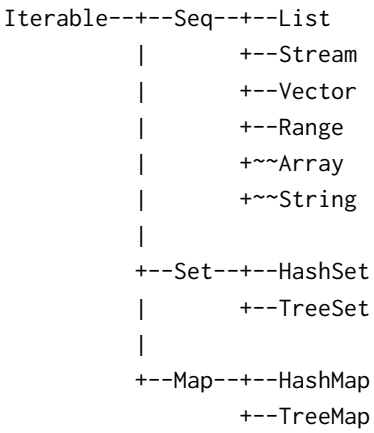
More On For-Expressions

Recap: Collections

Core classes



Recap: Collection Methods

Core methods:

- `map`
- `flatMap`
- `filter`

and also

- `foldLeft`
- `foldRight`

For-Expressions

Simplify combinations of core methods `map`, `flatMap`, `filter`.

Instead of:

```
(1 until n) flatMap (i =>
   (1 until i) map (j => (i, j))) filter ( pair =>
      isPrime(pair._1 + pair._2))
```

one can write:

```
   for {
     i <- 1 until n
     j <- 1 until i
     if isPrime(i + j)
   } yield (i, j)
```

Other Uses of For-Expressions

Operations of sets, or databases, or options.

Question: Are for-expressions tied to collections?

Answer: No! All that is required is some interpretation of `map`, `flatMap` and `withFilter`.

There are many domains outside collections that afford such an interpretation.

Tow examples: Random values and futures.

Random Values

You know about random numbers:

```
import java.util.Random
val rand = new Random
rand.nextInt
```

Question: What is a systematic way to get random values for other domains:

```
booleans
strings
pairs and tuples
lists
sets
```

?

Generators

Let's define a class `Generator[T]` that can generate random values of type `T`:

```
trait Generator[+T] {
  def generate: T
}
```

Some instances:

```
val integers = new Generator[Int] {
  def generate = scala.util.Random.nextInt()
}
val booleans = new Generator[Boolean] {
  def generate = integers.generate >= 0
}
val pairs = new Generator[(Int, Int)] {
  def generate = (integers.generate, integers.generate)
```

Streamlining It

Can we avoid the `new Generator ...` boilerplate?

Ideally, would like to write:

```
val pairs = for {
  x <- integers
  y <- integers
} yield (x, y)
```

Need `map` and `flatMap` for that!

Generator with Map and FlatMap

Here's a more convenient version of `Generator`:

```
trait Generator[+T] {
  self =>       // an alias for "this".

  def generate: T

  def flatMap[S](f: T => Generator[S]): Generator[S] = new Generator[S] {
    def generate = f(self.generate).generate
  }

  def map[S](f: T => S): Generator[S] = new Generator[S] {
    def generate = f(self.generate)
  }
}
```

Some Generators

```
implicit def integers: Generator[Int] = new Generator[Int] {
  def generate = scala.util.Random.nextInt()
}

implicit def choose(lo: Int, hi: Int): Generator[Int] = new Generator[Int] {
  def generate = scala.util.Random.nextInt(hi - lo) + lo
}

implicit def single[T](x: T): Generator[T] = new Generator[T] {
  def generate = x
}
```

More Generators

```
implicit def booleans: Generator[Boolean] = integers.map(_ >= 0)

implicit def pairs[T, U](implicit t: Generator[T], u: Generator[U]): Generator[(T, U)
  x <- t
  y <- u
} yield (x, y)
```

Application: Random Testing

You know about units tests:

- Come up with some some test inputs to program functions and a *postcondition*.
- The postcondition is a property if the expected result.
- Verify that the program satisfies the postcondition.

Question: Can we do without the test inputs?

Yes, by generating random test inputs

Random Test Function

Using generators, we can write a random test function:

```
def test[T](g: Generator[T], numTimes: Int = 100)
    (test: T => Boolean): Unit = {
  for (i <- 0 until numTimes) {
    val value = g.generate
    assert(test(value), "test failed for "+value)
  }
  println("passed "+numTimes+" tests")
}
```

Example usage:

```
test(lists[Int]) {(xs: List[Int]) =>
  xs.reverse == xs
}
```

ScalaCheck

Shift in viewpoint: Instead of writing tests, write *properties* that are assumed to hold.

This idea is implemented in the `ScalaCheck` tool.

It can be used either stand-alone or as part of ScalaTest.

See ScalaCheck tutorial on the course page.

Asynchronous Processing

Programs are often *asynchronous*: Several tasks, some results need waiting.

Examples:

- I/O
- Webservices
- Inter-process communication

Want to avoid blocking waits.

```
SlowService(request).get()
  // System hangs until SlowService has finished
```

Futures

A `Future` represents a value that will be computed in the future.

First version:

```
class Future[+T] {
  def get: T
}
```

If `SlowService` returns a future, we can now do something useful in the meantime:

```
val myFuture = MySlowService(request) // returns right away
...do other things...
val result = myFuture.get() // blocks until service "fills in" myFuture
```

Asynchronous Use of Futures

Problem: Once we call `get`, we still block!

Would like to use a *call-back*, be notified when future is ready.

Here's how this works:

```
val future = MySlowService(request)
future onSuccess { reply =>
  // when the future gets "filled", use its value
  println(reply)
}
```

This assumes an `onSuccess` operation in class `Future`:

```
def onSuccess[U](cont: T => U): U
```

Downside of Callbacks

Problem with too many callbacks: spaghetti-code.

Would like to write code like:

```
val user = getUserById(id)
val orders = getOrdersForUser(user.email)
val products = getProductsForOrders(orders)
val stock = getStockForProducts(products)
```

But have it work asynchronously out of the box.

Composition of Futures

We can do better with (you guessed it!) for expressions.

```
for {
  user <- getUserById(id)
  orders <- getOrdersForUser(user.email)
  products <- getProductsForOrders(orders)
  stock <- getStockForProducts(products)
} yield stock
```

To make this work, futures need `map` and `flatMap` operations.

Outline of Class Future

```
class Future[+T] { self =>
  def get: T
  def onSuccess[U](cont: T => U): U
  def map[U](f: T => U): Future[U] =
  def flatMap[U](f: T => Future[U]): Future[U]
}
```

Monads

Data structures with `map` and `flatMap` seem to be quite common.

In fact there's a name that describes this class of a data structures together with some algebraic laws that they should have.

They are called *monads*.

Monads are very popular in the Haskell programming language.