Concepts and Technologies for Distributed Systems and Big Data Processing

Futures, Actors, and Streams

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Programming a Concurrent World

- How to compose programs handling
  - ***asynchronous events?***
  - ***streams*** of asynchronous events?
  - ***distributed*** events?

➠ Programming abstractions for concurrency!

Overview

- Futures, promises
- Async/await
- Actors

Why a Growable Language for Concurrency?

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Which one is going to "win"?

Background

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    - Scala Actors (2006)
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Other proposals and research projects:

- Scala Joins (2008)
- FlowPools (2012)
- Spores (safer closures)
- Capabilities and uniqueness
- ...

Scala Primer

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- Methods: **`def`** `meth(x: T, y: S): R = { .. }`

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- Methods: `def meth(x: T, y: S): R = { .. }`
- Classes: `class C extends D { .. }`

Scala Primer (2)

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  - `case class Person(name: String, age: Int)`

Scala Primer (2)

- Generics:
  - `class C[T] { var fld: T = _ ; .. }`
  - `def convert[T](obj: T): Result = ..`
- Pattern matching:
  - `case class Person(name: String, age: Int)`
  - ```
    val isAdult =
          p match { case Person(_, a) => a >= 18
                    case Alien(_, _) => false }
    ```
    ```

Example

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    - Send HTTP request containing JSON

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```
import scala.util.parsing.json._

def convert[T](obj: T): Future[JSONType]
def sendReq(json: JSONType): Future[JSONType]
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Example

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Ousterhout et al. *Making sense of performance in data analytics frameworks.* NSDI '15

Callbacks

- How to respond to ***asynchronous completion event?***

➟ Register callback

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➟ Register callback

```
val person = Person("Tim", 25)

val fut: Future[JSONType] = convert(person)

fut.foreach { json =>
  val resp: Future[JSONType] = sendReq(json)
  ..
}
```

Exceptions

- Serialization to JSON may fail at runtime
    - Closure passed to `foreach` not executed in this case
    - How to handle asynchronous exceptions?

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```
val fut: Future[JSONType] = convert(person)

fut.onComplete {
  case Success(json) =>
    val resp: Future[JSONType] = sendReq(json)
  case Failure(e) =>
    e.printStackTrace()
}
```

Partial Functions

```
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  case Success(json) => ..
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```scala
{
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… creates an instance of PartialFunction[T, R]:

```scala
val pf: PartialFunction[Try[JSONType], Any] = {
  case Success(json) => ..
  case Failure(e) => ..
}
```

Type of Partial Functions

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```
abstract class Function1[A, B] {
  def apply(x: A): B
  ..
}

abstract class PartialFunction[A, B] extends Function1[A, B] {
  def isDefinedAt(x: A): Boolean
  def orElse[A1 <: A, B1 >: B]
        (that: PartialFunction[A1, B1]): PartialFunction[A1, B1]
  ..
}
```

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Simplified!

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}
```

Success and Failure

```
package scala.util

abstract class Try[+T]

case class Success[+T](v: T) extends Try[T]

case class Failure[+T](e: Throwable) extends Try[T]
```

Nested Exceptions

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```
val fut: Future[JSONType] = convert(person)

fut.onComplete {
  case Success(json) =>
    val resp: Future[JSONType] = sendReq(json)
    resp.onComplete {
      case Success(jsonResp) => .. // happy path
      case Failure(e1) =>
        e1.printStackTrace(); ???
    }
  case Failure(e2) =>
    e2.printStackTrace(); ???
}
```

Failed Futures

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Encapsulates failure

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```
abstract class Future[+T] extends Awaitable[T] {

  def map[S](f: T => S)(implicit ..): Future[S]

  // ..
}
```

Future Composition

```
val fut: Future[JSONType] = convert(person)

val processed = fut.map { json =>
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Encapsulates *all failures*

Problem: `processed` has type `Future[Future[T]]`

Future Pipelining

```
val fut: Future[JSONType] = convert(person)

val processed = fut.flatMap { json =>
  val resp: Future[JSONType] = sendReq(json)
  resp.map { jsonResp =>
    .. // happy path
  }
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```

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Future pipelining: the result of the inner future (result of `map`) determines the result of the outer future (`processed`)

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```
def flatMap[S](f: T => Future[S])(implicit ..): Future[S]
```

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object Future {

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“Code block” with result type T

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Singleton object

“Unrelated” to the singleton object!

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val firstGoodDeal = Future {
  usedCars.find(car => isGoodDeal(car))
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Type inference:

```
val firstGoodDeal = Future.apply[Option[Car]]({
  usedCars.find(car => isGoodDeal(car))
})
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Futures: Example

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Creating Futures: Operationally

- Invoking the shown factory method creates a ***task object*** encapsulating the computation
- The task object is ***scheduled for execution*** by an execution context
- An execution context is an object capable of executing tasks, typically using a ***thread pool***
- Future tasks are submitted to the current ***implicit execution context***

```
def apply[T](body: => T)(implicit
              executor: ExecutionContext): Future[T]
```

Implicit Execution Contexts

Implicit parameter requires selecting a execution context

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```
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Type in expressions to have them evaluated.
Type :help for more information.

scala> import scala.concurrent._
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```

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But...

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an (implicit ec: ExecutionContext) parameter to your method
or import scala.concurrent.ExecutionContext.Implicits.global.
       val fut = Future { 40 + 2 }
                        ^
```

Promise

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Main purpose: create futures for non-lexically-scoped asynchronous code

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Function for creating a Future that is completed with ***value*** after ***delay*** milliseconds

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Example

Function for creating a Future that is completed with ***value*** after ***delay*** milliseconds

```
def after[T](delay: Long, value: T): Future[T]
```

“after”, Version 1

```
def after1[T](delay: Long, value: T) =
  Future {
    Thread.sleep(delay)
    value
  }
```

“after”, Version 1

How does it behave?

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```
assert(Runtime.getRuntime()
              .availableProcessors() == 8)

for (_ <- 1 to 8) yield
  after1(1000, true)

val later = after1(1000, true)
```

“after”, Version 1

How does it behave?

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assert(Runtime.getRuntime()
                  .availableProcessors() == 8)

for (_ <- 1 to 8) yield
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Quiz: when is “later” completed?

“after”, Version 1

How does it behave?

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assert(Runtime.getRuntime()
              .availableProcessors() == 8)

for (_ <- 1 to 8) yield
  after1(1000, true)

val later = after1(1000, true)
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Quiz: when is “later” completed?

Answer: after either ~1 s or ~2 s (most often)

Promise

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object Promise {
  def apply[T](): Promise[T]
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Promise

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object Promise {
  def apply[T](): Promise[T]
}
```

```
trait Promise[T] {
  def success(value: T): Promise[T]
  def failure(cause: Throwable): Promise[T]

  def future: Future[T]
}
```

“after”, Version 2

```
def after2[T](delay: Long, value: T) = {
  val promise = Promise[T]()

  timer.schedule(new TimerTask {
    def run(): Unit = promise.success(value)
  }, delay)

  promise.future
}
```

“after”, Version 2

```
def after2[T](delay: Long, value: T) = {
  val promise = Promise[T]()

  timer.schedule(new TimerTask {
    def run(): Unit = promise.success(value)
  }, delay)

  promise.future
}
```

Much better behaved!

What is Async?

- Scala module
  - `"org.scala-lang.modules" %% "scala-async"`
- Purpose: ***simplify programming with futures***
- Scala Improvement Proposal SIP-22
- Releases for Scala 2.10 and 2.11

What Async Provides

- Future and Promise provide ***types*** and operations for managing ***data flow***
  - Very little support for control flow
- Async complements Future and Promise with constructs to manage ***control flow***

Programming Model

Basis: ***suspendible computations***

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- `async { .. }` — ***delimit*** suspendible computation

Programming Model

Basis: ***suspendible computations***

- `async { .. }` — ***delimit*** suspendible computation
- `await(future)` — ***suspend*** computation until `future` is completed

Async

Async

```
object Async {

  def async[T](body: => T): Future[T]

  def await[T](future: Future[T]): T

}
```

Example

```
val fstGoodDeal: Future[Option[Car]] = ..
val sndGoodDeal: Future[Option[Car]] = ..

val goodCar = async {
  val car1 = await(fstGoodDeal).get
  val car2 = await(sndGoodDeal).get
  if (car1.price < car2.price) car1
  else car2
}
```

Futures vs. Async

- "Futures and Async: When to Use Which?", Scala Days 2014, Berlin
  - Video: https://www.parleys.com/tutorial/futures-async-when-use-which

Async in Other Languages

Constructs similar to async/await are found in a number of widely-used languages:

- C#
- Dart (Google)
- Hack (Facebook)
- ECMAScript 7 [1]

[1] http://tc39.github.io/ecmascript-asyncawait/

From Futures to Actors

- Limitations of futures:
  - At most one completion event per future
  - Overhead when creating many futures
- How to model distributed systems?

The Actor Model

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- ***Model of concurrent computation*** whose universal primitive is the “actor” [Hewitt et al. ’73]

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Related to ***active objects***

The Actor Model

- ***Model of concurrent computatio*** the "actor" [Hewitt et al. '73]

Related to *active objects*

- Actors = concurrent "processes" communicating via asynchronous messages
- Upon reception of a message, an actor may
  - change its behavior/state
  - send messages to actors (including itself)
  - create new actors

The Actor Model

- ***Model of concurrent computatio*** the "actor" [Hewitt et al. '73]

Related to *active objects*

- Actors = concurrent "processes" communicating via asynchronous messages
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- Fair scheduling

The Actor Model

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  - send messages to actors (including itself)
  - create new actors
- Fair scheduling
- Decoupling: message sender cannot fail due to receiver

Example

```
class ActorWithTasks(tasks: ...) extends Actor {
  ...

  def receive = {
    case TaskFor(workers) =>
      val from = sender

      val requests = (tasks zip workers).map {
        case (task, worker) => worker ? task
      }

      val allDone = Future.sequence(requests)

      allDone andThen { seq =>
        from ! seq.mkString(",")
      }
  }
}
```

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Using ***Akka*** (http://akka.io/)

Anatomy of an Actor (1)

- An actor is an active object with its own behavior
- Actor behavior defined by:
    - subclassing `Actor`
    - implementing `def receive`

```
class ActorWithTasks(tasks: List[Task]) extends Actor {
  def receive = {
    case TaskFor(workers) =>  // send `tasks` to `workers`
    case Stop             =>  // stop `self`
  }
}
```

Anatomy of an Actor (2)

- Exchanged messages should be ***immutable***
  - And ***serializable***, to enable remote messaging
- Message types should implement ***structural equality***
- In Scala: ***case classes*** and ***case objects***
  - Enables pattern matching on the receiver side

```
case class  TaskFor(workers: List[ActorRef])
case object Stop
```

Anatomy of an Actor (3)

- Actors are ***isolated***
  - Strong encapsulation of state
- Requires restricting ***access*** and ***creation***
- Separate Actor instance and ActorRef
  - ActorRef public, safe interface to actor

```
val system = ActorSystem("test-system")
val actor1: ActorRef = system.actorOf[ActorWithTasks]

actor1 ! TaskFor(List())  // async message send
```

Why Actors?

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- Asynchronous message handling ➠ less risk of deadlocks

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“Macro-step semantics”

- “Share nothing”: strong isola race conditions
- Actors handle at most one message at a time ➟ sequential reasoning
- Asynchronous message handling ➟ less risk of deadlocks
- No “inversion of control”: access to own state and messages in safe, direct way

Why Actors? (cont'd)

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Reason 2: actors model reality of distributed systems

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Why Actors? (cont’d)

Reason 2: actors model reality of distributed systems

- Message sends truly asynchronous
- Message reception not guaranteed
- Non-deterministic message ordering
    - Some implementations preserve message ordering between ***pairs*** of actors

Therefore, actors well-suited as a foundation for distributed systems

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- Concurrency benefits from ***growable languages***
- ***Futures and promises*** a versatile abstraction for single, asynchronous events
  - Supported by ***async/await***
- ***The actor model*** faithfully models distributed systems