What next?

Have used classes for OOP's essence: inheritance, overriding, dynamic dispatch

Now, what if we want to have more than just 1 superclass

- **Multiple inheritance**: allow > 1 superclasses
  - Useful but has some problems (see C++)
- **Ruby-style mixins**: 1 superclass; > 1 method providers
  - Often a fine substitute for multiple inheritance and has fewer problems (see also Scala traits)
- **Java/C#-style interfaces**: allow > 1 types
  - Mostly irrelevant in a dynamically typed language, but fewer problems

Multiple Inheritance

- If inheritance and overriding are so useful, why limit ourselves to one superclass?
  - Because the semantics is often awkward (this topic)
  - Because it makes static type-checking harder (not discussed)
  - Because it makes efficient implementation harder (not discussed)
- Is it useful? Sure!
  - Example: Make a ColorPt3D by inheriting from Pt3D and ColorPt (or maybe just from Color)
  - Example: Make a StudentAthlete by inheriting from Student and Athlete
  - With single inheritance, end up copying code or using non-OOP-style helper methods

Trees, dags, and diamonds

- Note: The phrases subclass, superclass can be ambiguous
  - There are immediate subclasses, superclasses
  - And there are transitive subclasses, superclasses
- Single inheritance: the class hierarchy is a tree
  - Nodes are classes
  - Parent is immediate superclass
  - Any number of children allowed
- Multiple inheritance: the class hierarchy no longer a tree
  - Cycles still disallowed (a directed-acyclic graph)
  - If multiple paths show that X is a (transitive) superclass of Y, then we have diamonds

What could go wrong?

- If V and Z both define a method m, what does Y inherit? What does `super` mean?
  - `Directed resends` useful (e.g., Z::super)
- What if X defines a method m that Z but not V overrides?
  - Can handle like previous case, but sometimes undesirable (e.g., ColorPt3D wants Pt3D's overrides to "win")
- If X defines fields, should Y have one copy of them (f) or two (V::f and Z::f)?
  - Turns out each behavior can be desirable (next slides)
  - So C++ has (at least) two forms of inheritance

3DColorPoints

If Ruby had multiple inheritance, we would want ColorPt3D to inherit methods that share one @x and one @y
This code has \texttt{Person} define a pocket for subclasses to use, but an \texttt{ArtistCowboy} wants two pockets, one for each \texttt{draw} method.

```ruby
class Person
  attr_accessor :pocket
end
class Artist < Person # pocket for brush objects
def draw # access pocket
  ...
end
class Cowboy < Person # pocket for gun objects
def draw # access pocket
  ...
end
class ArtistCowboy < Artist, Cowboy # not Ruby!
end
```

### Mixins

- A \textit{mixin} is (just) a collection of methods
  - Less than a class: no instances of it
- Languages with mixins (e.g., Ruby modules) typically let a class have one superclass but \texttt{include} number of mixins
- Semantics: \textit{Including a mixin makes its methods part of the class}
  - Extending or overriding in the order mixins are included in the class definition
  - More powerful than helper methods because mixin methods can access methods (and instance variables) on \texttt{self} not defined in the mixin

```ruby
module Doubler
  def double
    self + self # assume included in classes w/ +
  end
end
class String
  include Doubler
end
class AnotherPt
  attr_accessor :x, :y
  include Doubler
  def + other
    ans = AnotherPt.new
    ans.x = self.x + other.x
    ans.y = self.y + other.y
    ans
  end
end
```

- Mixins change our lookup rules slightly:
  - When looking for receiver \texttt{obj}'s method \texttt{m}, look in \texttt{obj}'s class, then mixins that class includes (later includes shadow), then \texttt{obj}'s superclass, then the superclass' mixins, etc.
  - As for instance variables, the mixin methods are included in the same object
    - So usually bad style for mixin methods to use instance variables since a name clash would be like our \texttt{CowboyArtist} pocket problem (but sometimes unavoidable?)

### The two big ones

The two most popular/useful mixins in Ruby:

- Comparable: Defines \texttt{<, >, ==, !=, >>, <=} in terms of \texttt{<<}
- Enumerable: Defines many iterators (e.g., \texttt{map, find}) in terms of \texttt{each}

Great examples of using mixins:
- Classes including them get a bunch of methods for just a little work
- Classes do not "spend" their "one superclass" for this
- Do not need the complexity of multiple inheritance

- See the code for some examples

### Replacement for multiple inheritance?

- A mixin works pretty well for \texttt{ColorPt3D}:
  - Color a reasonable mixin except for using an instance variable
    ```ruby
    module Color
      attr_accessor :color
    end
    ```
- A mixin works awkwardly-at-best for \texttt{ArtistCowboy}:
  - Natural for \texttt{Artist} and \texttt{Cowboy} to be \texttt{Person} subclasses
  - Could move methods of one to a mixin, but it is odd style and still does not get you two pockets
    ```ruby
    module ArtistM ...
class Artist < Person
  include ArtistM
class ArtistCowboy < Cowboy
  include ArtistM
```
**Statically-Typed OOP**

- Now contrast multiple inheritance and mixins with Java/C#-style interfaces
- Important distinction, but interfaces are about static typing, which Ruby does not have
- So will use Java code after quick introduction to static typing for class-based OOP...
  - Sound typing for OOP prevents “method missing” errors

**Classes as Types**

- In Java/C# etc. each class is also a type
- Methods have types for arguments and result
  ```java
class A {
    Object m1(Example e, String s) {...}
    Integer m2(A foo, Boolean b, Integer i) {...}
}
```
- If C is a (transitive) subclass of D, then C is a subtype of D
  - Type-checking allows subtype anywhere supertype allowed
  - So can pass instance of C to a method expecting instance of D

**Interfaces are Types**

```java
interface Example {
    void m1(int x, int y);
    Object m2(Example x, String y);
}
```

- An interface is not a class; it is only a type
  - Does not contain method definitions, only their signatures (types)
    - Unlike mixins
  - Cannot use `new` on an interface
    - Like mixins

**Implementing Interfaces**

- A class can explicitly implement any number of interfaces
  - For class to type-check, it must implement every method in the interface with the right type
    - More on allowing subtypes later!
  - Multiple interfaces no problem; just implement everything
- If class type-checks, it is a subtype of the interface
  ```java
class A implements Example {
    public void m1(int x, int y) {...}
    public Object m2(Example e, String s) {...}
}
class B implements Example {
    public void m1(int pizza, int beer) {...}
    public Object m2(Example e, String s) {...}
}
```

**Multiple interfaces**

- Interfaces provide no methods or fields
  - So no questions of method/field duplication when implementing multiple interfaces, unlike multiple inheritance
- What interfaces are for:
  - “Caller can give any instance of any class implementing I”
    - So callee can call methods in I regardless of class
  - So much more flexible type system
- Interfaces have little use in a dynamically typed language
  - Dynamic typing already much more flexible, with trade-offs we studied

**Connections**

Let’s now answer these questions:

- What does a statically typed OOP language need to support “required overriding”?
- How is this similar to higher-order functions?
- Why does a language with multiple inheritance (e.g., C++) not need Java/C#-style interfaces?
**Required overriding**

Often a class expects all subclasses to override some method(s)
- The purpose of the superclass is to abstract common functionality, but some non-common parts have no default

A Ruby approach:
- Do not define must-override methods in superclass
- Subclasses can add it
- Creating instance of superclass can cause method-missing errors

```ruby
# do not use A.new
# all subclasses should define m2
class A
  def m1 v
    ... self.m2 e ...
  end
end
```

**Static typing**

- In Java/C#/C++, prior approach fails type-checking
  - No method m2 defined in superclass
  - One solution: provide error-causing implementation

```ruby
class A
  def m1 v
    ... self.m2 e ...
  end
  def m2 v
    raise "must be overridden"
  end
end
```

- Better: Use static checking to prevent this error...

**Abstract methods**

- Java/C#/C++ let superclass give signature (type) of method subclasses should provide
  - Called abstract methods or pure virtual methods
  - Cannot creates instances of classes with such methods
    - Catches error at compile-time
    - Indicates intent to code-reader
    - Does not make language more powerful

```java
abstract class A {
  T1 m1(T2 x) { ... m2(e); ... }
  abstract T3 m2(T4 x);
}
class B extends A {
  T3 m2(T4 x) { ... }
}
```

**Passing code to other code**

- Abstract methods and dynamic dispatch: An OOP way to have subclass “pass code” to other code in super class

```java
abstract class A {
  T1 m1(T2 x) { ... m2(e); ... }
  abstract T3 m2(T4 x);
}
class B extends A {
  T3 m2(T4 x) { ... }
}
```

- Higher-order functions: An FP way to have caller “pass code” to callee

```java
fun f (g,x) = ... g e ...
fun h x = ... f((fn y => ...),...)
```

**No interfaces in C++**

- If you have multiple inheritance and abstract methods, you do not also need interfaces
- Replace each interface with a class with all abstract methods
- Replace each “implements interface” with another superclass

So: Expect to see interfaces only in statically typed OOP without multiple inheritance
- Not Ruby
- Not C++