CSE 341, Spring 2018, Blocks; Inheritance Summary

Disclaimer: This lecture summary is not necessarily a complete substitute for attending class, reading the associated code, etc. It is designed to be a useful resource for students who attended class and are later reviewing the material.

This lecture covers two separate topics:

1. Blocks, Procs, and iterators — Ruby’s convenient, pervasive but somewhat strange approach to function closures
2. Subclassing, inheritance, and dynamic dispatch — the most essential aspect of OOP

Ruby’s Blocks

While Ruby has while loops and for loops not unlike Java, much Ruby code written in good style does not use them. Instead, many classes have methods that take blocks. These blocks are almost closures. For example, integers have a `times` method that takes a block and executes it the number of times you would imagine. For example,

```ruby
x.times { puts "hi" }
```

prints "hi" 3 times if `x` is bound to 3 in the environment. To pass a block to a method, you put it in braces after the method call. The example above has no regular arguments, but a method can take any number of regular arguments and then 0 or 1 block.

Blocks are closures in the sense that they can refer to variables in scope where the block is defined. For example, after this program executes, `y` is bound to 10:

```ruby
y = 7
[4,6,8].each { y += 1 }
```

Here `[4,6,8]` is an array with 3 elements. Arrays have a method `each` that takes a block and executes it once for each element. Typically, however, we want the block to be passed each array element. We do that like this, for example to sum an array’s elements and print out the running sum at each point:

```ruby
sum = 0
[4,6,8].each do |x|
  sum += x
  puts sum
end
```

When calling a method that takes a block, you should know how many arguments will be passed to the block when it is called. For the `each` method in `Array`, the answer is 1, but as the first example showed, you can ignore arguments if you have no need for them by omitting the `{...}.`.

Many collections, including arrays, have a variety of block-taking methods that look very familiar to functional programmers. For example, `inject` is just like the `fold` we studied in Haskell:

```ruby
sum = [4,6,8].inject(0) { |acc,elt| acc + elt }
```
The argument to `inject` is the initial accumulator. If you omit it, `inject` will use the 0th element of the array as the initial accumulator and start with the next array element. Some other useful iterators (methods that take care of iterating through the elements in one way or another) are `map` and `any?`. In a later lecture, we will learn that many of the iterators are actually defined in terms of `each` in a mixin so that they do not have to be reimplemented for each collection.

### Using blocks in your own methods

While many uses of blocks involve calling methods in the standard library, you can also define your own methods that take blocks. In fact, you can pass a block to `any` method. The method body calls the block using the `yield` keyword. For example, this code prints "hi" 3 times:

```ruby
def foo x
  if x
    yield
  else
    yield
    yield
  end
foo true { puts "hi" }
foo false { puts "hi" }
```

To pass arguments to a block, you put the arguments after the `yield`, e.g., `yield 7` or `yield(8,"str")`.

Using this approach, the fact that a method may expect a block is implicit; it is just that its body might use `yield`. An error will result if `yield` is used and no block was passed. The behavior when the block and the `yield` disagree on the number of arguments is somewhat flexible and not described in full detail here. A method can use the `block_given?` primitive to see if the caller provided a block. You are unlikely to use this method often: If a block is needed, it is conventional just to assume it is given and have `yield` fail if it is not. In situations where a method may or may not expect a block, often other regular arguments determine whether a block should be present. If not, then `block_given?` is appropriate.

### Full Closures: The Proc Class

Blocks are not quite closures because they are not objects. We cannot store them in a field, pass them as a regular method argument, assign them to a variable, put them in an array, etc. (Notice in Haskell and Racket, we could do the equivalent things with closures.) However, Ruby has “real” closures too: The class `Proc` has instances that are closures. The method `call` in `Proc` is how you apply the closure to arguments, for example `x.call` (for no arguments) or `x.call(3,4)`.

To make a `Proc` out of a block, just write `lambda { ... }` where `{ ... }` is any block. Interestingly, `lambda` is not a keyword. It is just a method in class `Object` (and every class is a subclass of `Object`, so `lambda` is available everywhere) that creates a `Proc` out of a block it is passed. You can define your own methods that do this too, but we won’t go into the syntax that accomplishes this.

### A Recursive (But Unnecessary) Example

Consider a linked-list class called `MyList` that uses instance variables `@head` and `@tail` in the expected ways, using the `nil` object to represent the empty-list. (The code accompanying these notes shows such a class with several useful methods.) One would not use such a class in typical Ruby code since the `Array` class is already plenty flexible to serve for purposes where in less dynamic languages we would use arrays or tuples or lists. After all, there are methods in `Array` for adding elements at the beginning, extracting the slice that omits the first element, mapping over an array, etc. But a linked-list still makes a useful example.

Suppose we want to implement a `map` method for `MyList` that works like the common `map` function from functional programming: It builds a new list of the same length by applying a caller-provided operation to
each element. Using a Proc object leads to a straightforward solution:

def map proc
  if @tail.nil?
    MyList.new(proc.call(@head), nil)
  else
    MyList.new(proc.call(@head), @tail.map(proc))
  end
end

As a side-note, notice that a more object-oriented approach would be for the NilClass (the class of nil) to also have a map method that returns nil. If it did (or if we added it), then our method in MyList could just be:

def map proc
  MyList.new(proc.call(@head), @tail.map(proc))
end

In Ruby, it is conventional to use blocks instead of Proc objects. One approach would be to provide callers a map method that took a block, used lambda to create a Proc and then used the code above as a private recursive helper method named something like map_helper. The reason for doing this is that we cannot pass the block we are given to a recursive call since we have no “name” for the block — we can only call yield.

But there is a way to implement map using only blocks. We show the solution followed by an explanation:

def map
  if @tail.nil?
    MyList.new(yield(@head), nil)
  else
    MyList.new(yield(@head), @tail.map { |x| yield x })
  end
end

The key trick is { |x| yield x }, which passes the recursive call a new block that, when yield is called on it will then yield to the block passed to this method, which is what we wanted. This is analogous to the unnecessary function wrapping we studied in functional languages (do not write fn x => f x because you can write f), but in this case, the wrapping is necessary because there is no name like f for the current block.

It may depend on the Ruby implementation whether or not this technique is efficient.

As with the Proc solution, a more object-oriented approach would add a map method to NilClass; this is orthogonal to blocks versus Proc.

Subclassing, Inheritance, and Dynamic Dispatch

Basic Idea and Terminology

Subclassing is an essential feature of class-based OOP. If class C is a subclass of D, then every instance of C is also an instance of D. The definition of C inherits the methods of D, i.e., they are part of C’s definition too. Moreover, C can extend by defining new methods that C has and D does not. And it can override methods, by changing their definition from the inherited definition. In Ruby, this is much like in Java. In Java, a subclass also inherits the field definitions of the superclass, but in Ruby fields are not part of a class definition because each object instance just creates its own instance variables.

Every class in Ruby except Object has one superclass. The classes form a tree where each node is a class and the parent is its superclass. The Object class is the root of the tree. In class-based languages, this is
called the class hierarchy. By the definition of subclassing, a class has all the methods of all its ancestors in
the tree (i.e., all nodes between it and the root, inclusive), subject to overriding.

Some Ruby Specifics

- A Ruby class definition specifies a superclass with `class C < D ... end` to define a new class C with
  superclass D. Omitting the `< D` implies `< Object`, which is what our examples so far have done.
- Ruby’s built-in methods for reflection can help you explore the class hierarchy. Every object has a
  `class` method that returns the class of the object. Consistently, if confusingly at first, a class is itself
  an object in Ruby (after all, every value is an object). The class of a class is `Class`. This class defines
  a method `superclass` that returns the superclass.
- Every object also has methods `is_a?` and `instance_of?`. The method `is_a?` takes a class (e.g.,
  `x.is_a? Integer`) and returns true if the receiver is an instance of `Integer` or any (transitive) subclass
  of `Integer`, i.e., if it is below `Integer` in the class hierarchy. The method `instance_of?` is similar but
  returns true only if the receiver is an instance of the class exactly, not a subclass. Note that in Java
  the primitive `instanceof` is analogous to Ruby’s `is_a?`.

Using methods like `is_a?` and `instance_of?` is “less object-oriented” and therefore often not preferred style.
They are in conflict with duck typing.

A First Example: Point and ColorPoint

Here are definitions for simple classes that describe simple two-dimensional points and a subclass that adds
a color (just represented with a string) to instances.

```ruby
class Point
  attr_reader :x, :y
  attr_writer :x, :y
  def initialize(x,y)
    @x = x
    @y = y
  end
  def distFromOrigin
    Math.sqrt(@x * @x + @y * @y)
  end
end
class ColorPoint < Point
  attr_reader :color
  attr_writer :color
  def initialize(x,y,c="clear")
    super(x,y)
    @color = c
  end
end
```

There are many ways we could have defined these classes. Our design choices here include:

- We make the @x, @y, and @color instance variables mutable, with public getter and setter methods.
• The default “color” for a ColorPoint is "clear”.

• For pedagogical purposes revealed below, we implement the distance-to-the-origin two different ways. The distFromOrigin method accesses instance variables directly whereas distFromOrigin2 uses the getter methods on self. Given the definition of Point, both will produce the same result.

The initialize method in ColorPoint uses the super keyword, which allows an overriding method to call the method of the same name in the superclass. This is not required when constructing Ruby objects, but it is often desired.

Given the existence of Point, defining ColorPoint is good style because it allows us to reuse much of our work from Point and it makes sense to treat any instance of ColorPoint as though it “is a” Point. But it is worth considering three alternative ways to define the ColorPoint class.

First, we could just define ColorPoint “from scratch,” copying over (or retyping) the code from Point. In a dynamically typed language, the difference in semantics (as opposed to style) is small: instances of ColorPoint will now return false if sent the message is_a? with argument Point, but otherwise they will work the same. In languages like Java, superclasses have effects on static typing. One advantage of not subclassing Point is that any later changes to Point will not affect ColorPoint — in general in class-based OOP, one has to worry about how changes to a class will affect any subclasses.

Second, we could have ColorPoint be a subclass of Object but have it contain an instance variable, call it @pt, holding an instance of Point. Then it would need to define all of the methods defined in Point to forward the message to the object in @pt. Here are two examples, omitting all the other methods (x, y, z, distFromOrigin, distFromOrigin2):

```ruby
def initialize(x,y,c="clear")
  @pt = Point.new(x,y)
  @color = c
end
```

This approach is bad style since again subclassing is shorter and we want to treat a ColorPoint as though it “is a” Point. But in general, many programmers in object-oriented languages overuse subclassing. In situations where you are making a new kind of data that includes a pre-existing kind of data as a separate sub-part of it, this instance-variable approach is better style.

Third, in Ruby, we can extend and modify classes with new methods. So we could simply change the Point class by replacing its initialize method and adding getter/setter methods for @color. This would be appropriate only if every Point object, including instances of all other subclasses of Point, should have a color.

Simple Overriding and Three-Dimensional Points

Now let’s consider a different subclass of Point, which is for three-dimensional points:

```ruby
class ThreeDPoint < Point
  attr_reader :z
  attr_writer :z
  def initialize(x,y,z)
    super(x,y)
    @z = z
  end
end
```
Here, the code-reuse advantage is limited to inheriting methods x, x=, y, and y=, as well as using other methods in Point via super. Notice that in addition to overriding initialize, we used overriding for distFromOrigin and distFromOrigin2.

Computer scientists have been arguing for decades about whether this subclassing is good style. On the one hand, it does let us reuse quite a bit of code. On the other hand, one could argue that a ThreeDPoint is not conceptually a (two-dimensional) Point, so passing the former when some code expects the latter could be inappropriate. Others say a ThreeDPoint is a Point because you can “think of it” as its projection onto the plane where z equals 0. We will not resolve this legendary argument, but you should appreciate that often subclassing is bad/confusing style even if it lets you reuse some code in a superclass.

The argument against subclassing is made stronger if we have a method in Point like distance that takes another (object that behaves like a) Point and computes the distance between the argument and self. If ThreeDPoint wants to override this method with one that takes another (object that behaves like a) ThreeDPoint, then ThreeDPoint instances will not act like Point instances: their distance method will fail when passed an instance of Point.

More Interesting Overriding (Dynamic Dispatch) with Polar Points

The final subclass of Point we will define describes objects that behave equivalently to instances of Point (except for the arguments to initialize) but use an internal representation in terms of polar coordinates (radius and angle):

class PolarPoint < Point
  def initialize(r,theta)
    @r = r
    @theta = theta
  end
  def x
    @r * Math.cos(@theta)
  end
  def y
    @r * Math.sin(@theta)
  end
  def x= a
    b = y  # avoids multiple calls to y method
    @theta = Math.atan(b / a)
    @r = Math.sqrt(a*a + b*b)
    self
  end
  def y= b
    a = y  # avoid multiple calls to y method
  end
end
@theta = Math.atan(b / a)
@r = Math.sqrt(a*a + b*b)
self
end
def distFromOrigin
  @r
end
  # distFromOrigin2 already works!!
end

Notice instances of PolarPoint do not have instance variables @x and @y, but the class does override the x, x=, y, and y= methods so that clients cannot tell the implementation is different: they can use instances of Point and PolarPoint interchangeably. A similar example in Java would still have fields from the superclass, but would not use them. The advantage of PolarPoint over Point, which admittedly is for sake of example, is that distFromOrigin is simpler / more efficient.

The key point of this example is that the subclass does not override distFromOrigin2, but the inherited method works correctly. To see why, consider the definition in the superclass:

def distFromOrigin2
  Math.sqrt(x * x + y * y)
end

Unlike the definition of distFromOrigin, this method uses other method calls for the arguments to the multiplications. Recall this is just syntactic sugar for:

def distFromOrigin2
  Math.sqrt(self.x() * self.x() + self.y() * self.y())
end

In the superclass, this can seem like an unnecessary complication since self.x() is just a method that returns @x and methods of Point can access @x directly, as distFromOrigin does.

However, as you learned when you studied Java’s support for class-based OOP, overriding methods x and y in a subclass of Point changes how distFromOrigin2 behaves in instances of the subclass. Given a PolarPoint instance, its distFromOrigin2 method is defined with the code above, but when called, self.x and self.y will call the methods defined in PolarPoint, not the methods defined in Point.

This semantics goes by many names, including dynamic dispatch, late binding, and virtual method calls. There is nothing quite like it in functional programming, since the way self is treated in the environment is special, as the next lecture considers in more detail.