Compiling OO Languages

CSE413
Autumn 2007

Agenda for Today

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

Notes: 1)The student class inherits from (is a subclass of) the Person class
2) Both classes have their own implementation of print_mailing_label();

C++ Example

```
Person aPerson;
Student aStudent;
// Static binding done at compile time
// Function called depends on the declared type
// of the variable used.
aPerson.print_mailing_label();
aStudent.print_mailing_label();

Person *p_ptr;
p_ptr = &aPerson;  // OR p_ptr = &aStudent;
// Dynamic binding done at runtime
// Function called depends on what type the object
   p_ptr points to is, could be a Person or a Student
p_ptr->print_mailing_label();
```


Dynamic vs. Static binding

- **Static method binding**:
  - The compiler can figure out at compile time what function to call.
  - C++ has this by default, can designate functions as virtual to get dynamic binding.
- **Dynamic method binding**:
  - Compiler must instead generate code that will figure out *at run-time* what function to call.
  - Java uses dynamic binding for functions by default.

Object Representation

- The naïve explanation is that an object contains:
  - **Fields** declared in its class and in all superclasses
  - **Methods** declared in its class and in all superclasses
- 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

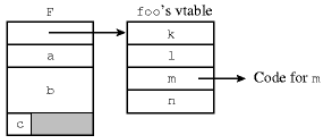
- Each object contains:
  - An entry for each field (variable)
  - A pointer to a runtime data structure "describing the class"
    - Key component: method dispatch table

Method Dispatch Tables

- Often known as "vtables"
- One pointer per method
- Offsets fixed at compile time
- One instance of this *per class*, (not per object)

Member Lookup - vtable

```
class foo {
    int a;
    double b;
    char c;
public:
    virtual void k ( ...
    virtual int l ( ...
    virtual void m ();
    virtual double n( ...
    ...
} F;
```



Method Tables and Inheritance

- One possible 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 there
  - Look in parent class table if not there
    - Repeat until found
- Actually used in some dynamic systems (e.g. SmallTalk, etc.)

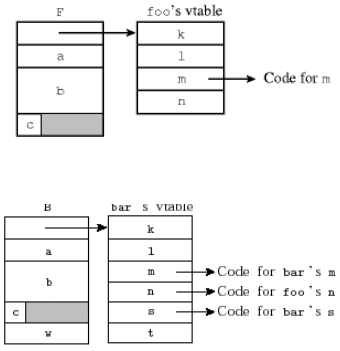

```
class foo {
   int a;
   double b;
   char c;
public:
   virtual void k();
   virtual int l();
   virtual void m();
   virtual double n();
   ...
} F;

class bar : public foo {
   int w;
public:
   void m(); // overrides version in foo
   virtual double s ()
   virtual char *t ();
} B;
```

O(1) Method Dispatch

- **Better Idea**: First part of method table for extended class has pointers 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

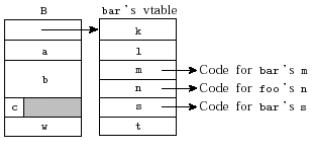
Single Inheritance

```
class foo {
    int a;
    double b;
    char c;
public:
    virtual void k ( ...
    virtual int l ( ...
    virtual void m ();
    virtual double n( ...
    ...
} F;
class bar : public foo {
    int w;
public:
    void m ();  //override
    virtual double s ( ...
    virtual char *t ( ...
    ...
} B;
```



Single Inheritance

```
class bar : public foo {
    int w;
public:
    void m ();  //override
    virtual double s ( ...
    virtual char *t ( ...
    ...
} B;
```




```
class foo { ...
class bar : public foo { ...
...
foo F;
bar B;
foo* q;
bar* s;
...
q = &B;         // ok; references through q will use prefixes
                // of B's data space and vtable
s = &F;         // static semantic error; F lacks the additional
                // data and vtable entries of a bar
```

Method Dispatch Footnotes

- Still want pointer to parent class method table for other purposes
  - Casts and instanceof


```
class Bird {
 private:
    int age;
    double weight;
    char favorite_letter;
 public:
    void eat();
    virtual int sleep();
    virtual void speak();
}

class Eagle : public Bird {
 private:
    int zip_code;
 public:
    virtual void speak(); // overrides Bird version
    virtual double findfish();
    void look_important();
    virtual void buildnest();
}
Bird B;
Eagle E;
```

What if **we** had to generate code for objects in a language like Java??

- 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
- Use first 32 bits of object for pointer to method table/class information
- Objects are allocated on the heap
  - No actual representation in the generated code

Assuming like in java where use . for access,
and objects are always allocated on the heap

Local Variable Field Access

- Source

  int n = obj.field;
- X86
  - (Assuming that obj is a local variable in the current method) :

    mov eax, [ebp + $offset_{obj}$]
    mov eax, [eax + $offset_{field}$]
    mov [eax + $offset_{n}$], eax

Assuming like in java where use . for access,
and objects are always allocated on the heap

Example: Local Variable Field Access

- Source

```
Bird b_ptr = new Eagle()
int n = b_ptr.age;
```

- X86

```
mov eax, [ebp + offset_b_tr]  ; get address of object
mov eax, [eax + offset_age]   ; get value of field

mov [eax + offset_n], eax     ; store result in 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
- **Mechanism**: a reference to the current object is an *implicit* parameter to every method
  - Can be in a register or on the stack

Implementing the *this* pointer

- 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 (more about that to come)

x86 Local Field Access

- Source

```
int n = fld;  or  int n = this.fld;
```

- X86: ???

x86 Method Tables (vtbls)

- Generate these in the assembly language source program
- Need to pick a naming convention for method labels; one possibility:
  - For methods, classname$methodname
    - Need something more sophisticated to implement overloading
  - For the vtables themselves, classname$$
- First method table entry points to superclass table

```
class foo {
  int a;
  double b;
  char c;
public:
  virtual void k();
  virtual int l();
  virtual void m();
  virtual double n();
  ...
} F;

class bar : public foo {
  int w;
public:
  void m(); // overrides version in foo
  virtual double s ()
  virtual char *t ();
} B;
```

Method Tables For Foo and Bar

```
class foo {
  ...
  virtual void k();
  virtual int l();
  virtual void m();
  virtual double n();
}
class bar : public foo {
  ...
  void m(); // overrides vers in foo
  virtual double s ()
  virtual char *t ();
};
```

```
                .data
foo$$   dd  0       ; no superclass
        dd  foo$k
        dd  foo$l
        dd  foo$m
        dd  foo$n
bar$$   dd  foo$$       ; parent
        dd  foo$k
        dd  foo$l
        dd  bar$m
        dd  foo$n
        dd  bar$s
        dd  bar$t
```


Method Table Footnotes

- **Key point**: First four method entries in bar's method table are pointers to methods declared in foo 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 (pointer to new object, `this`, in ecx)
  - Result of new is pointer to the constructed object

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

Method Call

- Source

  obj.meth(…);
- X86

```
<push arguments from right to left>  ; (if 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)
```

Runtime Type Checking

- Use the method table for the class as a "runtime representation" of the class
- The test for "o instanceof C" is:
  - 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"

More Code Generation

Other Control Flow: switch

- **Naïve**: generate a chain of nested if-else if statements
- **Better**: switch is designed to allow an O(1) selection, provided the set of switch values is reasonably compact
- **Idea**: create a 1-D array of jumps or labels and use the switch expression to select the right one
  - Need to generate the equivalent of an if statement to ensure that expression value is within bounds

Switch

- Source

```
switch (exp) {
  case 0: stmts0;
  case 1: stmts1;
  case 2: stmts2;
}
```

- X86

```
    <put exp in eax>
    "if (eax < 0 || eax > 2)
        jmp defaultLabel"
    mov eax, swtab[eax*4]
    jmp eax
            .data
swtab       dd L0
            dd L1
            dd L2
            .code
L0:         <stmts0>
L1:         <stmts1>
L2:         <stmts2>
```


Arrays

- Several variations
- C/C++/Java
  - 0-origin; an array with n elements contains variables a[0]…a[n-1]
  - 1 or more dimensions; row major order
- Key step is to evaluate a subscript expression and calculate the location of the corresponding element

0-Origin 1-D Integer Arrays

- Source

```
exp1[exp2]
```

- x86