between C and Fortran
- Java does not have "real" 2-D arrays. A Java 2-D array is a pointer to a list of pointers to the rows

a[i][j] in C/C++/etc.

- To find a[i][j], we need to know
  - Values of i and j
  - How many *columns* the array has
- Location of a[row][column] is (assuming 0-indexed)
  - Base of a + (row*(#of columns) + column)*elementSize
- Can factor to pull out any constant part and evaluate that at compile or link time – avoids recalculating at runtime
  - E.g., a[1][5] becomes a + 15 if a has 10 columns and byte-sized elements.

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Motivating Exercise: 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());
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public static void main(String[] args) {
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```

Object Representation

- How do we represent objects so that we can achieve this behavior?
- The naive 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?)

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 looks like a C struct with an extra pointer
- Fields hidden by declarations in extended classes are *still* allocated in the object and are *still accessible* from *superclass methods*

Method Dispatch Tables

- What are these tables?
  - Collection of pointers to methods
  - One pointer per method – points to beginning of method code
- One of these per class, not per object
  - Each object contains a pointer to the table for its *runtime* class, to ensure correct dynamic dispatch.
- Often known as “vtables” (virtual method tables)
- The table structure is 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 if method declared locally
    - Otherwise, look in parent class table
    - Repeat (grandparent, great-grandparent, etc.)
  - 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
  - Means method dispatch uses a fixed table offsets known at compile time, regardless of the runtime type – therefore, O(1)
    - In C, object->foo(params) becomes:

      *(object->vtbl[foo_OFFSET])(params)
- 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 for other purposes
  - Anytime you need runtime type information, e.g., casts and instanceof
- Multiple inheritance requires more complex mechanisms
  - Also true for multiple interfaces

Example, Revisited

```
class One {
  int tag;
  int it;
  void setTag()     { tag = 1; }
  int getTag()          { return tag; }
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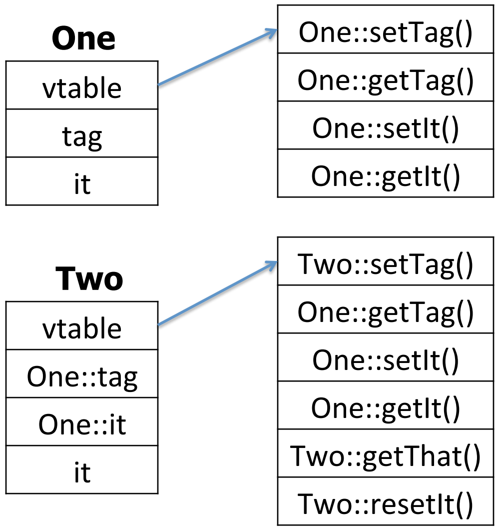
Implementation

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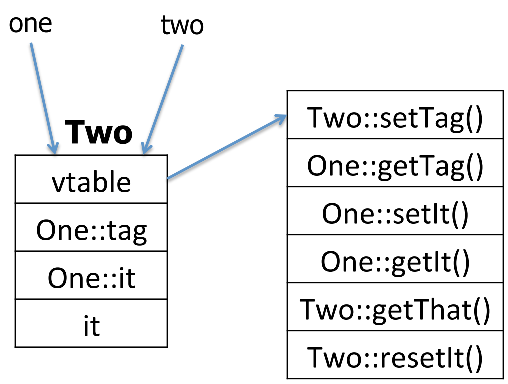


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```


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

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 (from assignment)
```

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:

```
int it;
void setIt(int i) {
  it = i;
}
…
obj.setIt(42);
```

- You really get:

```
int it;
void setIt(ObjType this, int i) {
    this.it = i;
}
…
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

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

- Notice that if we have `this` stored in a register (e.g., ecx), we do one less load from memory than a standard field access.

x86 Method Tables

- Generate these as initialized data in the assembly language source program
- Need to pick a naming convention for method labels; one possibility:
  - For methods, classname$methodname
    - Would need something more sophisticated for overloading
  - For the vtables themselves, classname$$
- By convention, first method table entry points to superclass table
- Also useful: second entry points to default (0-argument) constructor (if you have constructors)

Method Tables For 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
```

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
  - Makes dynamic dispatch easy

Object Creation – new

- Steps needed
  - Call storage manager (malloc or similar) to get the memory
  - 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, with constructors

- 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   eax                   ; in case constructor clobbers eax
<push constructor arguments> ; arguments (if needed)
call   One$One               ; call constructor (no vtable 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 at compile time, so just generate a direct call to the appropriate method.

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

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	[eax+offset$_{meth}$]	; call indirect via method tbl
<pop arguments>		; (if needed)
mov	ecx,[ebp+offset$_{ecxtemp}$]	; (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 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