Elements of Programming Languages

Lecture 11: Object-oriented functional programming

James Cheney

University of Edinburgh

November 2, 2023
Overview

- We’ve now covered:
  - basics of functional 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:

```java
class List<A> {
    private A head;
    private List<A> tail;
    class ListIterator<A> implements Iterator<A> {
        ... (can access head, tail)
    }
}
```
In Scala, classes and objects (and traits) can be nested arbitrarily

class A { object B { val x = 1 } }
scala> val a = new A

object C {class D { val x = 1 } }
scala> val d = new C.D

class E { class F { val 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.

```scala
def foo(): Int = {
    val z = 1
    class X { val x = z + 1}
    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:

  ```scala
  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):

  ```scala
  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*
- For example, in an interface (that is, trait or abstract class) `I`:

```
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:

```
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”; most recent definition “wins” (avoiding some problems of multiple inheritance)
- Java 8’s support for “default” methods in interfaces also allows a form of mixin composition.
Tastes terrific, 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 TastyDessertTopping { ... }
```
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 are not primitives; 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 `new Function {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”
Iterators and foreach loops

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
```
foreach in Scala

- The construct `for (x <- coll) { 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
  member of Int
  ```
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> for(x <- List("a","b","c");
       if (x != "b") yield (x + "z")
res0: List[Int] = List(az,cz)
```

This is shorthand for:

```
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:
  - imperative programming