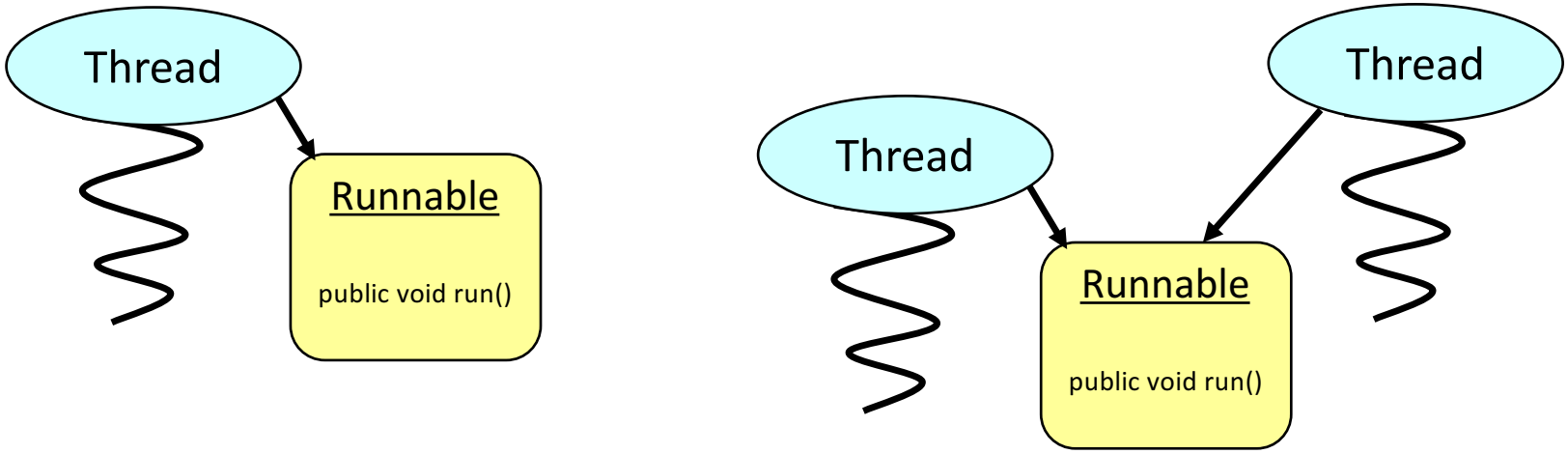
Concurrent and Asynchronous Programming in Scala

JVM Threading: Threads and Runnable Objects

- Thread encapsulates a schedulable entity
- Runnable interface used to represent work for thread to do
- Scala provides access to these "primitive" features



JVM Threading: Threads and Runnable Objects

- Easy to use basic JVM threading from Scala

```
class TickTock ( val word: String, val delay: Int ) extends Runnable  {
  override def run = {
    while ( !Thread.interrupted ) {
      try {
        print(s"$word ")
        Thread.sleep(delay)
      } catch {
        case ie: InterruptedException => {
          println("Interrupted: shutting down");
          Thread.currentThread.interrupt
        }
      }
    }
  }
}
```

JVM Threading: Threads and Runnable Objects

- Two instances of the task executed in separate threads

```
object TickTock extends App {

  val t1 = new Thread(new TickTock("tick", 500))
  val t2 = new Thread(new TickTock("tock", 750))

  t1.start
  t2.start

  Thread.sleep(5000)

  t1.interrupt
  t2.interrupt
}
```

```
tock tick tick tock tick tock tick tick tock … Interrupted: shutting down
Interrupted: shutting down
```

JVM Threading: Threads and Runnable Objects

- Executor framework simplifies execution

```
object TickTockExecutor extends App {

  import java.util.concurrent._

  val ticker = new TickTock("tick", 500)
  val tocker = new TickTock("tock", 750)

  val engine = Executors.newFixedThreadPool(2)
  engine.execute(ticker)
  engine.execute(tocker)

  Thread.sleep(5000)
  engine.shutdownNow
}
```

```
tock tick tick tock tick tock tick tick tock …Interrupted: shutting down
Interrupted: shutting down
```

Problems

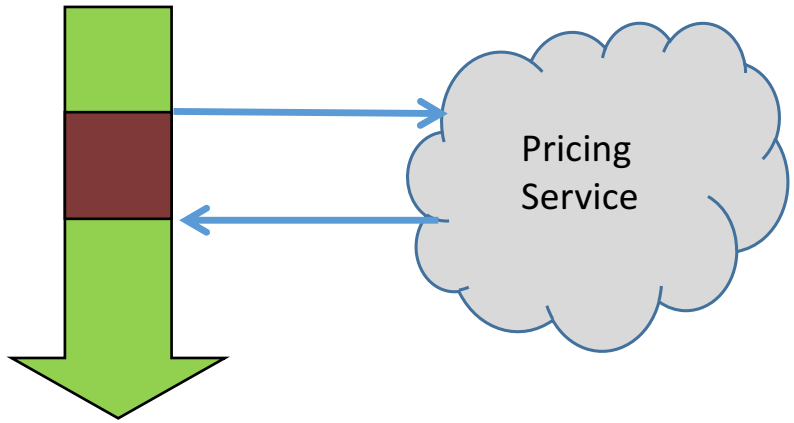
- Limited capabilities
  - run method returns Unit
  - often want task to return a value
- Scalability is limited
  - threads relatively heavyweight objects
  - limited number can be supported in VM
- Shared state difficult to protect
  - locks/synchronized blocks
  - introduces complexity to code
  - difficult to debug or reason about
  - blocking threads wastes resources

Asynchronous Programming

- A different approach
  - "do something" while calling thread continues
  - hand back a result when finished

- Higher level of abstraction

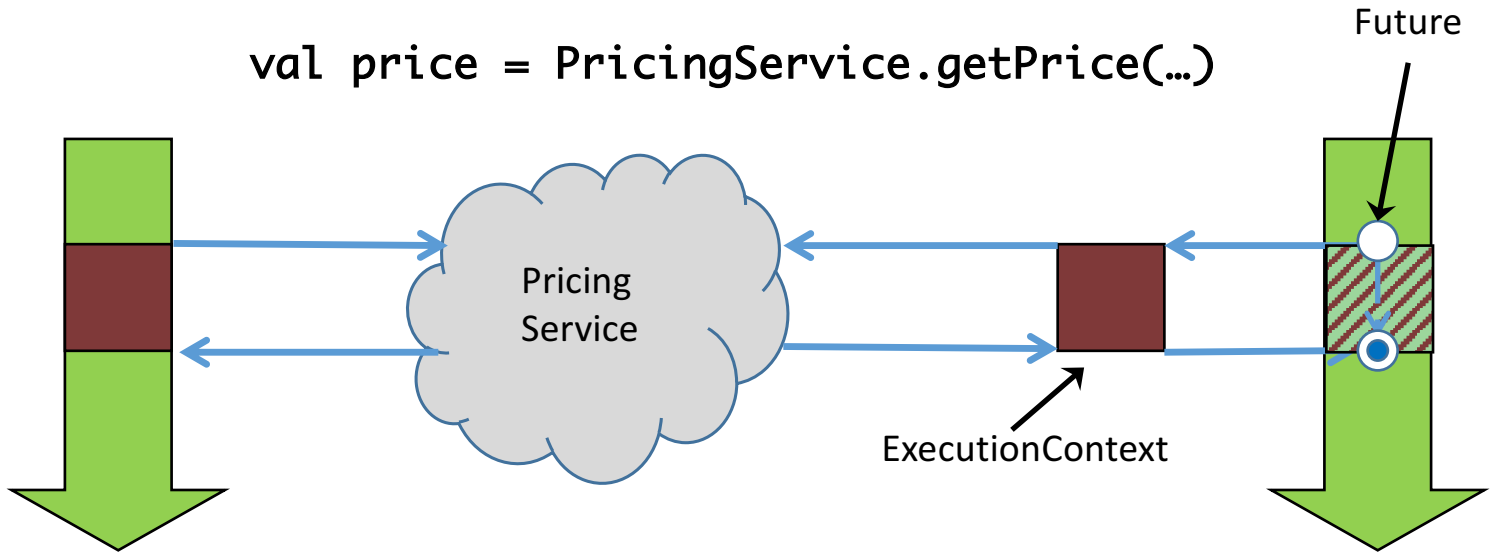
```
val price = PricingService.getPrice(…)
```



Asynchronous Programming

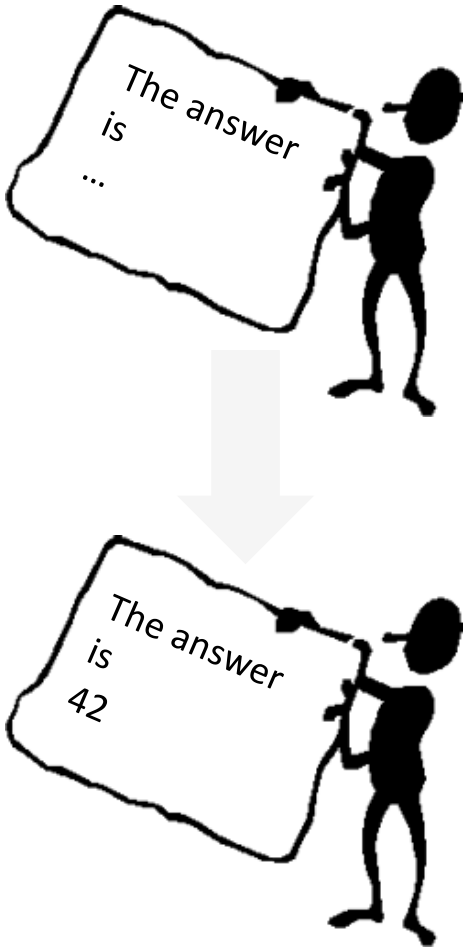
- A different approach
  - "do something" while calling thread continues
  - hand back a result when finished

- Higher level of abstraction



Futures

- Placeholder representing a value that will be available
  - at some time in the future
- Common idea in asynchronous programming
- Implementations available in different languages
  - Java
  - Scala
  - …



Futures

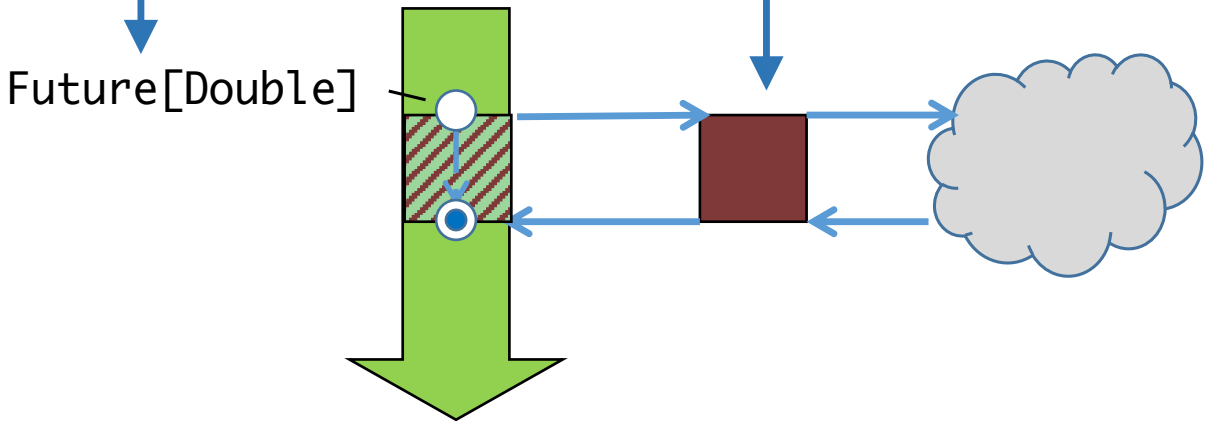
- Service with asynchronous interface

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

object PricingService {
  val prices: Map[String, Double] = Map (
    "GOOG" -> 733.20,
    "AAPL" -> 112.0,
    "MSFT" -> 35.33
  )
  def priceForSym( sym: String ): Future[Double] = Future {
    Thread.sleep(2000)
    prices(sym)
  }
}
```

Futures

- Using the service

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

val fPrice = PricingService.priceForSym("AAPL")
```



Futures – Completion

- Two possibilities
  - operation succeeds and result returned
  - operation fails and Throwable object returned
- Use callbacks for each case

```
val pf = PricingService.priceForSym( … )

…

pf onSuccess {
  case p: Double => println(f"The price is $p%.4f")
}

pf onFailure {
  case ex: Throwable => println(s"There was a problem: $ex")
}
```

```
The price is 500.1000
```

```
There was a problem: java.util.NoSuchElementException: key not found: IBM
```

Futures – Completion

- Unified callback handling both success and failure
  - function passed object of type `Try[T]`

```
…
import scala.util.{Success,Failure}
…
pf onComplete {
  case Success(p: Double) => println(f"Price: $p%.4f")
  case Failure(ex) => println(s"Failed: $ex")
}
…
```

Futures – Completion

- Future type provides foreach method
  - Asynchronously invokes supplied function to process future value once it becomes available

```
scala> PricingService.priceForSym("AAPL")
     |                .foreach ( p => println(s"Price for AAPL: $p") )

scala> Price for AAPL: 112.0
```

Working with Futures

- Possible to block for a Future[T]
  - not advised unless unavoidable
- Await.result(*future*, *duration*)
  - return value of *future* on success
  - throw exception if completion fails
  - throw timeout exception if *duration* expires
- Await.ready(*future*, *duration*)
  - return *future* object
  - throw timeout exception if *duration* expires

```
import scala.concurrent.duration._
…
val pf = Future { PricingService.priceForSym("AAPL") }
val price = Await.result(pf, 2 seconds)
println(f"Waited for result: $price%.4f")
```

Working with Futures

- Future[T] is a monadic type
- Higher order functions available
  - map, filter, flatMap, …
  - Build pipelines of processing on Futures
  - Allow sophisticated concurrency behaviour to be specified

```
def strategy ( price: Double ): String = {
  val profit = price - 400.0
  if ( profit > 100.0 ) "sell" else "hold"
}
val action = PricingService.priceForSym( "GOOG" )
                           .map ( strategy(_) )

action foreach {
   println(a => println(s"Action for GOOG: $a")
}
```

Action for GOOG: sell

Working with Futures

- Future[T] is a monadic type
- Higher order functions available
  - map, filter, flatMap, …
  - Build pipelines of processing on Futures

```
def asStrategy ( price: Double ): Future[String] = {
  Future {
    val profit = price - 100.0
    if ( profit > 100.0 ) "sell" else "hold"
  }
}
val action = PricingService.priceForSym("AAPL")
                           .flatMap ( asStrategy(_) )

pf foreach {
  println(a => println(s"Action for GOOG: $a")
}
```

Action for GOOG: sell

Working with Futures

- Use with for comprehension
- Based on translation to flatMap/map

```
scala> val action = for (
     |   price <- PricingService.priceForSym("GOOG");
     |   act <- asStrategy(price)
     | ) yield act

actionforeach {
  println(a => println(s"Action for GOOG: $a")
}
```

Action for GOOG: sell

Working with Futures

- Future[T] may not complete successfully
- Use onFailure callback to deal with failure case
    - or onComplete

```
…
val action = PricingService.priceForSym("XXX").flatMap( asStrategy(_) )

action onComplete {
        case Success(action: String) =>
                        println(s"Success: $action")
        case Failure(ex) =>
                        println(s"Failed: $ex")
}
```

```
Failed: java.util.NoSuchElementException: key not found: XXX
```

A Word About for Comprehension

- Remember that for comprehension translates to calls to flatMap
- Based on sequencing of computation
- Even if computations are asynchronous, they will be sequenced

```
val answer = for (
  a <- Future { Thread.sleep(2000); scala.util.Random.nextInt(100) };
  b <- Future { Thread.sleep(1000); scala.util.Random.nextInt(100) };
  c <- Future { Thread.sleep(3000); scala.util.Random.nextInt(100) }
) yield ( a + b + c )

answer foreach ( println(_))
141
```

A Word About for Comprehension

- If the steps do not depend on each other then they should be executed concurrently
- Start Futures before the for comprehension

```
val first  = Future { Thread.sleep(5000);  scala.util.Random.nextInt(100) }
val second = Future { Thread.sleep(10000); scala.util.Random.nextInt(100) }
val third  = Future { Thread.sleep(4000);  scala.util.Random.nextInt(100) }

val sum = for (
            a <- first;
            b <- second;
            c <- third
          ) yield ( a + b + c )

sum foreach ( println(_) )
143
```

Filter and Future[T]

- filter works as for other container types
  - If predicate is true, Future completes successfully
  - If predicate is false, Future fails with NoSuchElementException

```
scala> val f = Future { r.nextInt(100) } filter( _ % 2 == 0 )

scala> f onComplete {
     |   case Success(i)  => println(s"$i")
     |   case Failure(e)  => println(s"$e")
     | }
76
```

```
scala> val f = Future { r.nextInt(100) } filter( _ % 2 == 0 )

scala> f onComplete {
     |   case Success(i)  => println(s"$i")
     |   case Failure(e)  => println(s"$e")
     | }
java.util.NoSuchElementException: Future.filter predicate is not satisfied
```

Zip and Future[T]

- zip combines two containers (collections) into a single container of tuples
  - Combine two Futures into a single Future of tuple
  - Completes when both Futures have completed

```
scala> val a = Future { Thread.sleep(10000); scala.util.Random.nextInt(100) }
a: scala.concurrent.Future[Int] = List()

scala> val combined = a zip Future { Thread.sleep(4000); 100 }
combined: scala.concurrent.Future[(Int, Nothing)] = List()

scala> combined onComplete {
     |   case Success(t) => println(t)
     |   case Failure(e) => println(e)
     | }
(65,100)
```

Zip and Future[T]

- zip combines two containers (collections) into a single container of tuples
    - If one of the Futures does not complete successfully, the combined Future fails with the exception

```
scala> val a = Future { Thread.sleep(10000); scala.util.Random.nextInt(100) }
a: scala.concurrent.Future[Int] = List()

scala> val combined = a zip Future { Thread.sleep(4000);
                                     throw new RuntimeException("oops") }
combined: scala.concurrent.Future[(Int, Nothing)] = List()

scala> combined onComplete {
     |   case Success(t) => println(t)
     |   case Failure(e) => println(e)
     | }
java.lang.RuntimeException: oops
```

Sequence and Future[T]

- sequence is a common monad transformer

  `List [ M[_] ] => M [ List[_] ]`

- Transform List of Monads into Monad of List

```
val a = Future { Thread.sleep(5000); scala.util.Random.nextInt(100) }
val b = Future { Thread.sleep(10000); scala.util.Random.nextInt(100) }
val c = Future { Thread.sleep(4000); scala.util.Random.nextInt(100) }

scala> val lf = List ( a, b, c )
fl: List[scala.concurrent.Future[Int]] = List(List(), List(), List())

scala> val fl = Future.sequence(fl)
fl: scala.concurrent.Future[List[Int]] = List()

scala> fl foreach ( println(_) )
List(28, 67, 24)
```

Traverse and Future[T]

- Traverse is another common monad transformer
- Transform a List of A into a Monad of List of B
    - Applying function A => M[B] to each element

```
scala> val timeList = List( 5, 9, 4 )
timeList: List[Int] = List(5, 9, 4)

scala> val fl = Future.traverse(timeList)
                              ( t => Future { Thread.sleep( t * 1000 );
                                              scala.util.Random.nextInt(100) } )
fl: scala.concurrent.Future[List[Int]] = List()

scala> fl foreach ( println(_) )
List(23, 64, 75)
```

Working with a Sequence of Future[T]

- Future.firstCompletedOf(List[Future[_]])
  - Return a "Future" that completes when the first Future in the list completes

```
scala> val l = List( Future{Thread.sleep(7000);  1},
                     Future{Thread.sleep(6000);  2},
                     Future{Thread.sleep(10000); 3} )
l: List[scala.concurrent.Future[Int]] = List(List(), List(), List())

scala> Future.firstCompletedOf(l) onComplete {
     |   case Success(i) => println(i)
     |   case Failure(e) => println(e)
     | }
2
```

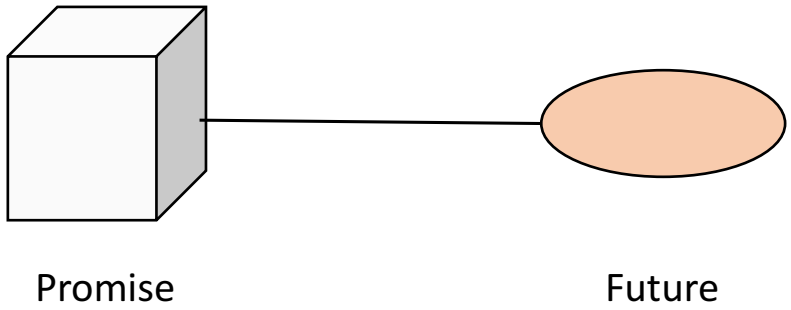
Future[T] Timeout Without Blocking

- Future.firstCompletedOf can be used to implement a basic timeout capability for Future
  - Without using the blocking Await… calls

```
scala> val lf = List ( Future{ Thread.sleep(5000); throw timeOutEx },
     |                 Future{ Thread.sleep(7000); "Success"} )
lf: List[scala.concurrent.Future[String]] = List(List(), List())

scala> val ff = Future.firstCompletedOf(lf)
ff: scala.concurrent.Future[String] = List()

scala> ff onComplete {
     |   case Success(i) => println(i)
     |   case Failure(e) => println(e)
     | }
java.lang.RuntimeException: Out of time
```

Promises

- Future is a read-only value
  - Value written from another context
- Promise used to represent write side
  - Connected to a Future
  - Strictly "write once"



Promises

```
…
val vow = promise[Int]

val p1 = vow.future
val p2 = vow.future    // Returns same Future as for p1

p1 onComplete {
  case Success(v)  => println(s"p1 got $v")
  case Failure(ex) => println(s"p1 failed with $ex")
}

p2 onComplete {
  case Success(v)  => println(s"p2 got $v")
  case Failure(ex) => println(s"p2 failed with $ex")
}

Thread.sleep(1000)
vow success 42

// vow failure new ArithmeticException
```

p1 got 42
p2 got 42

Alternative Approach to Timeout

- Previous example relied on async operation that included Thread.sleep()
  - Not recommended approach
  - Blocks thread, prevents execution context scheduling other work
- Alternative approach can use explicit Promise completion
  - Define a single Promise and obtain a future from this Promise
  - Utilise "external" scheduler to fire a timeout event, which completes the with a Failure (a timeout exception)
  - Arrange for successful completion when the main task completes successfully
  - This will be completely non-blocking

Alternative Approach to Timeout

- Code for timeout via Promise completion

```
val timeoutScheduler = Executors.newScheduledThreadPool(1)
val p = Promise[String]()
val rf = p.future
val timeoutAction = new Runnable {
                                      def run = p tryFailure timeoutException
                                    }

p tryCompleteWith Future { longRunningTask }
timeoutScheduler.schedule( timeoutAction, 8000, TimeUnit.MILLISECONDS )

rf onComplete {
  case Success(s) => println(s)
  case Failure(e) => println(s"Error: $e")
}
```

Finished

```
val longRunningTask = { Thread.sleep(5000); "Finished" }
```