The Seductions of Scala

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<*shameless-plug*/>

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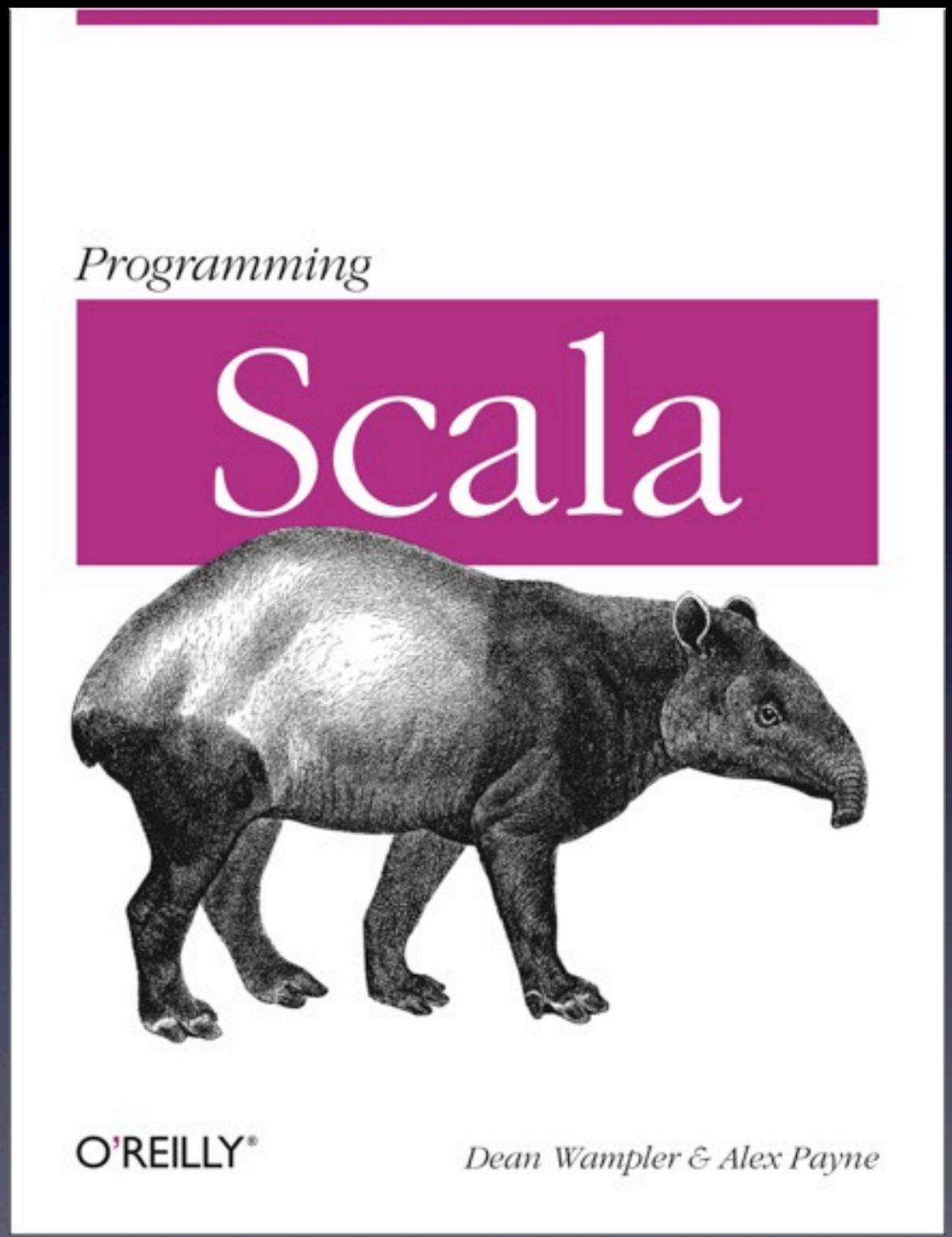

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Why do we *need* a *new* language?

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I picked Scala to learn in 2007 because I wanted to learn a functional language. Scala appealed because it runs on the JVM and interoperates with Java. In the end, I was seduced by its power and flexibility.

#1

We need

Functional

Programming

• • •

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First reason, we need the benefits of FP.

... for *concurrency*.

... for *concise* code.

... for *correctness*.

#2
We need a better
Object Model

• • •

... for *composability*.

... for *scalable designs*.

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Java's object model (and to a lesser extent, C#'s) has significant limitations.

Scala's *Thesis:* Functional Prog. *Complements* Object-Oriented Prog.

Despite surface contradictions...

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We think of objects as mutable and methods as state-modifying, while FP emphasizes immutability, which reduces bugs and often simplifies code. Objects don't have to be mutable!

But we want to
keep our *investment*
in *Java/C#*.

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We rarely have the luxury of starting from scratch...

Scala is...

- A *JVM* and *.NET* language.
- *Functional* and *object oriented*.
- *Statically* typed.
- An *improved* Java/C#.

Martin Odersky

- Helped design java *generics*.
- Co-wrote *GJ* that became *javac* (v1.3+).
- Understands Computer Science *and* Industry.

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Odersky is the creator of Scala. He's a prof. at EPFL in Switzerland. Many others have contributed to it, mostly his grad. students.
GJ had generics, but they were disabled in javac until v1.5.

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Not all objects are functions, but they can be...

Objects as *Functions*

```
class Logger(val level:Level) {

  def apply(message: String) = {
    // pass to logger system
    log(level, message)
  }
}
```


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A simple wrapper around your favorite logging library (e.g., Log4J).

makes "level" a field

```
class Logger(val level:Level) {

  def apply(message: String) = {
    // pass to logger system
    log(level, message)
  }
}
```

method

class body is the "primary" constructor

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Note how variables are declared, "name: Type".

```
class Logger(val level:Level) {

 def apply(message: String) = {
  // pass to logger system
  log(level, message)
 }
}

val error = new Logger(ERROR)

…
error(“Network error.”)
```


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After creating an instance of Logger, in this case for Error logging, we can “pretend” the object is a function!

```
class Logger(val level:Level) {

  def apply(message: String) = {
    // pass to logger system
    log(level, message)
  }
}

…
error("Network error.")
```

apply is called

"function object"

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Adding a parameterized arg. list after an object causes the compiler to invoke the object's "apply" method.

Put an arg list after any object, *apply* is called.

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This is how any object can be a function, if it has an apply method. Note that the signature of the argument list must match the arguments specified. Remember, this is a statically-typed language!

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While an object can be a function, every “bare” function is actually an object, both because this is part of the “theme” of scala’s unification of OOP and FP, but practically, because the JVM requires everything to be an object!

Int, Double, etc.

are true *objects*.

But they are compiled to primitives.

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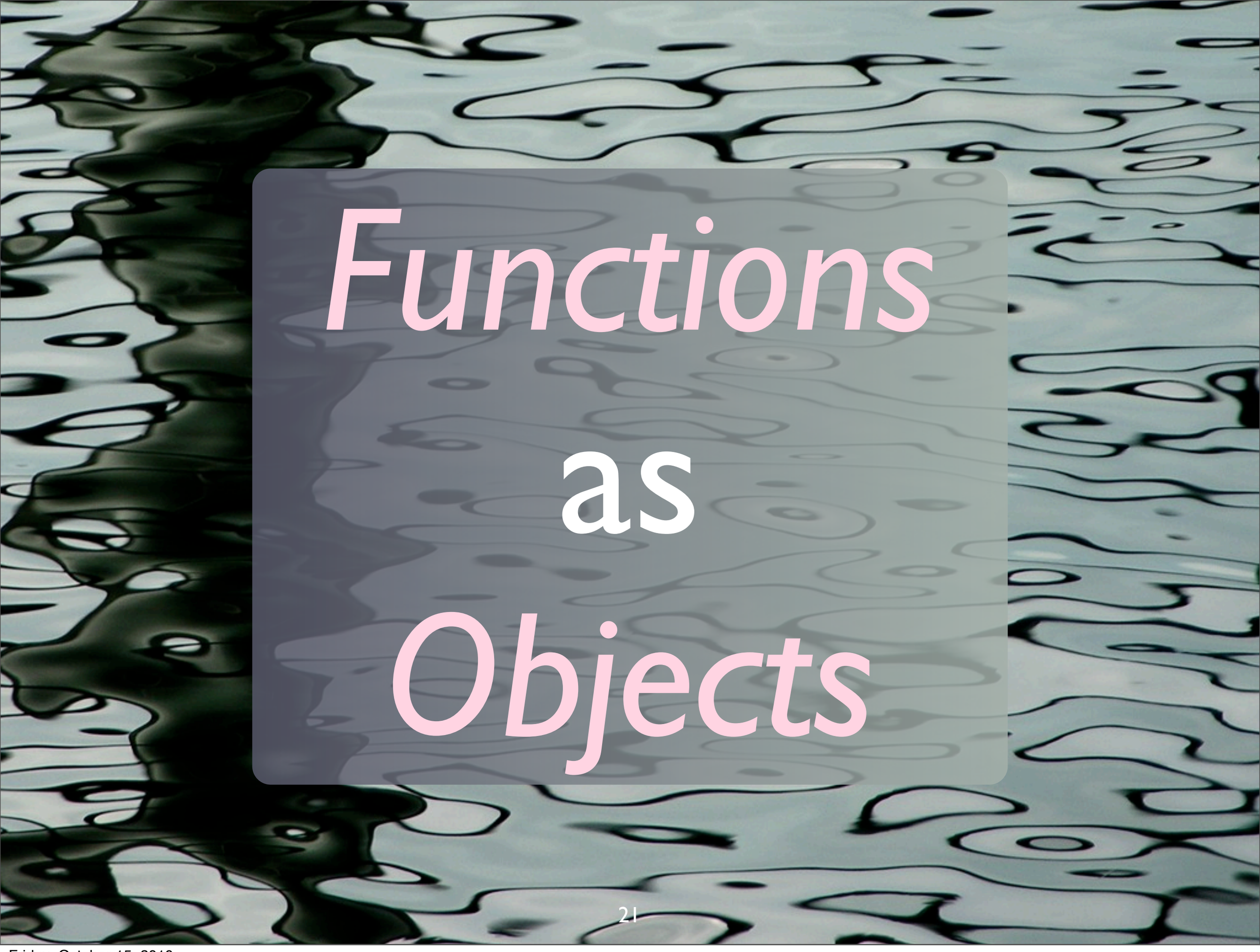
There isn't an object-primitive divide, at the source level, in Scala, but it optimizes to primitives to avoid boxing, where it can.

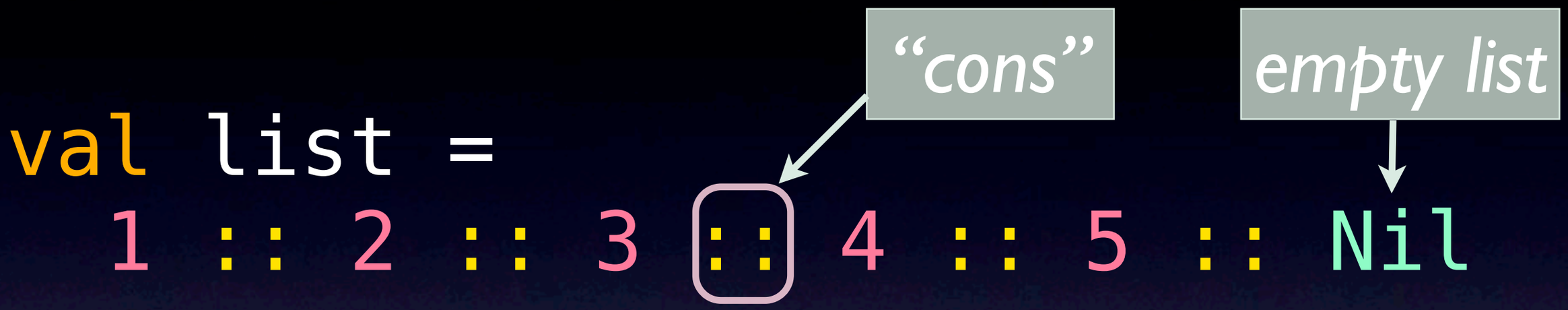

Functions
as
Objects

First, About Lists

```
val list = List(1, 2, 3, 4, 5)
```

The same as this "list literal" syntax:

```
val list =
  1 :: 2 :: 3 :: 4 :: 5 :: Nil
```



Any method ending in ":" binds to the right!

```
val list = Nil.::(5).::(4).::(
 3).::(2).::(1)
```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We build up a literal list with the "::" cons operator to prepend elements, starting with an empty list, the Nil "object". "::" binds to the right, so the second form shown is equivalent to the first. Note the "infix operator notation"; x.m(y) ==> x m y

Infix Operator Notation

```
"hello" + "world"
```

is actually just

```
"hello".+("world")
```


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Note the “infix operator notation”; x.m(y) ==> x m y. It’s not just a special case backed into the language grammar (like Java’s special case for string addition). Rather, it’s a general feature of the language you can use for your classes.

Oh, and Maps

```
val map = Map(
  “name” -> “Dean”,
  “age”  -> 39)
```


Maps also have a literal syntax, which should look familiar to you Ruby programmers ;) Is this a special case in the language grammar?

Oh, and Maps

```
val map = Map(
  “name” -> “Dean”,
  “age”  -> 39)
```

“baked” into the language grammar?

No, just method calls...

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Scala provides mechanisms to define convenient “operators” as methods, without special exceptions baked into the grammer (e.g., strings and “+” in Java).

Oh, and Maps

```
val map = Map(
  “name” -> “Dean”,
  “age”  -> 39)
```

What we like to write:

```
val map = Map(
  Tuple2(“name”, “Dean”),
  Tuple2(“age”,  39))
```

What Map() wants:

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We won’t discuss implicit conversions here, due to time....

Oh, and Maps

```
val map = Map(
  “name” -> “Dean”,
  “age”  -> 39)
```

What we like to write:

```
val map = Map(
  (“name”, “Dean”),
  (“age”,  39))
```

What Map() wants:

More succinct syntax for Tuples

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We won’t discuss implicit conversions here, due to time....

Oh, and Maps

```
val map = Map(
  “name” -> “Dean”,
  “age”  -> 39)
```

An “implicit conversion” converts a string to a type that has the -> method.

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We won’t discuss implicit conversions here, due to time....

Implicit Conversions

```
class ArrowAssoc[T1](t:T1) {
  def -> [T2](t2:T2) =
    new Tuple2(t1, t2)
}
```

```
implicit def
toArrowAssoc[T](t:T) =
   new ArrowAssoc(t)
```


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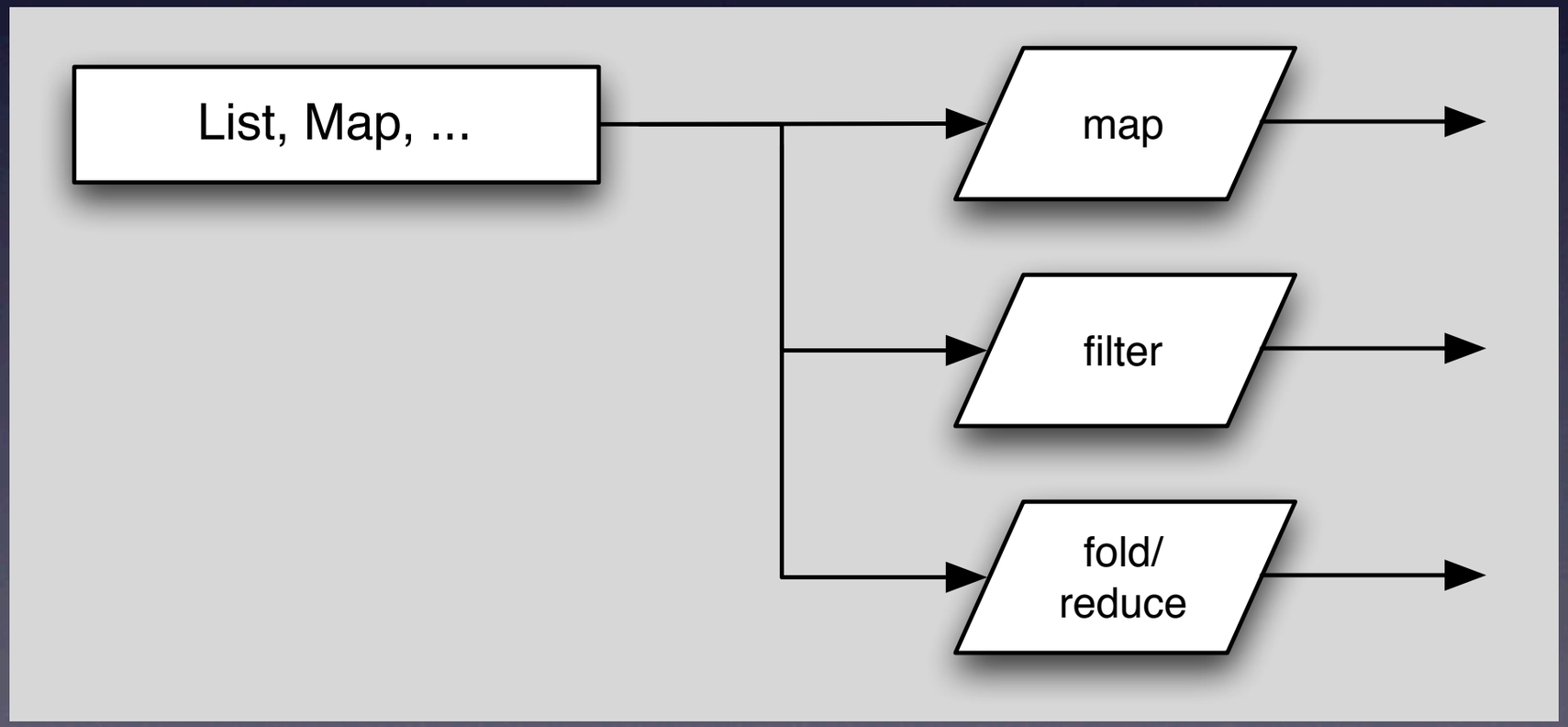
We won't discuss implicit conversions here, due to time....

Classic Operations on *Functional Data Types*



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Collections like List and Map have a set of common operations that can be used on them.

Back to *functions* as *objects*...

```
val list = “a” :: “b” :: Nil

list map {
  s => s.toUpperCase
}
```

```
// => "A" :: "B" :: Nil
```


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Let’s map a list of strings with lower-case letters to a corresponding list of uppercase strings.

map called on list

map argument list

"function literal"

```
list map {
  s => s.toUpperCase
}
```

function argument list

function body

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Note that the function literal is just the "s => s.toUpperCase". The {…} are used like parentheses around the argument to map, so we get a block-like syntax.

```
list map {
  s => s.toUpperCase
}
```

```
list map {
  (s:String) => s.toUpperCase
}
```

Explicit type

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We've used type inference, but here's how we could be more explicit about the argument list to the function literal.

So far,
we've used
type inference
a lot...

How the Sausage Is Made

Parameterized type

```
class List[A] {
  …
  def map[B](f: A => B): List[B]
  …
}
```

Declaration of map

The function argument

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Here's the declaration of List's map method (lots of details omitted…). Scala uses [...] for parameterized types, so you can use "<" and ">" for method names!

How the Sausage Is Made

like an "abstract" class

```
trait Function1[-A,+R]
  extends AnyRef {
  def apply(a:A): R
  ...
}
```

No method body:
=> abstract

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We look at the actual implementation of Function1 (or any FunctionN). Note that the scaladocs have links to the actual source listings.
(We're omitting some details…) The trait declares an abstract method "apply" (i.e., it doesn't also *define* the method.)
Traits are a special kind of abstract class/interface definition, that promote "mixin composition". (We won't have time to discuss…)

What the Compiler Does

```
(s:String) => s.toUpperCase
```

What you write.

```
new Function1[String,String] {
  def apply(s:String) = {
    s.toUpperCase
  }
}
```

No "return" needed

What the compiler generates

An anonymous class

You use the function literal syntax and the compiler instantiates an anonymous class using the corresponding FunctionN trait, with a concrete definition of apply provided by your function literal.

```
val list = “a” :: “b” :: Nil

list map {
  s => s.toUpperCase
}
```

Can use {…} instead of (…)

Function “object”

```
// => "A" :: "B" :: Nil
```


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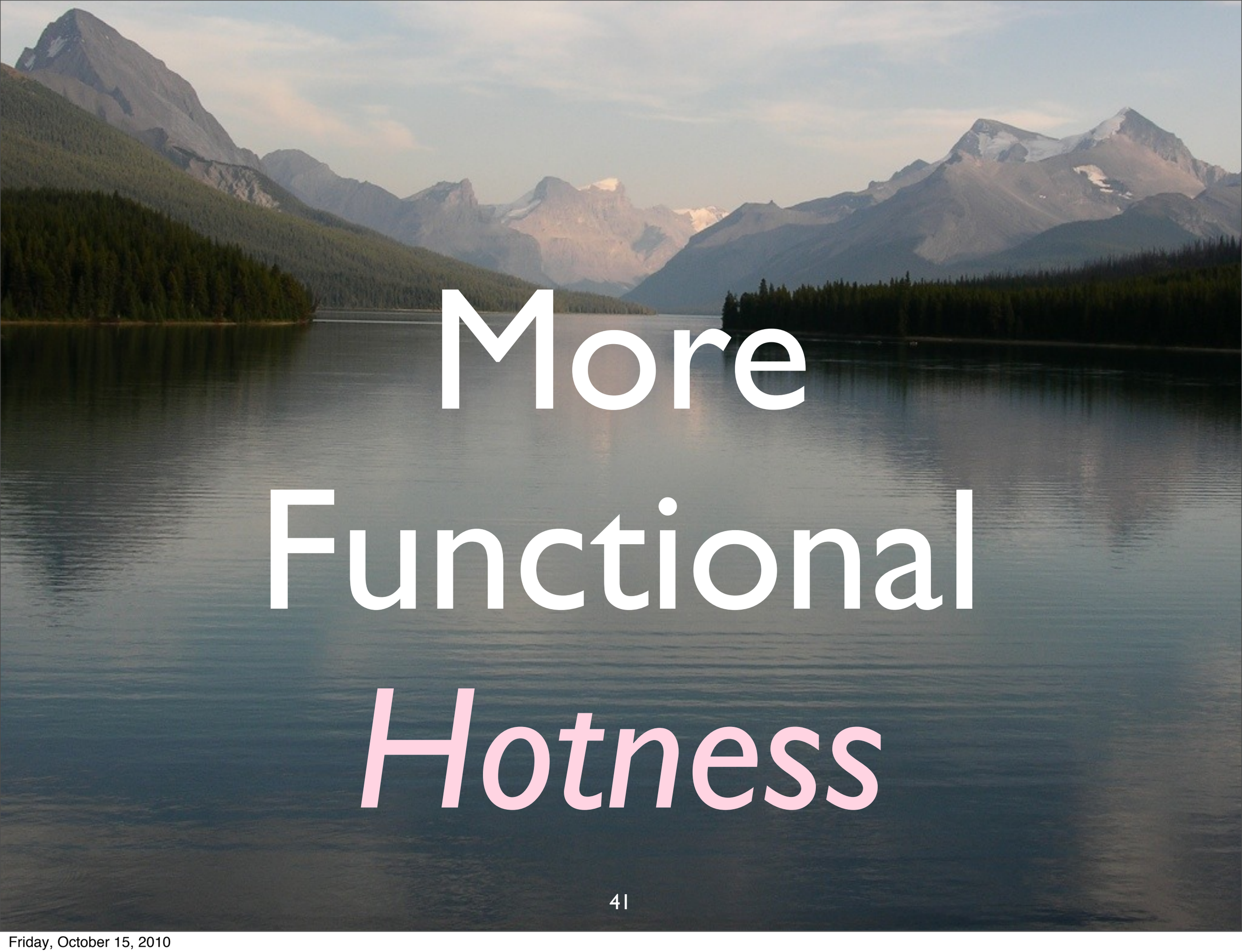
Back to where we started. Note again that we can use “{…}” instead of “(…)” for the argument list (i.e., the single function) to map. Why, to get a nice block-like syntax.



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FP is going mainstream because it is the best way to write robust concurrent software. Here’s an example...

Avoiding Nulls

```
abstract class Option[T] {…}

case class Some[T](t: T)
  extends Option[T] {…}

case object None
  extends Option[Nothing] {…}
```

Child of all other types

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I am omitting MANY details. You can't instantiate Option, which is an abstraction for a container/collection with 0 or 1 item. If you have one, it is in a Some, which must be a class, since it has an instance field, the item. However, None, used when there are 0 items, can be a singleton object, because it has no state! Note that type parameter for the parent Option. In the type system, Nothing is a subclass of all other types, so it substitutes for instances of all other types. This combined with a proper called covariant subtyping means that you could write "val x: Option[String = None" it would type correctly, as None (and Option[Nothing]) is a subtype of Option[String].

Case Classes

```
case class Some[T](t: T)
```

Provides factory, pattern matching, equals, toString, and other goodies.

```
class Map1[K, V] {
  def get(key: K): V = {
    return v;      // if found
    return null; // if not found
  }
}
```

```
class Map2[K, V] {
  def get(key: K): Option[V] = {
    return Some(v); // if found
    return None; // if not found
  }
}
```

Which is the better API?

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Returning Option tells the user that “there may not be a value” and forces proper handling, thereby drastically reducing sloppy code leading to NullPointerExceptions.

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We've seen a lot of syntax. Let's recap a few of the ways Scala keeps your code succinct.

Infix Operator Notation

```
"hello" + "world"
```

same as

```
"hello".+("world")
```


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Syntactic sugar: obj.operation(arg) == obj operation arg

Type *Inference*

```
// Java
HashMap<String,Person> persons =
  new HashMap<String,Person>();
```

vs.

```
// Scala
val persons
  = new HashMap[String,Person]
```


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Java (and to a lesser extent C#) require explicit type “annotations” on all references, method arguments, etc., leading to redundancy and noise.
Note that Scala use [] rather than <>, so you can use “<“ and “>” as method names!

Type *Inference*

```
// Java
HashMap<String,Person> persons =
  new HashMap<String,Person>();
```

vs.

```
// Scala
val persons
  = new HashMap[String,Person]
```


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Java (and to a lesser extent C#) require explicit type “annotations” on all references, method arguments, etc., leading to redundancy and noise.
Note that Scala use [] rather than <>, so you can use “<“ and “>” as method names!

```scala
// Scala
val persons
 = new HashMap[String,Person]
```

no () needed.
Semicolons inferred.

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Other things aren't needed...

User-defined *Factory* Methods

```
// Using Scala's Map type now:
val persons = Map (
  "dean" -> deanPerson,
  "alex" -> alexPerson)
```

no new needed.
Can return a subtype!

```
class Person {
  private String firstName;
  private String lastName;
  private int    age;

  public Person(String firstName, String lastName, int age){
    this.firstName = firstName;
    this.lastName  = lastName;
    this.age       = age;
  }

  public void String getFirstName() {return this.firstName;}
  public void setFirstName(String firstName) {
    this.firstName = firstName;
  }

  public void String getLastName() {return this.lastName;}
  public void setLastName(String lastName) {
    this.lastName = lastName;
  }

  public void int getAge() {return this.age;}
  public void setAge(int age) {
    this.age = age;
  }
}
```

Typical Java

Typical Java boilerplate for a simple “struct-like” class.
Deliberately too small to read...

```
class Person(
  var firstName: String,
  var lastName: String,
  var age: Int)
```

Typical Scala!

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Scala is much more succinct. It eliminates a lot of boilerplate.

Class body is the "primary" constructor

Parameter list for c'tor

```
class Person(
  var firstName: String,
  var lastName: String,
  var age: Int)
```

Makes the arg a field with accessors

No class body {…}. nothing else needed!

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Scala is much more succinct. It eliminates a lot of boilerplate.

Actually, not *exactly* the same:

```
val person = new Person(“dean”,…)
val fn = person.firstName
// Not:
// val fn = person.getFirstName
```

Doesn’t follow the JavaBean convention.

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Note that Scala does not define an argument list for “firstName”, so you can call this method as if it were a bare field access. The client doesn’t need to know the difference!

Even Better...

```
case class Person(
    firstName: String,
    lastName: String,
    age: Int)
```

Constructor args are automatically vals, plus other goodies.

Case classes also get equals, hashCode, toString, and the “factory” method we’ve mentioned (e.g., for List and Map) that, by default, creates an instance of the type without the “new”. We’ll see more about case classes later.

Scala's Object Model: *Traits*

Composable Units of Behavior

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Fixes limitations of Java's object model.

Java

```
class Person
 extends Logger { … }
```

```
class Person
 implements Logger { … }
```


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Made-up example Java type.

Java's object model

- *Good*
  - Promotes abstractions.
- *Bad*
  - No *composition* through reusable *mixins*.

Chances are, the “logging” and “filtering” behaviors are reusable, yet Java provides no built-in way to “mix-in” reusable implementations. Ad hoc mechanisms must be used.

Traits

Like interfaces with implementations,

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One way to compare traits to what you know...

Traits

… or like

abstract classes +

multiple inheritance

(if you prefer).

… and another way.

Logger, revisited:

```
trait Logger {
 def log(level: Level,
         message: String) = {
  Log.log(level, message)
 }
}
val dean =
   new Person(…) with Logger
dean.log(ERROR, “Bozo alert!!”)
```

mixed in Logging

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I changed some details compared to our original Logger example, e.g., no “level” field. Mix in Logger.

Building Our Own Controls

Exploiting First-Class Functions

Recall *Infix* Operator Notation:

```
1 + 2          // => 3
1.+(2)         // => 3
```

also the same as

```
1 + {2}
```

Why is this useful??

Syntactic sugar: obj.operation(arg) == obj operation arg

Make your own *controls*

```
// Print with line numbers.
loop (new File("…")) {
  (n, line) =>

  format("%3d: %s\n", n, line)
}
```


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If I put the “(n, line) =>” on the same line as the “{“, it would look like a Ruby block.

Make your own *controls*

```
// Print with line numbers.
loop (new File("…")) {
  (n, line) =>

  format("%3d: %s\n", n, line)
}
```

control?

File to loop through

Arguments passed to…

what do for each line

How do we do this?

Output on itself:

```
1: // Print with line …
2:
3:
4: loop(new File("…")) {
5:     (n, line) =>
6:
7:     format("%3d: %s\n", …
8: }
```

```
import java.io._

object Loop {

  def loop(file: File,
           f: (Int,String) => Unit) =
    {…}
}
```


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Here's the code that implements loop...

```
import java.io._
object Loop {
  def loop(file: File,
    f: (Int,String) => Unit) =
  {…}
}
```

*_ like * in Java*

"singleton" class == 1 object

loop "control"

two parameters

function taking line # and line

like "void"

Singleton "objects" replace Java statics (or Ruby class methods and attributes). As written, "loop" takes two parameters, the file to "numberate" and a the function that takes the line number and the corresponding line, does something, and returns Unit. User's specify what to do through "f".

```
loop (new File("…")) {
  (n, line) => …
}
```

```
object Loop {
  def loop(file: File,
           f: (Int,String) => Unit) =
    {…}
}
```

two parameters

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The oval highlights the comma separating the two parameters in the list. Watch what we do on the next slide...

```
loop (new File("…")) {
  (n, line) => …
}
```

```
object Loop {
  def loop(file: File)  (
      f: (Int,String) => Unit) =
    {…}
}
```

two parameters lists

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We convert the single, two parameter list to two, single parameter lists, which is valid syntax.

Why 2 Param. Lists?

```
// Print with line numbers.
import Loop.loop

loop (new File("…")) {
  (n, line) =>

  format("%3d: %s\n", n, line)
}
```

import

1st param.: a file

2nd parameter: a "function literal"

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Having two, single-item parameter lists, rather than one, two-item list, is necessary to allow the syntax shown here. The first parameter list is (file), while the second is {function literal}. Note that we have to import the loop method (like a static import in Java). Otherwise, we could write Loop.loop.

```
object Loop {
   def loop(file: File) (
      f: (Int,String) => Unit) =
   {
      val reader =
       new BufferedReader(
         new FileReader(file))
      def doLoop(i:Int) = {…}
      doLoop(1)
   }
}
```

nested method

Finishing Numberator...

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Finishing the implementation, loop creates a buffered reader, then calls a recursive, nested method "doLoop".

```
object Loop {
   …
      def doLoop(n: Int):Unit ={
       val l = reader.readLine()
       if (l != null) {
        f(n, l)
        doLoop(n+1)
      }
    }
  }
}
```

recursive

"f" and "reader" visible from outer scope

Finishing Numberator...

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Here is the nested method, doLoop.

doLoop is *Recursive*.

There is no *mutable*

loop counter!

Classic Functional Programming technique

It is *Tail* Recursive

```
def doLoop(n: Int):Unit ={
  …
  doLoop(n+1)
}
```

Scala optimizes tail recursion into loops

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A tail recursion - the recursive call is the last thing done in the function (or branch).

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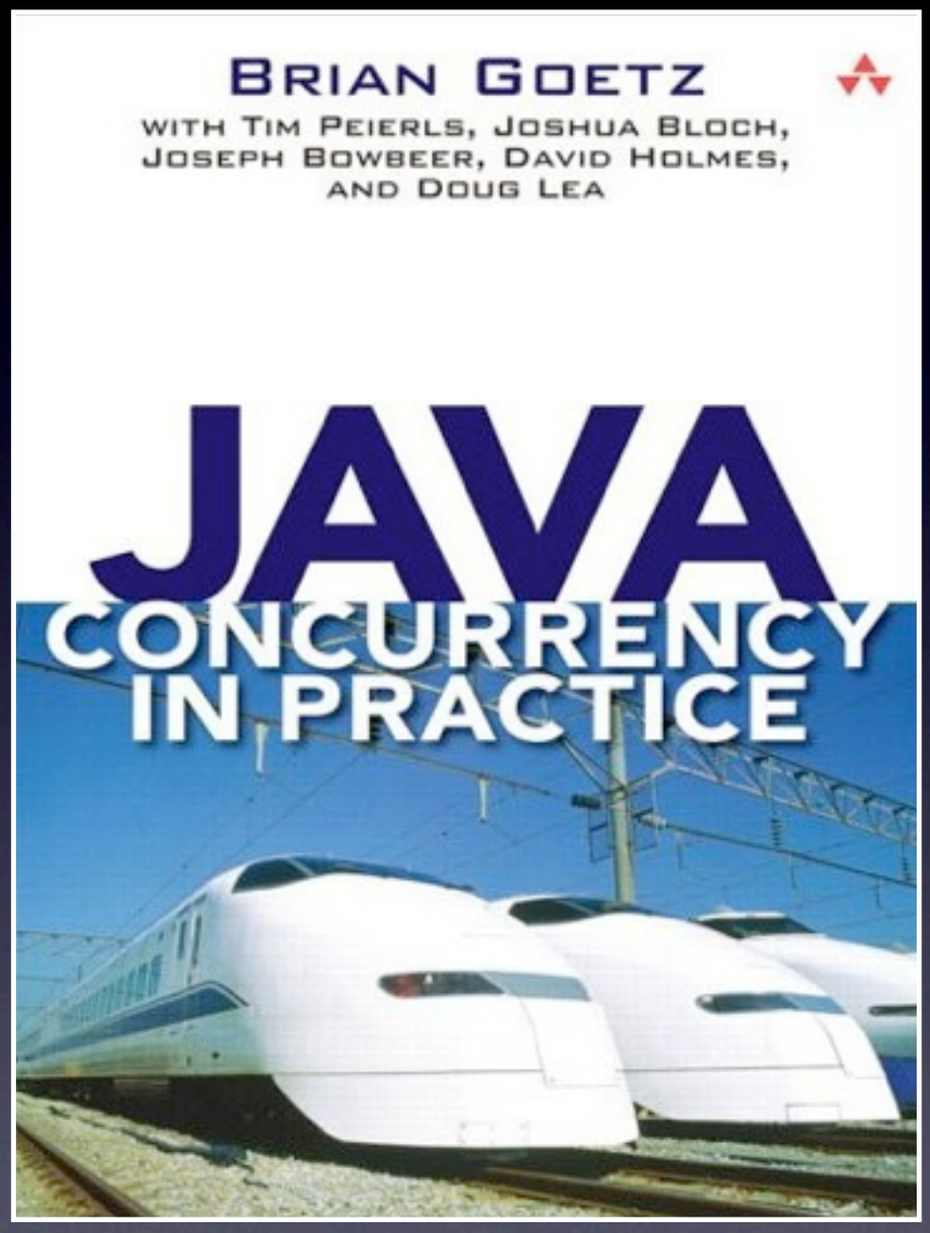
FP is going mainstream because it is the best way to write robust concurrent software. Here's an example...

When you share mutable state...

Hic sunt dracones
(Here be dragons)



Hard!

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It's very hard to do multithreaded programming robustly. We need higher levels of abstraction, like Actors.

Actor Model

- *Message* passing between autonomous *actors*.
- No *shared* (mutable) *state*.

Actor Model

- First developed in the 70's by Hewitt, Agha, Hoare, *etc.*
- Made "famous" by *Erlang*.
  - Scala's Actors patterned after Erlang's.

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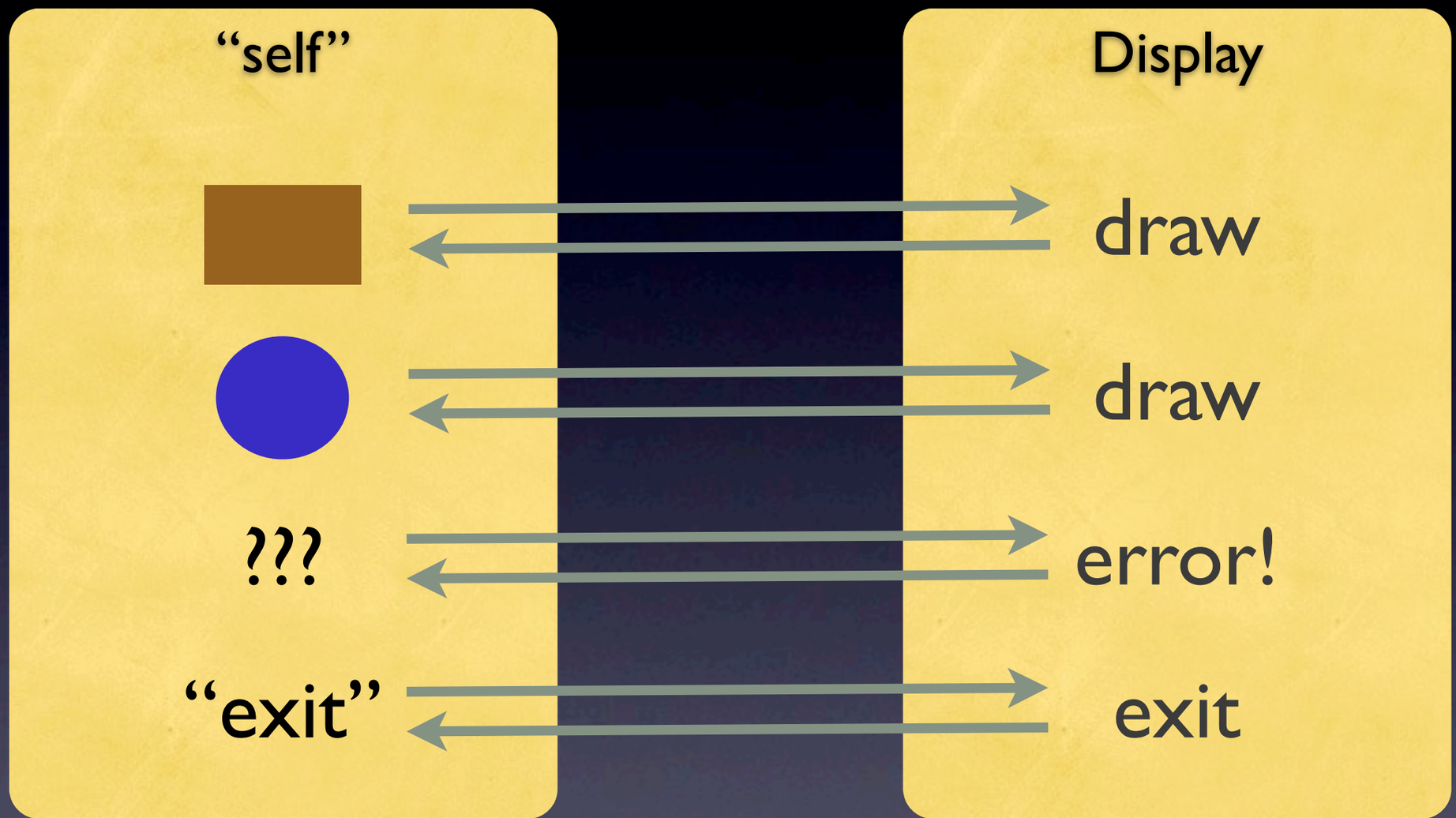
The actor model is not new!!

2 Actors:



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Our example. An actor for drawing geometric shapes and another actor that drives it.

```
package shapes

case class Point(
 x: Double, y: Double)
```

```
abstract class Shape {
  def draw()
}
```

Hierarchy of geometric shapes

“Case” classes for 2-dim. points and a hierarchy of shapes. Note the abstract draw method in Shape. The “case” keyword makes the arguments “vals” by default, adds factory, equals, etc. methods. Great for “structural” objects.
(Case classes automatically get generated equals, hashCode, toString, so-called “apply” factory methods - so you don’t need “new” - and so-called “unapply” methods used for pattern matching.)

```
package shapes

case class Point(
 x: Double, y: Double)
```

```
abstract class Shape {
  def draw()
}
```

abstract "draw" method

Hierarchy of geometric shapes

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"Case" classes for 2-dim. points and a hierarchy of shapes. Note the abstract draw method in Shape. The "case" keyword makes the arguments "vals" by default, adds factory, equals, etc. methods. Great for "structural" objects.
(Case classes automatically get generated equals, hashCode, toString, so-called "apply" factory methods - so you don't need "new" - and so-called "unapply" methods used for pattern matching.)

```
case class Circle(
  center:Point, radius:Double)
      extends Shape {
  def draw() = …
}
```

concrete "draw" methods

```
case class Rectangle(
  ll:Point, h:Double, w:Double)
      extends Shape {
  def draw() = …
}
```

Hierarchy of geometric shapes

Friday, October 15, 2010

Case classes for 2-dim. points and a hierarchy of shapes. Note the abstract draw method in Shape.
For our example, the draw methods will just do "println(this.toString)".

```
package shapes
import scala.actors._, Actor._
object ShapeDrawingActor
         extends Actor {
  def act() {
    loop {
      receive {
        ...
          }
        }
      }
    }
  }
```

Actor for drawing shapes

Friday, October 15, 2010

An actor that waits for messages containing shapes to draw. Imagine this is the window manager on your computer. It loops indefinitely, blocking until a new message is received...

Note: This example uses Scala's built in Actor library, but there are others have some advantages. See for example, akkasource.org.

```
package shapes
import scala.actors._, Actor._
object ShapeDrawingActor
        extends Actor {
  def act() {
    loop {
      receive {
        …
      }
    }
  }
}
```

Actor library

"singleton" Actor

loop indefinitely

receive and handle each message

Actor for drawing shapes

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Note: This example uses Scala's built in Actor library, but there are others have some advantages. See for example, akkasource.org.

Receive method

```
receive {
 case s:Shape =>
    s.draw()
    sender ! "drawn"
 case "exit" =>
    println("exiting...")
    sender ! "bye!"
    // exit
 case x =>
    println("Error: " + x)
    sender ! "Unknown: " + x
}
```


“Receive” blocks until a message is received. Then it does a pattern match on the message. In this case, looking for a Shape object, the “exit” message, or an unexpected object, handled with the last case, the default.

```
receive {
 case s:Shape =>
    s.draw()
    sender ! "drawn"
 case "exit" =>
    println("exiting...")
    sender ! "bye!"
    // exit
 case x =>
    println("Error: " + x)
    sender ! "Unknown: " + x
}
```

pattern matching

Each pattern is tested and the first match “wins”. The messages we expect are a Shape object, the “exit” string or anything else. Hence, the last “case” is a “default” that catches anything, we we treat as an unexpected error.

```
receive {
  case s:Shape =>
    s.draw()
    sender ! "drawn"
  case "exit" =>
    println("exiting...")
    sender ! "bye!"
    // exit
  case x =>
    println("Error: " + x)
    sender ! "Unknown: " + x
}
```

draw shape & send reply

done

unrecognized message

After handling each message, a response is sent to the sender, which we get by calling the “sender” method. The “!” is the message send method (from Erlang).

```
package shapes
import …
object ShapeDrawingActor extends Actor {
  def act() {
    loop {
      receive {
        case s: Shape =>
          s.draw()
          sender ! "drawn"
        case "exit" =>
          println("exiting...")
          sender ! "bye!" //; exit
        case x =>
          println("Error: " + x)
          sender ! "Unknown: " + x
    } } } }
```

Altogether

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The whole thing, with “elided” imports and other edits, so it would fit. It looks busy on a presentation slide, but isn’t a lot of code in an editor!

```
import shapes._
import scala.actors.Actor._


def sendAndReceive(msg: Any) ={
 ShapeDrawingActor ! msg
```

```
  self.receive {
    case reply => println(reply)
  }
}
```

script to try it out

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Here's the driver actor, a scala script (precompilation not required) to drive the drawing actor.
Normally, you would not do such synchronous call and response coding, if avoidable, as it defeats the purpose of using actors for concurrency.

```
import shapes._
import scala.actors.Actor._
```

helper method

```
def sendAndReceive(msg: Any) ={
 ShapeDrawingActor ! msg
```

send message...

```
  self.receive {
    case reply => println(reply)
  }
}
```

wait for a reply

script to try it out

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The “!” method sends a message. Then we wait for a reply. In our receive method, we match on any “reply” and just print it.
This script uses the method “self” to get the actor corresponding to “me”.

```
…
ShapeDrawingActor.start()
sendAndReceive(
  Circle(Point(0.0,0.0), 1.0))
sendAndReceive(
  Rectangle(Point(0.0,0.0), 2, 5))
sendAndReceive(3.14159)
sendAndReceive("exit")

// => Circle(Point(0.0,0.0),1.0)
// => drawn.
// => Rectangle(Point(0.0,0.0),2.0,5.0)
// => drawn.
// => Error: 3.14159
// => Unknown message: 3.14159
// => exiting...
// => bye!
```


Start the drawing actor, then send it four messages. The blue shows what gets printed (after the “// => “).

```
…
ShapeDrawingActor.start()
sendAndReceive(
  Circle(Point(0.0,0.0), 1.0))
sendAndReceive(
  Rectangle(Point(0.0,0.0), 2, 5))
sendAndReceive(3.14159)
sendAndReceive("exit")

// => Circle(Point(0.0,0.0),1.0)
// => drawn.
// => Rectangle(Point(0.0,0.0),2.0,5.0)
// => drawn.
// => Error: 3.14159
// => Unknown message: 3.14159
// => exiting...
// => bye!
```


1st message and response.

```
…
ShapeDrawingActor.start()
sendAndReceive(
  Circle(Point(0.0,0.0), 1.0))
sendAndReceive(
  Rectangle(Point(0.0,0.0), 2, 5))
sendAndReceive(3.14159)
sendAndReceive("exit")

// => Circle(Point(0.0,0.0),1.0)
// => drawn.
// => Rectangle(Point(0.0,0.0),2.0,5.0)
// => drawn.
// => Error: 3.14159
// => Unknown message: 3.14159
// => exiting...
// => bye!
```


2nd message and response.

```
…
ShapeDrawingActor.start()
sendAndReceive(
  Circle(Point(0.0,0.0), 1.0))
sendAndReceive(
  Rectangle(Point(0.0,0.0), 2, 5))
sendAndReceive(3.14159)
sendAndReceive("exit")

// => Circle(Point(0.0,0.0),1.0)
// => drawn.
// => Rectangle(Point(0.0,0.0),2.0,5.0)
// => drawn.
// => Error: 3.14159
// => Unknown message: 3.14159
// => exiting...
// => bye!
```


3rd message and response.

```
…
ShapeDrawingActor.start()
sendAndReceive(
  Circle(Point(0.0,0.0), 1.0))
sendAndReceive(
  Rectangle(Point(0.0,0.0), 2, 5))
sendAndReceive(3.14159)
sendAndReceive("exit")

// => Circle(Point(0.0,0.0),1.0)
// => drawn.
// => Rectangle(Point(0.0,0.0),2.0,5.0)
// => drawn.
// => Error: 3.14159
// => Unknown message: 3.14159
// => exiting...
// => bye!
```


4th message and response.

```
…
receive {
  case s:Shape =>
    s.draw()
    sender ! "drawn"
  case …
  case …
}
```

pattern matching

polymorphism

A powerful combination!

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The power of combining the best features of FP (pattern matching and “destructuring”) and OOP (polymorphic behavior).

Recap

Scala is...

a *better*

Java and C#,

object-oriented

and

functional,

101

succinct,

elegant,

and

powerful.

Thanks!

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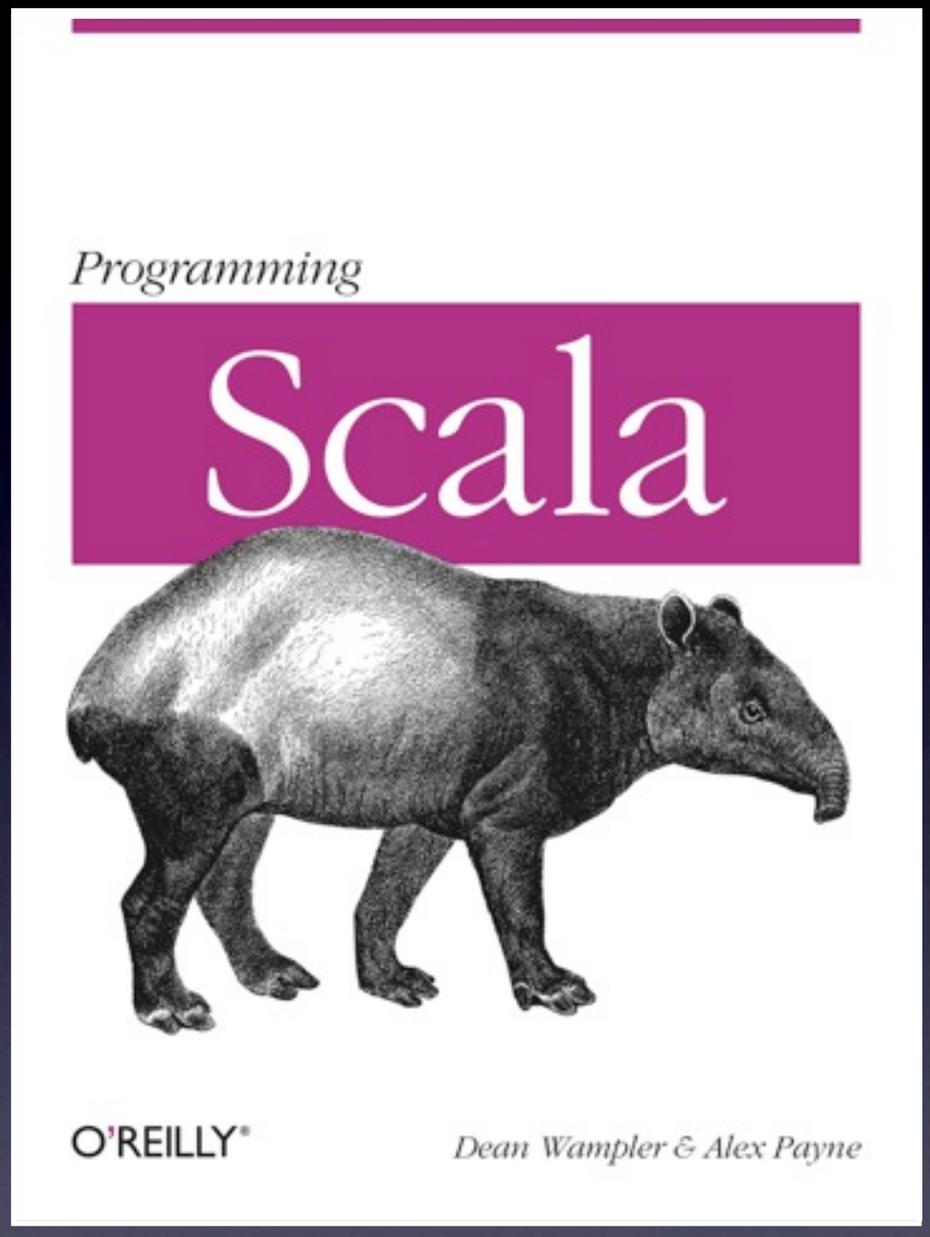

Extra Slides


Modifying
Existing
Behavior
with Traits

Example

```
trait Queue[T] {
  def get(): T
  def put(t: T)
}
```

A pure abstraction (in this case...)

Friday, October 15, 2010

A very simple abstraction for a Queue.

Log put

```
trait QueueLogging[T]
 extends Queue[T] {
  abstract override def put(
     t: T) = {
    println("put("+t+")")
    super.put(t)
  }
}
```


(We're ignoring "get"…) "Super" is not yet bound, because the "super.put(t)" so far could only call the abstract method in Logging, which is not allowed. Therefore, "super" will be bound "later", as we'll so. So, this method is STILL abstract and it's going to override a concrete "put" "real soon now".

Log put

```
trait QueueLogging[T]
  extends Queue[T] {
  abstract override def put(
      t: T) = {
    println("put("+t+")")
    super.put(t)
  }
}
```

What is "super" bound to??

Friday, October 15, 2010

(We're ignoring "get"…) "Super" is not yet bound, because the "super.put(t)" so far could only call the abstract method in Logging, which is not allowed. Therefore, "super" will be bound "later", as we'll so. So, this method is STILL abstract and it's going to override a concrete "put" "real soon now".

```
class StandardQueue[T]
          extends Queue[T] {
  import ...ArrayBuffer
  private val ab =
        new ArrayBuffer[T]
  def put(t: T) = ab += t
  def get() = ab.remove(0)
  …
}
```

Concrete (boring) implementation

Friday, October 15, 2010

Our concrete class. We import scala.collection.mutable.ArrayBuffer wherever we want, in this case, right were it's used. This is boring; it's just a vehicle for the cool traits stuff...

```
val sq = new StandardQueue[Int]
       with QueueLogging[Int]

sq.put(10)              // #1
println(sq.get()) // #2
// => put(10)          (on #1)
// => 10               (on #2)
```

Example use

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We instantiate StandardQueue AND mixin the trait. We could also declare a class that mixes in the trait.
The “put(10)” output comes from QueueLogging.put. So “super” is StandardQueue.

Mixin composition; no class required

```
val sq = new StandardQueue[Int]
         with QueueLogging[Int]

sq.put(10)                  // #1
println(sq.get())           // #2
// => put(10)                 (on #1)
// => 10                      (on #2)
```

Example use

Friday, October 15, 2010

We instantiate StandardQueue AND mixin the trait. We could also declare a class that mixes in the trait.
The “put(10)” output comes from QueueLogging.put. So “super” is StandardQueue.

Like Aspect-Oriented Programming?

Traits give us *advice*, but not a *join point* "*query*" *language*.

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If you know AspectJ or Spring AOP, traits make it easy to implement "advice", but there is no join point language for querying over the set of all possible join points, like a real AOP framework provides.

Traits are a powerful *composition* mechanism!

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Not shown, nesting of traits...


Functional
Programming

What is *Functional Programming*?

Don't we already write "functions"?

$$y = \sin(x)$$

Based on *Mathematics*

"Functional Programming" is based on the behavior of mathematical functions and variables.

$$y = \sin(x)$$

Setting *x* fixes *y*

∴ *variables* are *immutable*

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"Functional Programming" is based on the behavior of mathematical functions.
"Variables" are actually immutable values.

20 += 1 ??

We never *modify* the 20 "object"

Concurrency

No *mutable state*

∴ *nothing* to *synchronize*

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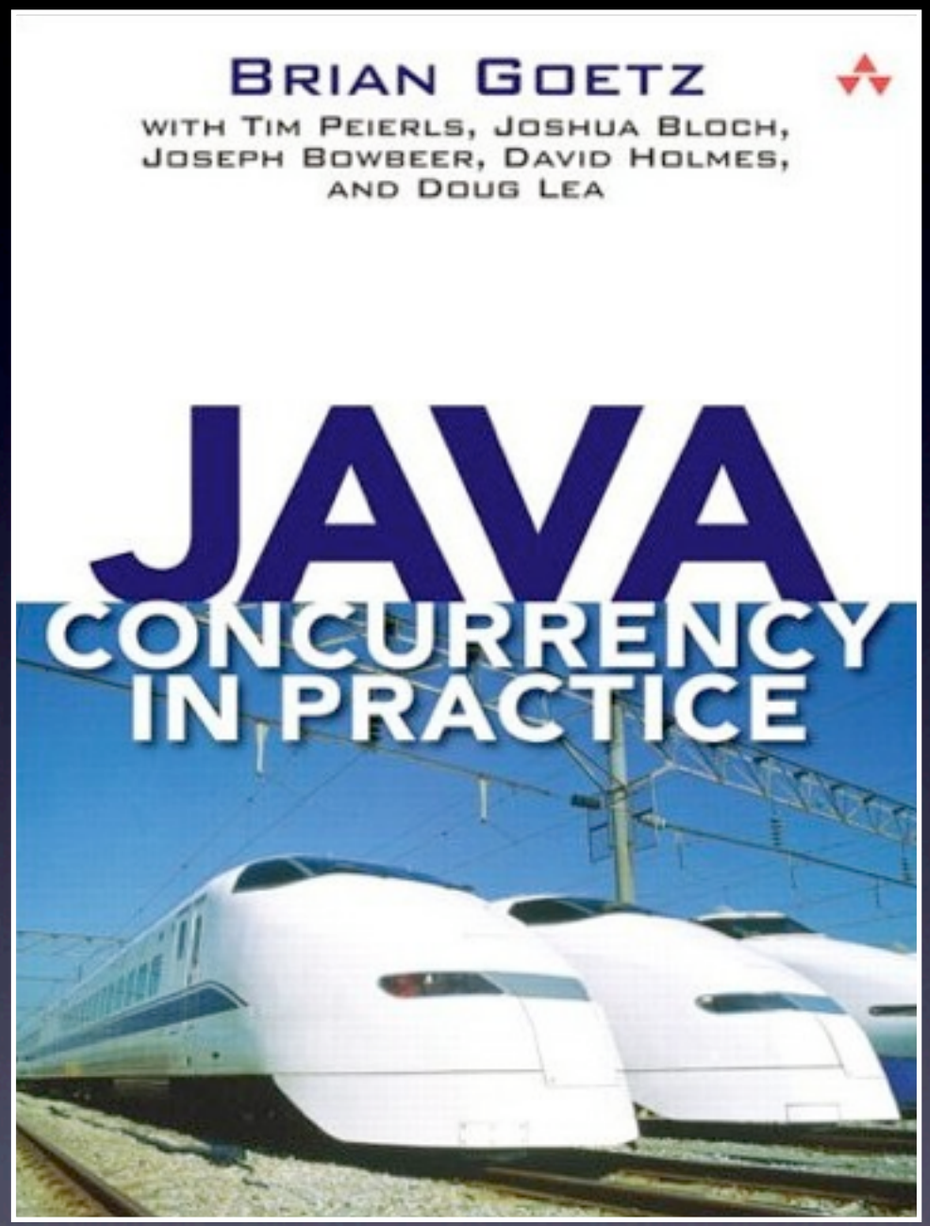
FP is breaking out of the academic world, because it offers a better way to approach concurrency, which is becoming ubiquitous.

When you share mutable state...

Hic sunt dracones
(Here be dragons)



$$y = \sin(x)$$

Functions don't

change state

$\therefore$ *side-effect* free

Friday, October 15, 2010

A math function doesn't change any "object" or global state. All the work it does is returned by the function. This property is called "referential transparency".

Side-effect free functions

- Easy to *reason* about *behavior*.
- Easy to invoke *concurrently*.
- Easy to invoke *anywhere*.
- Encourage *immutable* objects.

Friday, October 15, 2010

side-effect free functions are far less likely to introduce subtle integration bugs, especially in concurrent systems. By encouraging immutable objects (e.g., when methods return new objects, rather than modify existing ones), that improves concurrency robustness.

tan(Θ) = sin(Θ)/cos(Θ)

Compose functions of other functions

∴ *first-class citizens*

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Function are “first-class citizens”; you can assign them to variables and pass them to other (higher-order) functions, giving you composable behavior.

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FP is going mainstream because it is the best way to write robust concurrent software. Here’s an example...

Avoiding Nulls

```
abstract class Option[T] {…}

case class Some[T](t: T)
  extends Option[T] {…}

case object None
  extends Option[Nothing] {…}
```

Child of all other types

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I am omitting MANY details. You can't instantiate Option, which is an abstraction for a container/collection with 0 or 1 item. If you have one, it is in a Some, which must be a class, since it has an instance field, the item. However, None, used when there are 0 items, can be a singleton object, because it has no state! Note that type parameter for the parent Option. In the type system, Nothing is a subclass of all other types, so it substitutes for instances of all other types. This combined with a proper called covariant subtyping means that you could write "val x: Option[String = None" it would type correctly, as None (and Option[Nothing]) is a subtype of Option[String].

Case Classes

```
case class Some[T](t: T)
```

Provides factory, pattern matching, equals, toString, and other goodies.

```
class Map1[K, V] {
  def get(key: K): V = {
    return v;      // if found
    return null; // if not found
  }
}
```

```
class Map2[K, V] {
  def get(key: K): Option[V] = {
    return Some(v); // if found
    return None; // if not found
  }
}
```

Which is the better API?

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Returning Option tells the user that “there may not be a value” and forces proper handling, thereby drastically reducing sloppy code leading to NullPointerExceptions.

For “Comprehensions”

```
val l = List(
 Some(“a”), None, Some(“b”),
 None, Some(“c”))
```

```
for (Some(s) <- l) yield s
// List(a, b, c)
```

Pattern match; only take elements of “l” that are Somes.

No “if” statement

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We’re using the type system and pattern matching built into case classes to discriminate elements in the list. No conditional statements required.
This is just the tip of the iceberg of what “for comprehensions” can do and not only with Options, but other containers, too.