Run Time Environment

Implementing Object-Oriented Languages

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Recapitulation

• What Have We Learned?
  – AR is a Run-Time structure to hold \textit{State} regarding the execution of a procedure
  – AR can be allocated in Static, Stack or even Heap
  – Links to allow Call-Return and Access to Non-local Variables
  – Symbol-table plays important role

• Not Yet Done with Procedures
  – Saving Context before call and restoring after the call
  – Need to understand how to generate code for body
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Mapping “message” or names to methods

• Static mapping, known at compile-time  
  – Fixed offsets & indirect calls  
  (Java, C++)

• Dynamic mapping, unknown until run-time  
  – Look up name in class’ table of methods  
  (Smalltalk)

Want uniform placement of standard services  
  \(NEW, PRINT, \ldots\)

This is really a Data-Structures Problem

• Build a Table of Function Pointers
• Use a Standard Invocation Sequence
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With static, compile-time mapped classes

Message dispatch becomes an indirect call through a function table
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Method Code:

```c
void A::fee(){
    ...
    self->i = 0;
    ...
}
```

```
t0 = &self + 4;
*t0 = 0;
```

Class A

- fee()
- fie()
- foe()
- fum()

```
objects of class A
```

Method Accesses Object Data as Offsets from the `self` Reference
Single Inheritance & Dynamic Dispatch

• Use **prefixing** of tables

```java
Class Point {
    int x, y;
    public void draw();
    public void d2o();
}
```

```java
Class ColorPoint extends Point {
    Color c;
    public void draw();
    public void rev();
}
```

The Inheritance Hierarchy

To simplify object creation, we allow a class to inherit methods from an ancestor, or superclass. The descendant class is called the subclass of its ancestor.

The Concept:

Method table is an extension of table from One

Principle:

• B subclass A ⇒ d ∈ B can be used wherever a ∈ A is expected
  – B has all the methods defined in its super class
  – B may override a method definition from A
• Subclass provides all the interfaces of superclass
The Inheritance Hierarchy

Two distinct Implementation Philosophies

**Static Class Structure**
- Can map name to code at compile time
- Leads to 1-level jump vector
- Copy superclass methods
- Fixed offsets & indirect calls
- Less flexible & expressive

**Dynamic Class Structure**
- Cannot map name to code at compile time
- Multiple jump vector (1/class)
- Must search for method
- Run-time lookups caching
- Much more expensive to run

Impact on name space
- Method can see instance variables of self, class, & superclasses
- Many different levels where a value can reside

In essence, OOL differs from ALL in the shape of its name space **AND** in the mechanism used to bind names to implementations
Multiple Inheritance

The Idea:

• Allow more flexible sharing of methods & attributes
• Relax the inclusion requirement
  If B is a subclass of A, it need not implement all of A’s methods
• Need a linguistic mechanism for specifying partial inheritance

Problems when C inherits from both A & B

• C’s method table can extend A or B, but not both
  – Layout of an object record for C becomes tricky
• Other classes, say D, can inherit from C & B
  – Adjustments to offsets become complex
• Say, both A & B might provide fum() — which is seen in C?
  – C++ produces a “syntax error” when fum() is used
Multiple Inheritance Example

- Use **Prefixing** of Storage

  ```
  Class Point {
      int x, y;
  }
  
  Class CThing {
      Color c;
  }
  
  Class CPoint extends Point, CThing {
  }
  ```

Issue: does casting work properly?
Multiple Inheritance Example

- Use **Prefixing** of Storage

```cpp
Class Point {
    int x, y;
    void draw();
    void d2o();
}

Class CThing {
    Color c;
    void rev();
}

Class CPoint extends Point, CThing {
    void draw()
}
```
Casting with Multiple Inheritance

- Usage as Point:
  - No extra action (prefixing does everything)

- Usage as CThing:
  - Increment self by 12

- Usage as CPoint:
  - Lay out data for CThing at self + 12
  - When calling rev
    - Call in table points to a trampoline function that adds 12 to self, then calls rev
    - Ensures that rev, which assumes that self points to a CThing data area, gets the right data
Multiple Inheritance (Example)

Assume that C inherits fee() from A, fie() from B, & defines both foe() and fum()

This implementation
- Uses trampoline functions
- Optimizes well with inlining
- Adds overhead where needed (Zero offsets go away)
- Folds inheritance into data structure, rather than linkage

Assumes static class structure
For dynamic, why not rebuild on a change in structure?
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So, what can an Executing Method see?

- The Object’s own Attributes & Private Variables
- The Attributes & Private Variables of Classes that define it
  - May be many such classes, in many combinations
  - Class variables are visible to methods that inherit the class
- Object defined in the Global Name Space (or scope)
  - Objects may contain other objects
- Objects that contain their definition
  - A class as an instance variable of another class, ...

An Executing Method might reference any of these

Making this work requires compile-time elaboration for static case and run-time elaboration for dynamic case

Making it run quickly takes care, planning, and trickery…
Summary

• Support for Object-Oriented Languages:
  – Mostly focus on message dispatching
  – Finding the “correct” function in the Class Hierarchy
  – Adjusting Object Layout and Class References

• An Invocation Stack is still needed....