Futures

Asynchronous Programming in Scala

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Futures

- Futures are a lightweight parallelism API provided in the Scala core API

- While not without some niggles, they are ubiquitous and reliable, and hence widely used

Common Imports:

```scala
import scala.concurrent._
```

this brings in the main Futures API, including `Future` itself

```scala
import scala.concurrent.duration._
```

This brings a DSL for specifying times and timeout

```scala
import scala.concurrent.ExecutionContext.Implicits.global
```

When working with futures, an ExecutionContext is required (usually implicit) to provide thread pool configuration. `Implicits.global` is handy when you don't have another source.

Creating a Future

This is quite easy using the `Future` factory method

```
val futureInt = Future(1 + 1)
```

Can also use curlies for multi-line

```
val futureResult = Future {
  val a = someLongCalculation()
  val b = someOtherCalculation(a)
  b.refineResult()
}
```

If you already have results (or a failure) you can create success or failure immediately with

```
Future.successful(result)
// or
Future.failed(someException)
// also
Future.fromTry(Try(1 / 0))
```

Some Initial Rules

- Never block or Await in a future (this includes `Thread.sleep()`) - for testing or at the very top level you sometimes have to ignore this advice, but nowhere else!

- Try not to mix `ExecutionContexts` unless you know what you are doing

- Futures start executing immediately after they are created (do if you don't want this, make it lazy with a function)

- Scala futures are not cancellable (but if you run in the context of an actor system, you can terminate that)

Future States

(for demo purposes also I am allowed to use `Await` and `Thread.sleep()`)

```
val f1 = Future { Thread.sleep(1000); 10}

f1.value        // Option[scala.util.Try[Int]] = None
f1.isCompleted  // Boolean = false
// While None is in the value, the Future is not yet resolved either way

Thread.sleep(1000)  // force a pause to wait for the future to complete

f1.value        // Option[scala.util.Try[Int]] = Some(Success(10))
f1.isCompleted  // Boolean = true
// Completed successfully, type is whatever the Future block evaluated to

val f2 = Future { 1 / 0 }
Thread.sleep(10)  // micro pause
f2.value // Option[scala.util.Try[Int]] =
         // Some(Failure(java.lang.ArithmeticException: / by zero))
```

Composing Futures

Probably the single most useful thing about Futures is that they compose with `map` and `flatMap` while remaining asynchronous:

```scala
val f1 = Future { Thread.sleep(1000); 10}
val f2 = f1.map(_ * 10)

f1.value          // None
f1.isCompleted    // false
f2.value          // None
f2.isCompleted    // false

Thread.sleep(1000)

f1.value          // Some(Success(10))
f1.isCompleted    // true
f2.value          // Some(Success(100))
f2.isCompleted    // true
```

`flatMap` also works asynchronously. Combining with `for` expressions is even cooler

Futures with for

Let's say we have a simple expression like this

```scala
val a = 1
val b = 2
val c = 3
val s = "The answer is"

val sum = a + b + c
s"$s $sum"    // res11: String = The answer is 6
```

We can apply a simple re-writing pattern to make this fully async (and this trick always works)

```scala
val fRes = for {
  a <- fa   // where these are future results of a, b, c and s
  b <- fb
  c <- fc
  s <- fd
} yield {
  val sum = a + b + c   // the exact same code as before moved into yield
  s"$s $sum"
}
```

Async Evaluation

```scala
val fa = Future(1)
val fb = Future { Thread.sleep(1000); 2 }
val fc = Future(3)
val fd = Future { Thread.sleep(500); "The answer is"}

val fRes = for {
  a <- fa
  b <- fb
  c <- fc
  s <- fd
} yield {
  val sum = a + b + c
  s"$s $sum"
}

fRes.isCompleted      // false
fRes.value            // None

Thread.sleep(1000)
fRes.isCompleted      // true
fRes.value            // Some(Success(The answer is 6))
```

Forcing a Result

Using `for` and other combinators you can avoid blocking in almost all circumstances, but eventually you will need to get the answer. Use `Await.result` or `Await.ready` for this.

```
val success = Future( 2 / 1 )
val failure = Future( 1 / 0 )

Await.ready(failure, 1.second)

failure.value

failure.failed
```

`Await.ready` waits for the Future to be resolved one way or the other before continuing, but does not evaluate the result. If you used `Await.result` in this example, an Exception would be thrown at that point.

Other Future Operations

In addition to `map` and `flatMap` there are a number of other future operations:

```scala
val fa: Future[Any] = Future(10)
val fi = fa.collect {
  case i: Int => i
}

val ffi = fi.filter(_ > 11)

Await.ready(fi, 1.second)
Await.ready(ffi, 1.second)
```

```scala
ffi.transform(i => i * 5, {ex =>
  println(ex.getMessage)
  throw new RuntimeException("it failed to filter", ex)
})
```

More Operations

```scala
val f6 = Future(2)
val f7 = f6.andThen {  // for event side effects
  case Success(i) if i % 2 == 0 => println(s"it's even")
}

Await.result(f7, 1.second)  // It's even, Int: 2
```

```scala
f7.onComplete {
  case Success(i) => println(s"It worked, and the answer is $i")
  case Failure(ex) => println(s"It failed: ${ex.getMessage}")
}
```

```scala
f7.foreach(i => println(s"Got an $i"))  // simpler side effect for success
f7.failed.foreach(ex => println(ex.getMessage))  // and for failure
```

Recovering from Failures

```scala
val failedFuture = Future.failed(new RuntimeException("nah"))
failedFuture.fallbackTo(Future.successful(0))
```

or

```scala
val ff = Future.failed(new IllegalArgumentException("nope!"))

val fr = ff.recover {
  case _: IllegalArgumentException => 22
}
```

or

```scala
val ff2 = Future.failed(new IllegalStateException("Again, nope!"))
val fr2 = ff2.recoverWith {
  case _: IllegalArgumentException => Future.successful(22)
}
```

Dealing with Multiple Futures

```scala
val nums = List(1,2,3,4,5)
def square(i: Int): Future[Int] = Future(i * i)

val futs: List[Future[Int]] = nums.map(square)
val futList = Future.sequence(futs)
Await.ready(futList, 1.second)
// Future[List[Int]] = Future(Success(List(1, 4, 9, 16, 25)))

val futList2 = Future.traverse(nums)(square)
Await.ready(futList2, 1.second)
// Future[List[Int]] = Future(Success(List(1, 4, 9, 16, 25)))
```

A map over a Seq, followed by a `Future.sequence` can be replaced by a
`Future.traverse`

`Future.sequence` takes any `Seq[Future[T]]` and turns it into a `Future[Seq[T]]`
without blocking (also works for `Sets`)

Other Future Sequence Operations

```scala
val ft1 = Future { Thread.sleep(10); 10 }
val ft2 = Future { Thread.sleep(5); 5 }
val ft3 = Future { Thread.sleep(20); 20 }
val sft = List(ft1, ft2, ft3)
Await.ready(Future.firstCompletedOf(sft), 1.second)   // Future(Success(5))

Await.ready(Future.foldLeft(sft)(0)(_ + _), 1.second) // Future(Success(35))

Await.ready(Future.reduceLeft(sft)(_ + _), 1.second)  // Future(Success(35))
```

Promises

A promise is the "server" to the "client's" Future

By creating a Promise you create a socket into which you can send something

You can also obtain the Future from the Promise and hand that to someone else

When you put the value (or failure) into the Promise, the Future is resolved with that outcome

```scala
val promise = Promise[Int]
val future = promise.future

future.isCompleted  // false
future.value        // None

promise.success(10) // fulfill the promise

future.isCompleted  // true
future.value        // Some(Success(10))
```

A Broken Promise

```scala
val promise2 = Promise[Int]
val future2 = promise2.future

promise2.failure(new IllegalStateException("oops"))

future2.isCompleted  // true
future2.value        // Some(Failed(IllegalStateException: oops))
```

A Promise allows you to easily adapt another asynchronous event into a Scala
Future

Working with Java's Futures

For Java's `CompletableFutures`, there is already an adapter

```scala
import java.util.concurrent.CompletableFuture
import java.util.function.Supplier

val supp = new Supplier[Int] {
  def get: Int = {
    Thread.sleep(500)
    10
  }
}
val cf = CompletableFuture.supplyAsync(supp)
```

```scala
import scala.compat.java8.FutureConverters._

val sf2 = cf.toScala

Await.result(sf2, 1.second)    // Int: 10
```

Future Patterns - Batching

```scala
def calc(i: Int): Future[Int] = Future {
  println(s"Calculating for $i")
  Thread.sleep(500)
  i * i
}

def processSeq(xs: Vector[Int]): Future[Vector[Int]] = {
  val allFutures: Vector[Future[Int]] = xs.map(calc)
  Future.sequence(allFutures)
}
```

- Scala's Execution Context will prevent too many threads running at once

- But you can still overwhelm other resources, or run out of memory, etc.

- Need a way to batch up Futures into groups

Future Batching - foldLeft and flatMap

Combining `foldLeft` and `flatMap` makes this fairly easy

```scala
def processSeqBatch(xs: Vector[Int], batchSize: Int): Future[Vector[Int]] = {
  val batches = xs.grouped(batchSize)
  val start = Future.successful(Vector.empty[Int])
  batches.foldLeft(start) {(accF, batch) =>
    for {
      acc <- accF
      batchRes <- processSeq(batch)
    } yield acc ++ batchRes
  }
}

val nums = (1 to 20).toVector

val f = processSeq(nums)
Await.result(f, 20.seconds)  // starts all 20 at once

val f2 = processSeqBatch(nums, 2)
Await.result(f2, 20.seconds) // waits for each 2 to finish before starting next
```

Future Patterns - Retrying

An example failing call that eventually succeeds:

```scala
import scala.util.Try

var time = 0
def resetTries(): Unit = time = 0

def calc(): Int = {
  if (time > 3) 10 else {
    time += 1
    throw new IllegalStateException("not yet")
  }
}

Try(calc())   // fail
Try(calc())   // fail
Try(calc())   // fail
Try(calc())   // fail
Try(calc())   // success(10)

resetTries() // back to not working
```

Retrying Futures (naive)

```scala
def fCalc(): Future[Int] = Future(calc())

val f2 = fCalc().
  recoverWith { case NonFatal(_) => fCalc() }.
  recoverWith { case NonFatal(_) => fCalc() }.
  recoverWith { case NonFatal(_) => fCalc() }.
  recoverWith { case NonFatal(_) => fCalc() }

Await.ready(f2, 10.seconds)  // success(10)
```

But this is clunky, we can do better

Retrying Futures (loop)

```scala
def retry[T](op: => T, retries: Int): Future[T] =
  Future(op) recoverWith {
      case NonFatal(_) if retries > 0 => retry(op, retries - 1)
  }

resetTries()

val f3 = retry(calc(), 3)
Await.ready(f3, 10.seconds)  // failure

resetTries()

val f4 = retry(calc(), 5)
Await.ready(f4, 10.seconds)  // success
```

Retrying with Back-off

```scala
val timer = new Timer("retrying", true)

def after[T](duration: FiniteDuration)(op: () => Future[T])(
    implicit ec: ExecutionContext): Future[T] = {
  val promise = Promise[Future[T]]
  val futureHandle = promise.future
  val task = new TimerTask {
    override def run(): Unit = {
      ec.execute(() => promise.success(op()))
    }
  }
  timer.schedule(task, duration.toMillis)
  futureHandle.flatten
}

def retryBackoff[T](op: => T, backoffs: Seq[FiniteDuration])(
    implicit ec: ExecutionContext): Future[T] =
  Future(op) recoverWith {
    case NonFatal(_) if backoffs.nonEmpty =>
      after(backoffs.head)(() => retryBackoff(op, backoffs.tail))
  }
```

Retrying with Back-off part 2

```scala
var time = 0

def calc(): Int = {
  if (time > 3) 10 else {
    time += 1
    println("Not yet!")
    throw new IllegalStateException("not yet")
  }
}

val f5 = retryBackoff(calc(),
    Seq(500.millis, 500.millis, 1.second, 1.second, 2.seconds))
println(Await.ready(f5, 10.seconds))
```

Alternatives to Futures

- The Scala Futures API is well tested, ubiquitous and performant

- If you do need more, you may want to check out a `Task` implementation like those provided by [Monix](#) or [FS2](#)

- If you need even more control, see the later section on Functors, Monads and Applicative Functors

- But at the end of the day, `Future` does 99% of what you need and is always there, and usually the underlying implementation of all these others.