CS 412/413

Introduction to
Compilers and Translators

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Lecture 21: Implementing Objects

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Classes

- Components
  - fields/instance variables
    - values may differ from object to object
    - usually mutable
  - methods
    - values shared by all objects of a class
    - inherited from superclasses
    - usually immutable
    - usually function values with implicit argument: object itself (this/self)
  - all components have visibility: public/private/protected (subclass visible)

Implementing classes

- Environment binds type names to type objects, *i.e. class objects*
  - Java: class object visible in programming language (java.lang.Class)
- Class objects are environments:
  - identifier bound to type
    - + expression (e.g. method body)
    - + field/method
    - + static/non-static
    - + visibility

Code generation for objects

- Methods
  - Generating method code
  - Generating method calls (dispatching)
- Fields
  - Memory layout
  - Generating accessor code
  - Packing and alignment

Compiling methods

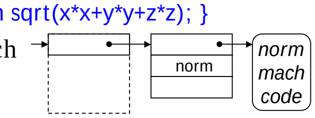
- Methods look like functions, are type-checked like functions...what is different?
- Argument list: implicit receiver argument
- Calling sequence: use *dispatch vector* instead of jumping to absolute address

The need for dispatching

- Problem: compiler can't tell what code to run when method is called

```
interface Point { float norm(); }
class ColoredPoint implements Point {...
  float norm() { return sqrt(x*x+y*y); }
class 3DPoint implements Point { ...
  float norm() return sqrt(x*x+y*y+z*z); }
```

- Solution: dispatch vector



Method dispatch

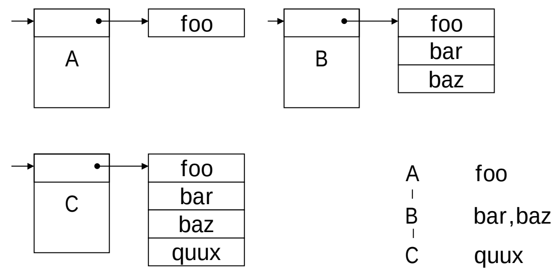
- Idea: every method has its own small integer index
- Index is used to look up method in dispatch vector

```
interface A {
   void foo();              0
}
interface B extends A {
   void bar();              1
   void baz();              2
}
```

```
class C implements B {
      void foo() {...}
      void bar() {...}
      void baz() {...}
      void quux() {...} 3
}
```

A
|
B
|
C

Dispatch vector layouts



Method arguments

- Methods have a special variable (in Java, "this") called the *receiver object*
- Historically (Smalltalk): method calls thought of as *messages* sent to *receivers*
- Receiver object is (implicit) argument to method

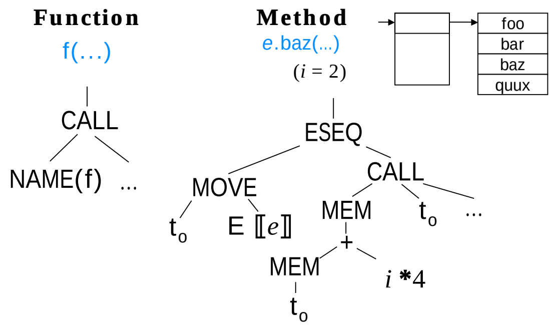
```
class Shape {
   int setCorner(int which, Point p) { ... }
}
```

compiled like

```
int setCorner(Shape this, int which, Point p) { ... }
```

How do we know the type of "this"?

Calling sequence



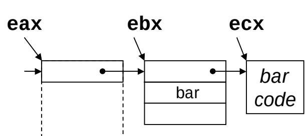
Example

A
|
B
|
C

foo
bar,baz
quux

B b = new C();
b.bar(3);

```
call new_C
push 3
push eax
mov ebx, [eax]
mov ecx, [ebx + 4]
jmp ecx
```



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Inheritance

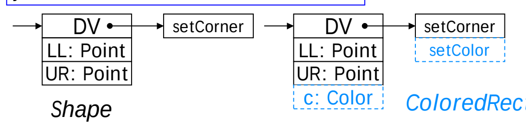
- Three traditional components of object-oriented languages
  - abstraction/encapsulation/information hiding
  - subtyping/interface inheritance -- interfaces inherit method signatures from supertypes
  - inheritance/implementation inheritance -- a class inherits signatures *and* code from a superclass (possibly "abstract")

Inheritance

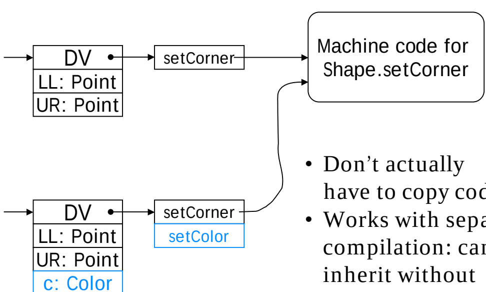
- Method code copied down from superclass if not *overridden* by subclass
- Fields also inherited (needed by inherited code in general)
- Fields checked just as for records: mutable fields must be invariant, immutable fields may be covariant

Object Layout

```
class Shape {
  Point LL, UR;
  void setCorner(int which, Point p);
}
class ColoredRect extends Shape {
  Color c;
  void setColor(Color c_);
}
```



Code Sharing



- Don't actually have to copy code!
- Works with separate compilation: can inherit without superclass source

Field Offsets

```
class Shape {
  Point LL /* 4 */ , UR; /* 8 */
  void setCorner(int which, Point p);
}
class ColoredRect extends Shape {
  Color c; /* 12 */
  void setColor(Color c_);
}
```

- Offsets of fields from beginning known statically, same for all subclasses
- Accesses to fields are indexed loads

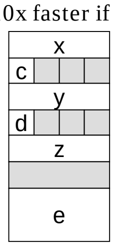
  ColoredRect x;
  E ⟦x.c⟧ = MEM(E ⟦x⟧ + 12)
  E ⟦x.UR⟧ = MEM(E ⟦x⟧ + 8)

Field Alignment

- In many processors, a 32-bit load must be to an address divisible by 4, address of 64-bit load must be divisible by 8
- In rest (e.g. Pentium), loads are 10x faster if aligned -- avoids extra load

⇒ Fields should be aligned

```
struct {
   int x; char c; int y; char d;
   int z; double e;
}
```



Interfaces, abstract classes

- Classes define a type *and* some values (methods)
- Interfaces are pure object types : no implementation
  - no dispatch vector: only a DV layout
- Abstract classes are halfway:
  - define some methods
  - leave others unimplemented
  - no objects (instances) of abstract class
- DV needed only for real classes

Static methods

- In Java, can declare methods *static* -- they have no receiver object
- Called exactly like normal functions
  - don't need to enter into dispatch vector
  - don't need implicit extra argument for receiver
- Treated as methods as way of getting functions inside the class scope (access to module internals) -- not really methods

Constructors

- Java, C++: classes can declare *object constructors* that create new objects: "new C(x, y, z)"
- Other languages (Modula-3, Iota+): objects constructed by "new C"; no initialization code

```
class LenList {
    int len, head; List next;
    LenList() { len = 0; }
}
```


Compiling constructors

- Compiled just like static methods except:
  - pseudo-variable "this" is in scope as in methods
  - this is initialized with newly allocated memory
  - first word in memory initialized to point to DV
  - value of this is return value of code

```
LenList() { len = 0; }
push 16              ; 3 fields + DV
call GC_malloc
mov [eax], LenList_DV
mov [eax+4], 0
ret
```

```
_DATA SEGMENT
LenList_DV DWORD LenList$first
           DWORD LenList$rest
           DWORD LenList$length
_DATA ENDS
```


Summary

- Method dispatch accomplished using dispatch vector, implicit method receiver argument
- No dispatch of static methods needed
- Inheritance causes extension of fields as well as methods; code can be shared
- Field alignment: declaration order matters!
- Each real class has a single dispatch vector in data segment: installed at object creation