



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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 - Futures, promises
 - Join-calculus
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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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 - Function type: `T => S` or `(T, S) => U`

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- Classes: **class** C **extends** D { .. }

Scala Primer (2)

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- 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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 - Convert object to JSON
 - Send HTTP request containing JSON

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import scala.util.parsing.json._  
  
def convert[T](obj: T): Future[JSOType]  
def sendReq(json: JSOType): Future[JSOType]
```

Example

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Example

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 - Convert object to JSON
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import scala.util.parsing.json._  
  
def convert[T](obj: T): Future[JSONType]  
def sendReq(json: JSONType): Future[JSONType]
```

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

Callbacks

- How to respond to ***asynchronous completion event?***
 - ⇒ Register callback

Callbacks

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⇒ Register callback

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

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

fut.foreach { json =>
  val resp: Future[JSOType] = 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

```
{  
  case Success(json) => ..  
  case Failure(e)   => ..  
}
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{  
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}
```

... creates an instance of `PartialFunction[T, R]`:

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

Type of Partial Functions

- Partial functions have a type `PartialFunction[A, B]`
- `PartialFunction[A, B]` is a subtype of `Function1[A, B]`

Type of Partial Functions

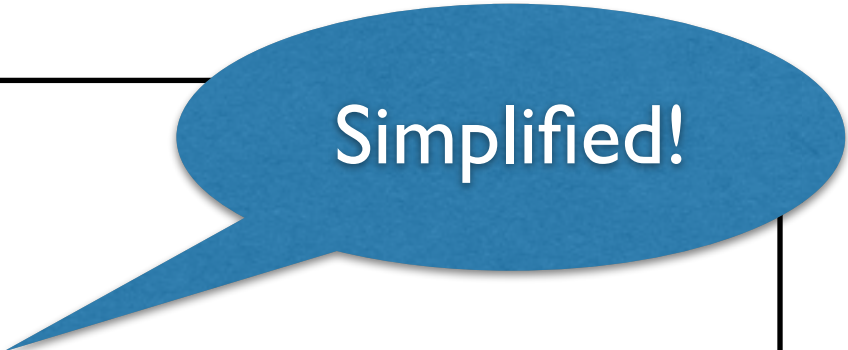
- Partial functions have a type `PartialFunction[A, B]`
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```
abstract class Function1[A, B] {  
  def apply(x: A): B  
  ..  
}  
  
abstract class PartialFunction[A, B] extends Function1[A, B] {  
  def isDefinedAt(x: A): Boolean  
  def orElse[A1 <: A, B1 >: B]  
    (that: PartialFunction[A1, B1]): PartialFunction[A1, B1]  
  ..  
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  ..  
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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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```
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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(); ???
}
```

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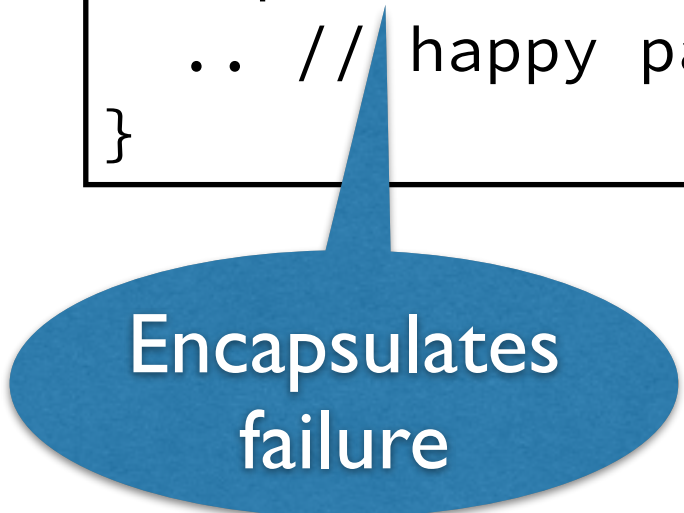
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Encapsulates
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```
abstract class Future[+T] extends Awaitable[T] {  
    def map[S](f: T => S)(implicit ..): Future[S]  
  
    // ..  
}
```

Future Composition

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

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

Future Pipelining

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

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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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Singleton object

“Unrelated”
to the singleton
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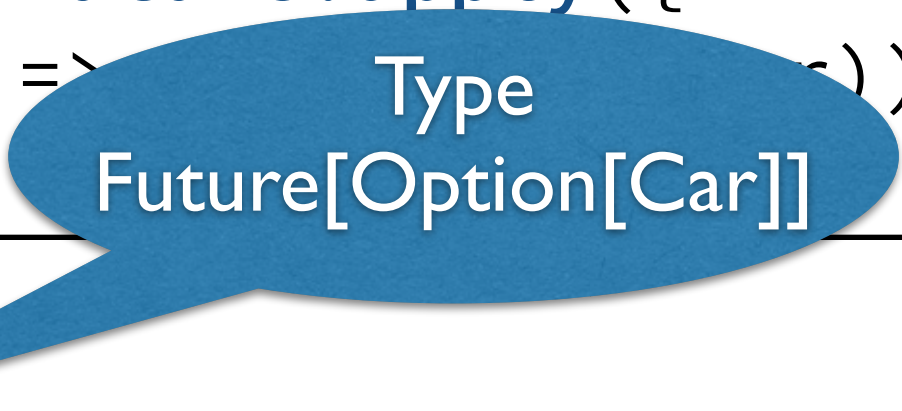
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val firstGoodDeal = Future.apply[Option[Car]]({  
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Creating Futures: Operationally

- 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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Type in expressions to have them evaluated.  
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scala> import scala.concurrent._  
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scala> val fut = Future { 40 + 2 }
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                      ^
```

Promise

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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?

"after", Version 1

How does it behave?

```
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)  
  
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Quiz: when is "later" completed?

"after", Version 1

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for (_ <- 1 to 8) yield  
  after1(1000, true)  
  
val later = after1(1000, true)
```

Quiz: when is "later" completed?

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

Promise

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

```
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?

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- 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
```

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“Macro-step semantics”

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- Asynchronous message handling \Rightarrow less risk of deadlocks



“Macro-step semantics”

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Reason 1: simplified concurrency

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



“Macro-step semantics”

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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