Lecture 20

CS 131: COMPILERS

Compiling Constructors

- Java and C++ classes can declare constructors that create new objects.
  - Initialization code may have parameters supplied to the constructor
  - e.g. new Color(r,g,b);
- Modula-3: object constructors take no parameters
  - e.g. new Color;
  - Initialization would typically be done in a separate method.
- Constructors are compiled just like static methods, except:
  - The “this” variable is initialized to a newly allocated block of memory big enough to hold D.V. pointer + fields according to object layout
  - Constructor code initializes the fields
    - What methods (if any) are allowed?
  - The D.V. pointer is initialized
    - When? Before/After running the initialization code?

Compiling Checked Casts

- How do we compile downcast in general? Consider this generalization of Oat's checked cast:

  if? (t x = exp) { … } else { … }

- Reason by cases:
  - t must be either null, ref or ref? (can't be just int or bool)
- If t is null:
  - The static type of exp must be ref? for some ref.
  - If exp == null then take the true branch, otherwise take the false branch
- If t is string or t[]:
  - The static type of exp must be the corresponding string? Or t[]?
  - If exp == null take the false branch, otherwise take the true branch
- If t is C:
  - The static type of exp must be D or D? (where C <: D)
  - If exp == null take the false branch, otherwise:
  - emit code to walk up the class hierarchy starting at D, looking for C
  - If found, then take true branch else take false branch
- If t is C?:
  - The static type of exp must be D? (where C <: D)
  - If exp == null take the true branch, otherwise:
  - Emit code to walk up the class hierarchy starting at D, looking for C
  - If found, then take true branch else take false branch

“Walking up the Class Hierarchy”

- A non-null object pointer refers to an LLVM struct with a type like:

```
%B = type { %_class_B*, i64, i64, i64 }
```

- The first entry of the struct is a pointer to the vtable for Class B
  - This pointer ***is*** the dynamic type of the object.
  - It will have the value @vtbl_B
- The first entry of the class table for B is a pointer to its superclass:

```
@_vtbl_B = global %_class_B { %_class_A* @_vtbl_A,
                    void (%B*)* @print_B,
                    i64 (%A*, %A*)* @blah_A }
```

- Therefore, to find out whether an unknown type X is a subtype of C:
  - Assume C is not Object (ruled out by “silliness” checks for downcast)

```
LOOP:
 If X == @_vtbl_Object then NO, X is not a subtype of C
 If X == @_vtbl_C    then YES, X is a subtype of C
 else X == @_vtbl_D, so set X to @_vtbl_E  where E is D’s parent and goto LOOP
```

MULTIPLE INHERITANCE

Method Dispatch (Single Inheritance)

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

Index

```
interface A {
  void foo();
}
```

0

```
interface B extends A {
  void bar(int x);
  void baz();
}
```

1
2

Inheritance / Subtyping:
C <: B <: A

```
class C implements B {
  void foo() {…}
  void bar(int x) {…}
  void baz() {…}
  void quux() {…}
}
```

0
1
2
3

Multiple Inheritance

- C++: a class may declare more than one superclass.
- Semantic problem: *ambiguity*

```
class A { int m(); }
class B { int m(); }
class C extends A,B {…}   // which m?
```

  - Same problem can happen with fields.
  - In C++, fields and methods can be duplicated when such ambiguity arises (though explicit sharing can be declared too)

- Java: a class may implement more than one interface.
  - No semantic ambiguity: if two interfaces contain the same method declaration, then the class will implement a single method

```
interface A { int m(); }
interface B { int m(); }
class C implements A,B {int m() {…}}   // only one m
```

Dispatch Vector Layout Strategy Breaks

```
interface Shape {                                   D.V.Index
  void setCorner(int w, Point p);               0
}

interface Color {
  float get(int rgb);                                       0
  void set(int rgb, float value);               1
}

class Blob implements Shape, Color {
  void setCorner(int w, Point p) {…}            0?
  float get(int rgb) {…}                                0?
  void set(int rgb, float value) {…}            1?
}
```

General Approaches

- Can't directly identify methods by position anymore.

- Option 1: Use a level of indirection:
  - Map method identifiers to code pointers (e.g. index by method name)
  - Use a hash table
  - May need to do search up the class hierarchy

- Option 2: Give up separate compilation
  - Use "sparse" dispatch vectors, or binary decision trees
  - Must know then entire class hierarchy

- Option 3: Allow multiple D.V. tables (C++)
  - Choose which D.V. to use based on static type
  - Casting from/to a class may require run-time operations

- Note: many variations on these themes
  - Different Java compilers pick different approaches to options1 and 2…

Option 2 variant 1: Sparse D.V. Tables

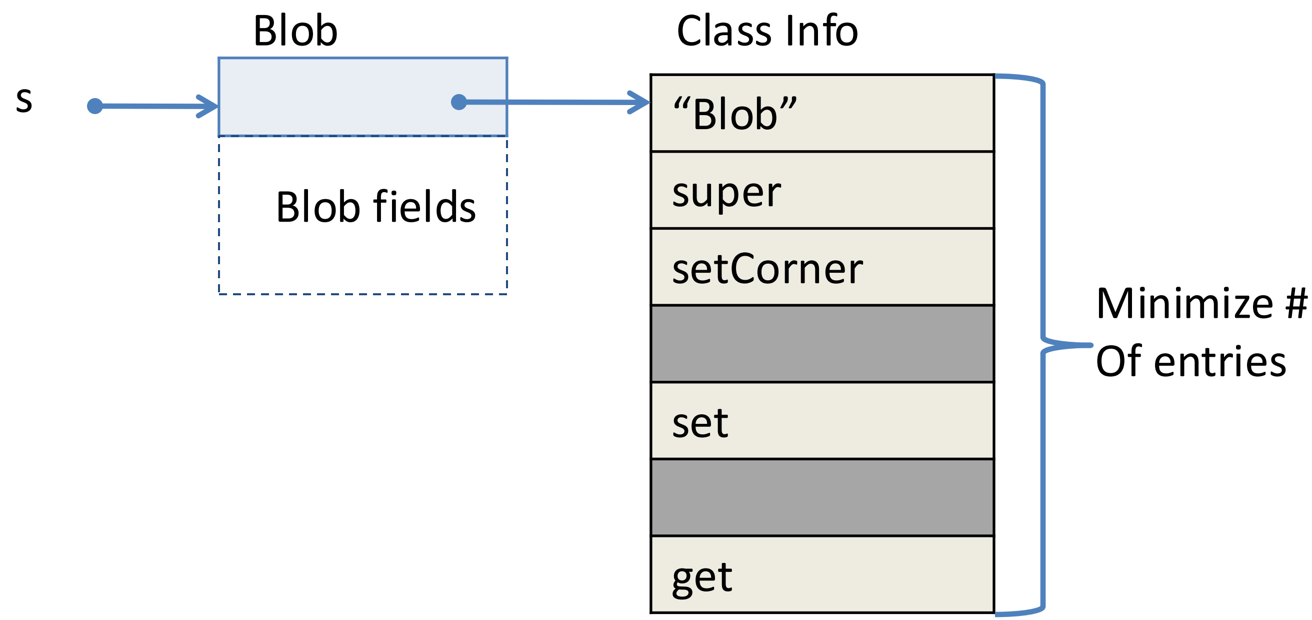
- Give up on separate compilation…
- Now we have access to the whole class hierarchy.

- So: ensure that no two methods in the same class are allocated the same D.V. offset.
  - Allow holes in the D.V. just like the hash table solution
  - Unlike hash table, there is never a conflict!

- Compiler needs to construct the method indices
  - Graph coloring techniques can be used to construct the D.V. layouts in a reasonably efficient way (to minimize size)
  - Finding an optimal solution is NP complete!

Example Object Layout

- Advantage: Identical dispatch and performance to single-inheritance case
- Disadvantage: Must know entire class hierarchy

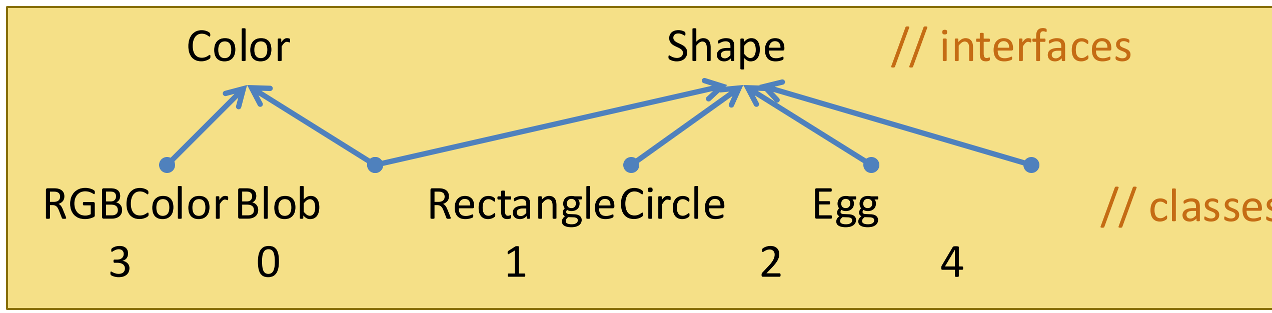


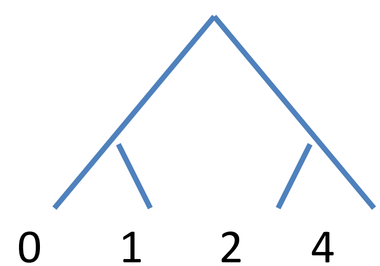
Option 2 variant 2: Binary Search Trees

- Idea: Use conditional branches not indirect jumps
- Each object has a class index (unique per class) as first word
  - Instead of D.V. pointer (no need for one!)
- Method invocation uses range tests to select among *n* possible classes in *lg n* time
  - Direct branches to code at the leaves.

```
Shape x;
x.SetCorner(…);
```

```
  Mov eax, ⟦x⟧
  Mov ebx, [eax]
  Cmp ebx, 1
  Jle  __L1
  Cmp ebx, 2
  Je __CircleSetCorner
  Jmp __EggSetCorner
__L1:
  Cmp ebx, 0
  Je __BlobSetCorner
  Jmp __RectangleSetCorner
```





Decision tree

Search Tree Tradeoffs

- Binary decision trees work well if the distribution of classes that may appear at a call site is skewed.
  - Branch prediction hardware eliminates the branch stall of ~10 cycles (on X86)
- Can use profiling to find the common paths for each call site individually
  - Put the common case at the top of the decision tree (so less search)
  - 90%/10% rule of thumb: 90% of the invocations at a call site go to the same class

- Drawbacks:
  - Like sparse D.V.'s you need the whole class hierarchy to know how many leaves you need in the search tree.
  - Indirect jumps can have better performance if there are >2 classes (at most one mispredict)

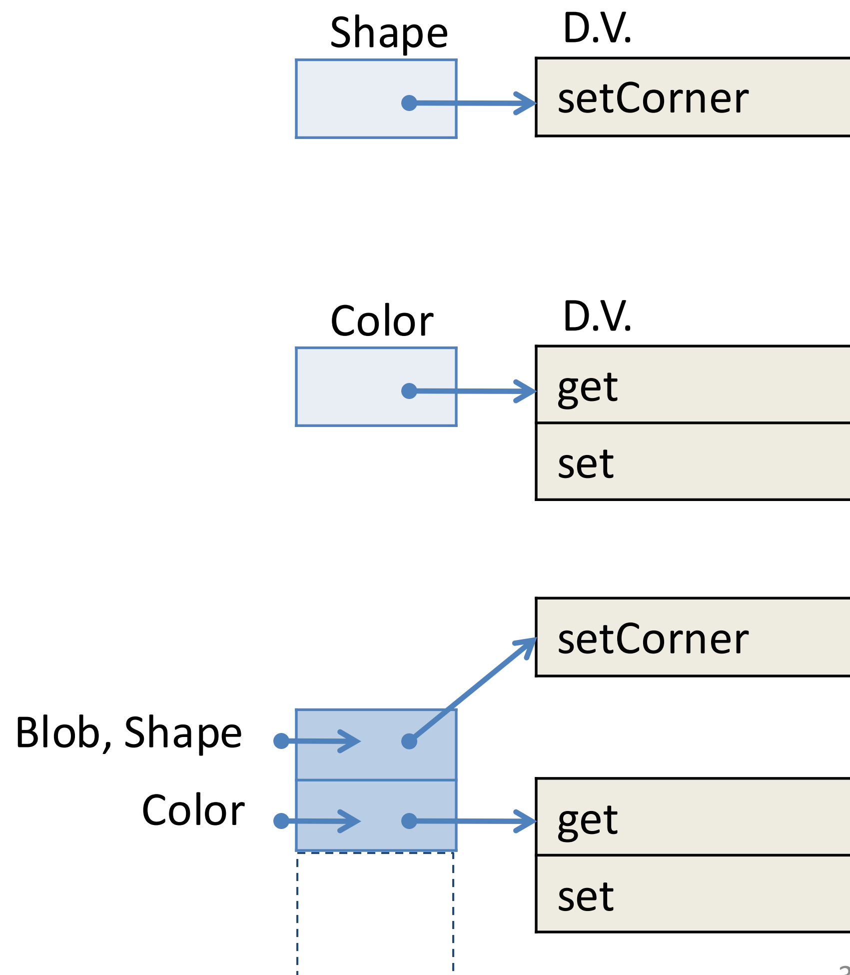
Option 3: Multiple Dispatch Vectors

- Duplicate the D.V. pointers in the object representation.
- Static type of the object determines which D.V. is used.

```
interface Shape {                          D.V.Index
  void setCorner(int w, Point p);          0
}

interface Color {
  float get(int rgb);                           0
  void set(int rgb, float value);          1
}

class Blob implements Shape, Color {
  void setCorner(int w, Point p) {…}
  float get(int rgb) {…}
  void set(int rgb, float value) {…}
}
```



Multiple Dispatch Vectors

- A reference to an object might have multiple "entry points"
  - Each entry point corresponds to a dispatch vector
  - Which one is used depends on the statically known type of the program.

  Blob b = new Blob();

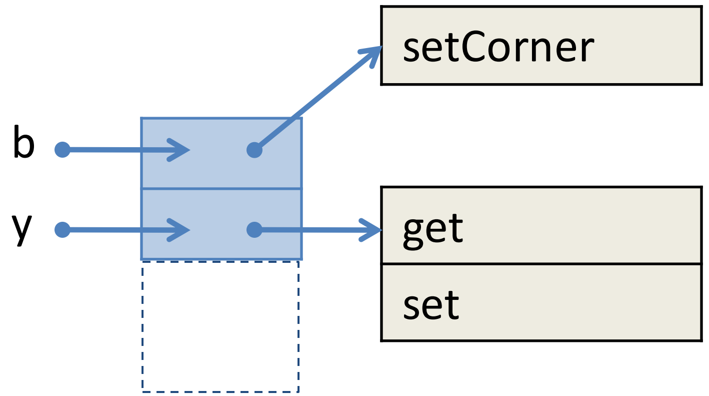
  Color y = b;   // implicit cast!

- Compile

  Color y = b;

  As

  Movq ⟦b⟧ + 8 , y



Multiple D.V. Summary

- Benefit: Efficient dispatch, same cost as for multiple inheritance
- Drawbacks:
  - Cast has a runtime cost
  - More complicated programming model… hard to understand/debug?

- What about multiple inheritance and fields?

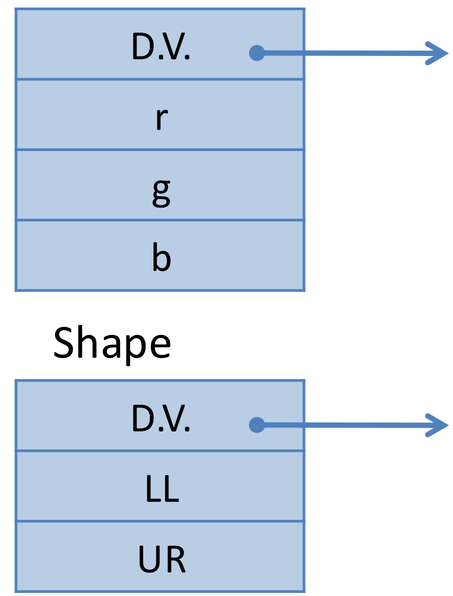
Multiple Inheritance: Fields

- Multiple supertypes (Java): methods conflict (as we saw)
- Multiple inheritance (C++): fields can also conflict
- Location of the object's fields can no longer be a constant offset from the start of the object.

```
class Color {
  float r, g, b; /* offsets: 4,8,12 */
}
class Shape {
  Point LL, UR; /* offsets: 4, 8 */
}
class ColoredShape extends
Color, Shape {
  int z;
}
```

Color

Shape



ColoredShape ??

C++ approach:

- Add pointers to the superclass fields
  - Need to have multiple dispatch vectors anyway (to deal with methods)
- Extra indirection needed to access superclass fields
- Used even if there is a single superclass
  - Uniformity