Overview

We’ve now covered:

- basics of functional and imperative programming (with semantics)
- basics of modular and OO programming (via Scala examples)

Today, finish discussion of “programming in the large”:

- some more advanced OO constructs
- and how they co-exist with/support functional programming in Scala
- list comprehensions as an extended example

Advanced constructs

- So far, we’ve covered the “basic” OOP model (circa Java 1.0), plus some Scala-isms
- Modern languages extend this model in several ways
- We can define a structure (class/object/trait) inside another:
  - As a member of the enclosing class (tied to a specific instance)
  - or as a static member (shared across all instances)
  - As a local definition inside a method
  - As an anonymous local definition
- Java (since 1.5) and Scala support “generics” (parameterized types as well as polymorphic functions)
- Some languages also support mixins (e.g. Scala traits)

Motivating inner class example

- A nested/inner class has access to the private/protected members of the containing class
- So, we can use nested classes to expose an interface associated with a specific object:

```scala
class List[A] {
  private A head;
  private List[A] tail;
  class ListIterator[A] implements Iterator[A] {
    // (can access head, tail)
  }
}
```
Classes/objects as members

- In Scala, classes and objects (and traits) can be nested arbitrarily

```
class A { object B { var x = 1 } }
scala> val a = new A
object C {class D { var x = 1 } }
scala> val d = new C.D
class E { class F { var x = 1 } }
scala> val e = new E
scala> val f = new e.F
```

Local classes

- A local class (Java terminology) is a class that is defined inside a method

```
def foo(): Int = {
  var z = 1
  class X { var x = z }
  z = 2
  return (new X).x
}
scala> foo()
res0: Int = 2
```

Anonymous classes/objects

- Given an interface or parent class, we can define an anonymous instance without giving it an explicit name
- In Java, called an anonymous local class
- In Scala, looks like this:

```
abstract class Foo { def foo() : Int }
val foo1 = new Foo { def foo() = 42 }
```

- We can also give a local name to the instance (useful since this may be shadowed)

```
val foo2 = new Foo { self =>
  val x = 42
  def foo() = self.x
}
```

Parameterized types

- As mentioned earlier, types can take parameters
- For example, List[A] has a type parameter A
- This is related to (but different from) polymorphism
  - A polymorphic function (like map) has a type that is parameterized by a given type.
  - A parameterized type (like List[_]) is a type constructor: for every type T, it constructs a type List[T].
Defining parameterized types

- In Scala, there are basically three ways to define parameterized types:
  - In a type abbreviation (NB: multiple parameters)
    ```scala
type Pair[A,B] = (A,B)
    ```
  - In a (abstract) class definition
    ```scala
    abstract class List[A]
    case class Cons[A](head: A, tail: List[A]) extends List[A]
    ```
  - In a trait definition
    ```scala
    trait Stack[A] { ...
    }
    ```

Using parameterized types inside a structure

- The type parameters of a structure are implicitly available to all components of the structure.
- Thus, in the List[A] class, map, flatMap, filter are declared as follows:
  ```scala
  abstract class List[A] {
    ...
    def map[B](f: A => B): List[B]
    def filter(p: A => Boolean): List[A]
    def flatMap[B](f: A => List[B]): List[B]
    // applies f to each element of this,
    // and concatenates results
  }
  ```

Parameterized types and subtyping

- By default, a type parameter is invariant
  - That is, neither covariant nor contravariant
- To indicate that a type parameter is covariant, we can prefix it with +
  ```scala
  abstract class List[+A] // see tutorial 6
  ```
- To indicate that a type parameter is contravariant, we can prefix it with -
  ```scala
  trait Fun[-A,+B] // see next few slides...
  ```
- Scala checks to make sure these variance annotations make sense!

Type bounds

- Type parameters can be given subtyping bounds
  ```scala
  type T <: C
  ```
  says that abstract type member T is constrained to be a subtype of C.
- This is checked for any module implementing I.
- Similarly, type parameters to function definitions, or class/trait definitions, can be bounded:
  ```scala
  fun f[A <: C](...) = ...
  class D[A <: C] { ...
  }
  ```
  Upper bounds A >: U are also possible...
Traits as mixins

- So far we have used Scala’s `trait` keyword for “interfaces” (which can include type members, unlike Java)
- However, traits are considerably more powerful:
  - Traits can contain fields
  - Traits can provide (“default”) method implementations
- This means traits provide a powerful form of modularity: *mixin composition*
  - Idea: a trait can specify extra fields and methods providing a “behavior”
  - Multiple traits can be “mixed in”, with fewer of the problems of multiple inheritance
- Java 8’s support for “default” methods in interfaces also allows a form of mixin composition.

Tastes great, and look at that shine!

- Shimmer is a floor wax!
  ```scala
  trait FloorWax { def clean(f: Floor) { ... } }
  ```
- No, it’s a delicious dessert topping!
  ```scala
  trait TastyDessertTopping {
    val calories = 1000
    def addTo(d: Dessert) { d.addCal(calories) }
  }
  ```
- In Scala, it can be both:
  ```scala
  object Shimmer extends FloorWax
  with TastyDessert { ... }
  ```

Pay no attention to the man behind the curtain...

- Scala bills itself as a “multi-paradigm” or “object-oriented, functional” language
- How do the “paradigms” actually fit together?
- Some features, such as case classes, are more obviously “object-oriented” versions of “functional” constructs
- Until now, we have pretended pairs, $\lambda$-abstractions, etc. are primitives in Scala
- They aren’t; and they need to be implemented in a way compatible with Java/JVM assumptions
  - But how do they really work?

Function types as interfaces

- Suppose we define the following interface:
  ```scala
  trait Fun[-A,+B] { // A contravariant, B covariant
def apply(x: A): B
  }
  ```
- This says: an object implementing `Fun[A,B]` has an apply method
- Note: This is basically the `Function` trait in the Scala standard library!
  - Scala translates $f(x)$ to `f.apply(x)`
  - Also, `{x: T => e}` is essentially syntactic sugar for
    ```scala
    new Function[Int,Int] {def apply(x:T) = e }
    ```
Iterators and collections in Java

- Java provides standard interfaces for *iterators* and *collections*

  ```java
  interface Iterator<E> {
      boolean hasNext()
      E next()
      ...
  }
  interface Collection<E> {
      Iterator<E> iterator()
      ...
  }
  ```

- These allow programming over different types of collections in a more abstract way than “indexed for loop”

Since Java 1.5, one can write the following:

```java
for(Element x : coll) {
    ... do stuff with x ...
}
```

Provided `coll` implements the `Collection<Element>` interface

- This is essentially syntactic sugar for:

  ```java
  for(Iterator<Element> i = coll.iterator();
      i.hasNext(); ) {
      Element x = i.next();
      ... do stuff with x ...
  }
  ```

foreach in Scala

- Scala has a similar `for` construct (with slightly different syntax)

  ```scala
  for (x <- coll) { ... do something with x ... }
  ```

- For example:

  ```scala
  scala> for (x <- List(1,2,3)) { println(x) }
  1
  2
  3
  ```

The construct `for (x <- coll) yield e` is syntactic sugar for:

```scala
coll.foreach{x => ... do something with x ...}
```

- If `x: T` and `coll` has method `foreach: (A => ()) => ()`
- Scala expands `for` loops before checking that `coll` actually provides `foreach` of appropriate type

If not, you get a somewhat mysterious error message...

```scala
scala> for (x <- 42) {println(x)}
<console>:11: error: value foreach is not a member of Int
  for (x <- 42) {println(x)}
  ^
```
Comprehensions: Mapping

- Scala (in common with Haskell, Python, C#, F# and others) supports a rich “comprehension syntax”
- Example:
  ```scala
  scala> for(x <- List("a","b","c")(yield (x + "z"))
  res0: List[Int] = List(az,bz,cz)
  ```
  This is shorthand for:
  ```scala
  List("a","b","c").map{x => x + "z"}
  ```
- (In fact, this works for any object implementing such a method.)

Comprehensions: Filtering

- Comprehensions can also include filters
  ```scala
  scala> for(x <- List("a","b","c");
  if (x != "b") yield (x + "z")
  res0: List[Int] = List(az,cz)
  ```
  This is shorthand for:
  ```scala
  List("a","b","c").filter{x => x != "b"}
  .map{x => x + "z"}
  ```

Comprehensions: Multiple Generators

- Comprehensions can also iterate over several lists
  ```scala
  scala> for(x <- List("a","b","c");
  y <- List("a","b","c");
  if (x != y) yield (x + y)
  res0: List[Int] = List(ab,ac,ba,bc,ca,cb)
  ```
  This is shorthand for:
  ```scala
  List("a","b","c").flatMap{x =>
  List("a","b","c").flatMap{y =>
  if (x != y) List(x + y) else {Nil}}}
  ```

Summary

- In the last few lectures we’ve covered
  - Modules and interfaces
  - Objects and classes
  - How they interact with subtyping, type abstraction
  - and how they can be used to implement “functional” features (particularly in Scala)
- This concludes our tour of “programming in the large”
- (though there is much more that could be said)
- Next time:
  - `small step` semantics
  - and type soundness