Functional Programming in Scala

Chapter 4
Handling errors without exceptions

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Handling errors without exceptions

- Pure functions are like mathematical functions: $f(x)$
  - Always returns the same single result
  - Produces no side effects in the outside world
- Throwing exceptions is a side effect, breaks referential transparency

Handling errors without exceptions

Key ideas:

- Use container type to expand codomain (range) of functions
- Return errors as values
- Use higher-order functions to
  - consolidate of error handling logic
  - preserve composability
  - “lift” normal functions to error handling functions

Handling errors without exceptions

The good and bad aspects of exceptions

Possible alternatives to exceptions

The Option data type

- Usage patterns for Option - the Option functor
- Option composition and lifting - the monad laws
- Wrapping exception-oriented APIs

The Either data type

Exercises

Summary

Throwing exceptions breaks referential transparency

```scala
def failingFn(i: Int): Int = {
  val y: Int = throw new Exception("fail!")
  try {
    val x = 42 + 5
    x + y
  }
  catch { case e: Exception => 43 }
}

scala> failingFn(12)
java.lang.Exception: fail!

def failingFn2(i: Int): Int = {
  try {
    val x = 42 + 5
    x + ((throw new Exception("fail!")): Int)
  }
  catch { case e: Exception => 43 }
}

scala> failingFn2(12)
res1: Int = 43
```

The bad aspects of exceptions

- Exceptions break the substitution model of reasoning
  - `throw new Exception("fail")` is context-dependent, taking on different meanings depending on which block it's in
- Exceptions can't be described in the type system
  - Does `f: Int => Int` always return? Might it fail? What exceptions might it throw? Who knows!
  - Java checked exceptions don't work with higher-order functions

The good aspects of exceptions

- Consolidate, centralize error-handling logic
- Error info (messages, stack traces, memory dumps)
- Exception subclasses
- Functions don’t have to handle callee errors

Problem: Procedures aren't always total

- Total function: always has an output (like a mathematical function)
- Partial function: output undefined for some inputs
  - `mean: List[Double] => Double`
  - `sqrt: Double => Double`
  - (Not to be confused with partially applied functions)
- Pure functions must be total
- Need strategy for turning partial function into total function

Option 1 - Return bogus value in error case

- Return a sentinel value, or `NaN`, or `null`
- Can't attach extra information to errors
- Must manually check result at call sites / before uses of value
- No applicable in polymorphic code
- Requires special calling convention
- Not easy to compose
- Not easy to pass to higher-order functions

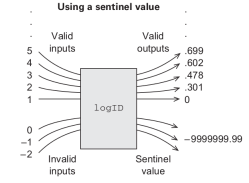
Option 2 - Return integer error codes

- Like assembly, C, Unix programs, etc.
- Not compatible with type system
- Plus all the bad things about Option 1
    - Especially bugs with not correctly error checking at call sites
    - `kill(fork())` bug - http://rachelbythebay.com/w/2014/08/19/fork/

Option 3 - Caller-provided default values

```scala
def mean(xs: IndexedSeq[Double], onEmpty: Double): Double =
  if (xs.isEmpty) onEmpty
  else xs.sum / xs.length
```

- Limited to passing / returning `Double`
- Parameter can only be used as a default value
- In error cases, can't branch or abort
- Immediate callers must decide default value



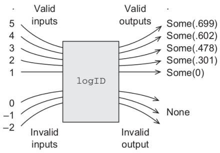
logID: Double => Double

Mapping all invalid inputs to a special value of the same type as the valid outputs. Ambiguous, and compiler can't check that caller handles it correctly.

Option 4 - The Option data type

```scala
sealed trait Option[+A]
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```

Using the Option type



`logID: Double => Option[Double]`

Every valid output is wrapped in Some. Invalid inputs are mapped to None. The compiler forces the caller to deal explicitly with the possibility of failure.

```scala
def mean(xs: Seq[Double]): Option[Double] =
  if (xs.isEmpty) None
  else Some(xs.sum / xs.length)
```

`mean` is now total

None is not null!

```scala
sealed trait Option[+A]
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```

- There is no such thing as a “generic” None
  - $\texttt{None} \notin \texttt{A}$
  - Can’t return None from function that returns an A
- Every usage of None must be assigned to a specific type
  - $\texttt{None:Option[A]} \neq \texttt{None:Option[B]}$,
    $\texttt{None:Option[A]} \notin \texttt{Option[B]}$
- Type system prevents null pointer dereference

`Option` as a container

```
sealed trait Option[+A]
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```

Think of `Option[A]` as a `List[A]` with length ≤ 1

- `None:Option[A]` $\approx$ `Nil:List[A]`
- `Some(a:A)` $\approx$ `List(a:A)`

Usage patterns for Option

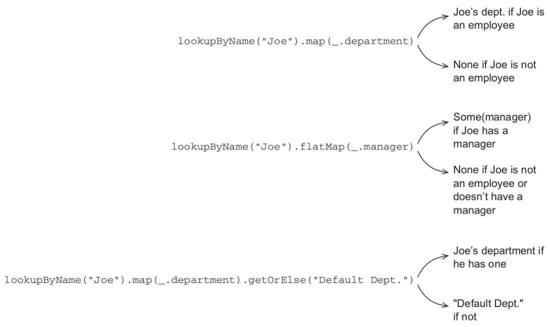
```scala
sealed trait Option[+A] {
  // Apply f if the Option is not None.
  def map[B](f: A => B): Option[B]

  // The B >: A says that the B type parameter must be
  // a supertype of A.
  def getOrElse[B>:A](default: => B): B

  // Apply f, which may fail, to the Option if not None.
  def flatMap[B](f: A => Option[B]): Option[B]

  // ‘ob: => Option[B]‘ means don’t evaluate ob unless needed.
  // The argument is non-strict / evaulated lazily
  // (just like if-else short-circuiting) - see chapter 5!
  def orElse[B>:A](ob: => Option[B]): Option[B]

  // Convert Some to None if the value doesn’t satisfy f.
  def filter(f: A => Boolean): Option[A]
}
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```

Exercise 4.1

```scala
sealed trait Option[+A] {
  def map[B](f: A => B): Option[B] = this match {
    case None => None
    case Some(a) => Some(f(a))
  }

  def getOrElse[B>:A](default: => B): B = this match {
    case None => default
    case Some(a) => a
  }

  def flatMap[B](f: A => Option[B]): Option[B] =
    map(f) getOrElse None

  def orElse[B>:A](ob: => Option[B]): Option[B]
    map(Some(_)) getOrElse ob

  def filter(f: A => Boolean): Option[A] = {
    flatMap(a => if (f(a)) Some(a) else None)
  }
}
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```

Usage scenarios for Option

```scala
sealed trait Option[+A] {
  def map[B](f: A => B): Option[B]
  def getOrElse[B>:A](default: => B): B
  def flatMap[B](f: A => Option[B]): Option[B]
  def orElse[B>:A](ob: => Option[B]): Option[B]
  def filter(f: A => Boolean): Option[A]
}
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```



```scala
lookupByName("Joe").map(_.department)
```

Joe's dept. if Joe is an employee

None if Joe is not an employee

```scala
lookupByName("Joe").flatMap(_.manager)
```

Some(manager) if Joe has a manager

None if Joe is not an employee or doesn't have a manager

```scala
lookupByName("Joe").map(_.department).getOrElse("Default Dept.")
```

Joe's department if he has one

"Default Dept." if not

Usage patterns for Option

```scala
sealed trait Option[+A] {
  def map[B](f: A => B): Option[B]
  def getOrElse[B>:A](default: => B): B
  def flatMap[B](f: A => Option[B]): Option[B]
  def orElse[B>:A](ob: => Option[B]): Option[B]
  def filter(f: A => Boolean): Option[A]
}
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```

1. Some initial computation `f:  A => Option[B]` may fail
2. Apply further computations with `map`, `flatMap`
   - Subsequent computations only run when there is still a value
   - In error cases, `None` is carried through the computations
3. Optionally `filter` on predicates to generate error
4. Do error handling at end with `getOrElse` or `orElse`
   - `getOrElse` provides default value
   - `OrElse` provides new chain of computations to try

Language Comparison

Scala:

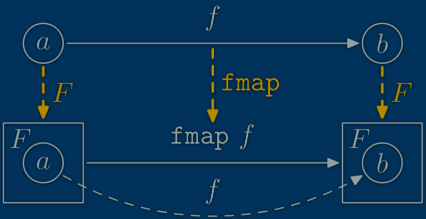
```scala
val dept: String =
  lookupByName("Joe").   // Impossible to forget None check.
  flatMap(_.dept).       // Type system does not allow you to.
  filter(_ != "Accounting").
  getOrElse("Default Dept")
```

Python:

```python
employee = lookupByName("Joe")
# If you forget this line
if employee is not None:
  # this will raise AttributeError.
  department = employee.dept
  if (department is not None) and (department != "Accounting"):
    dept = department
```

The Option functor

```scala
sealed trait Option[+A] {
  def map[B](f: A => B): Option[B]
  def flatMap[B](f: A => Option[B]): Option[B]
}
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```



Summary