Introduction to Scala

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Contents

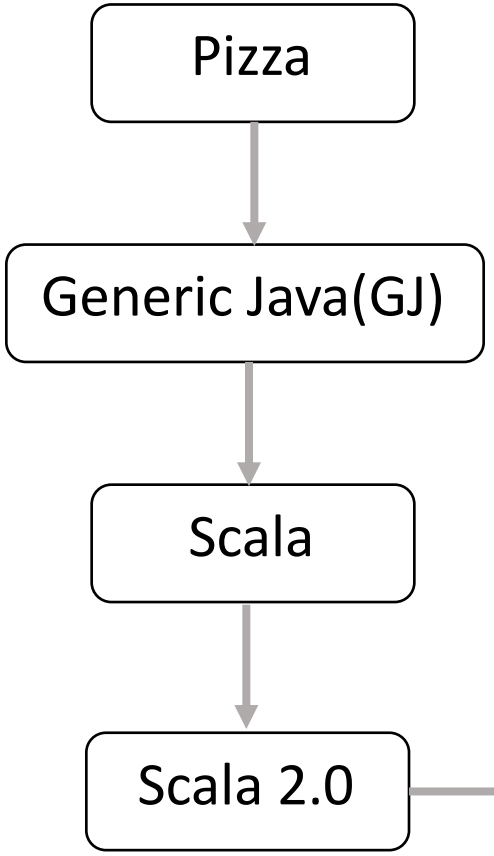
Introduction and Background

Welcome to Scala

- *Sc*alable *La*nguage

- A modern language developed for the Java™ platform
  - Interoperates with Java
  - Also .Net, JavaScript versions
- Supports Object Oriented and Functional paradigms
- Many toolkits/frameworks built on Scala
  - Akka
  - Play
  - Slick
  - Spark

A Short History



Initial investigation on adding Generics to Java- late 1990s

Compiler for superset of Java with Generics and basic FP – 2001

First experimental release of Scala - 2003

Martin Odersky

Mid-2016
Java 8 runtime integration
Ongoing performance improvements

Concise Syntax

- Java

```
public class Person {
  private String firstName;
  private String lastName;
  public Person() {
    this("John", "Doe");
  }
  public Person( String first, String last ) {
    this.firstName = first;
    this.lastName = last;
  }
  public String first() {
    return this.firstName;
  }
  public String last() {
    return this.lastName;
  }
}
```

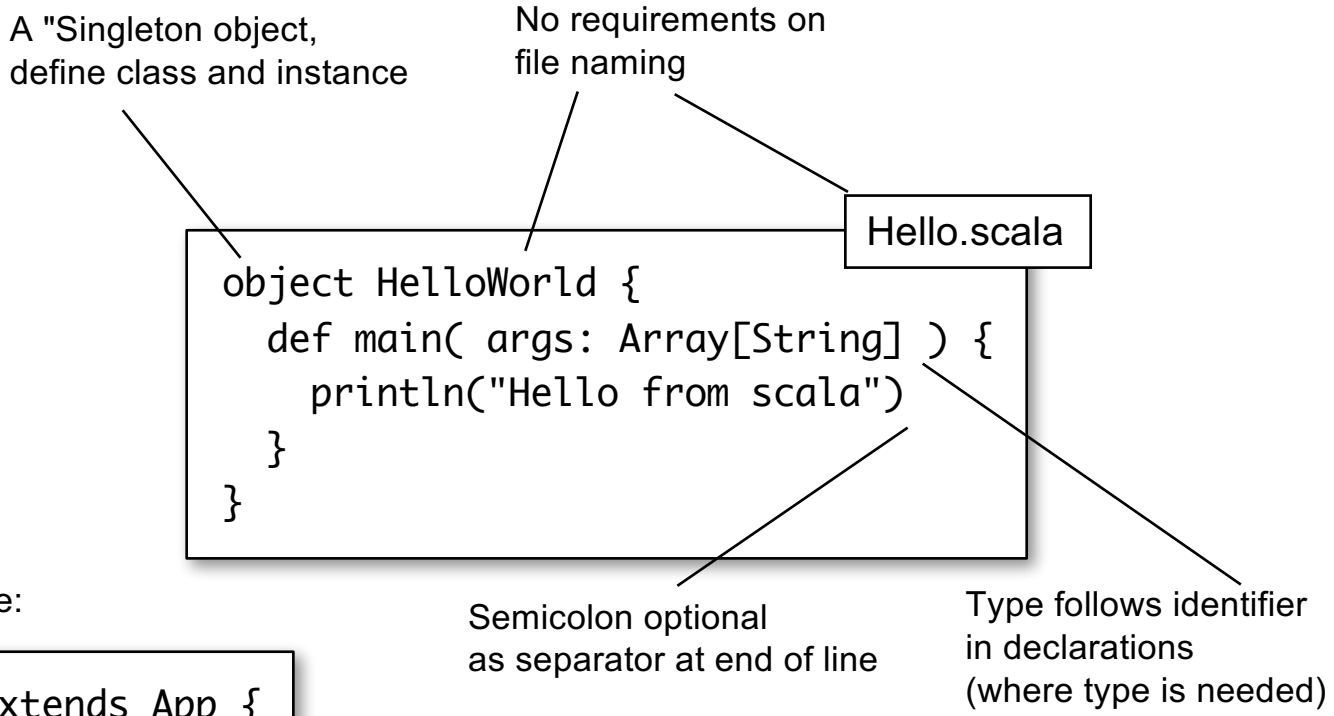
Concise Syntax

- Scala

```
class Person( val first: String = "John",
              val last: String = "Doe" )
```

Getting Started

- A first Scala program



Further simplification possible:

```
object HelloWorld extends App {
  println("Hello from scala")
}
```

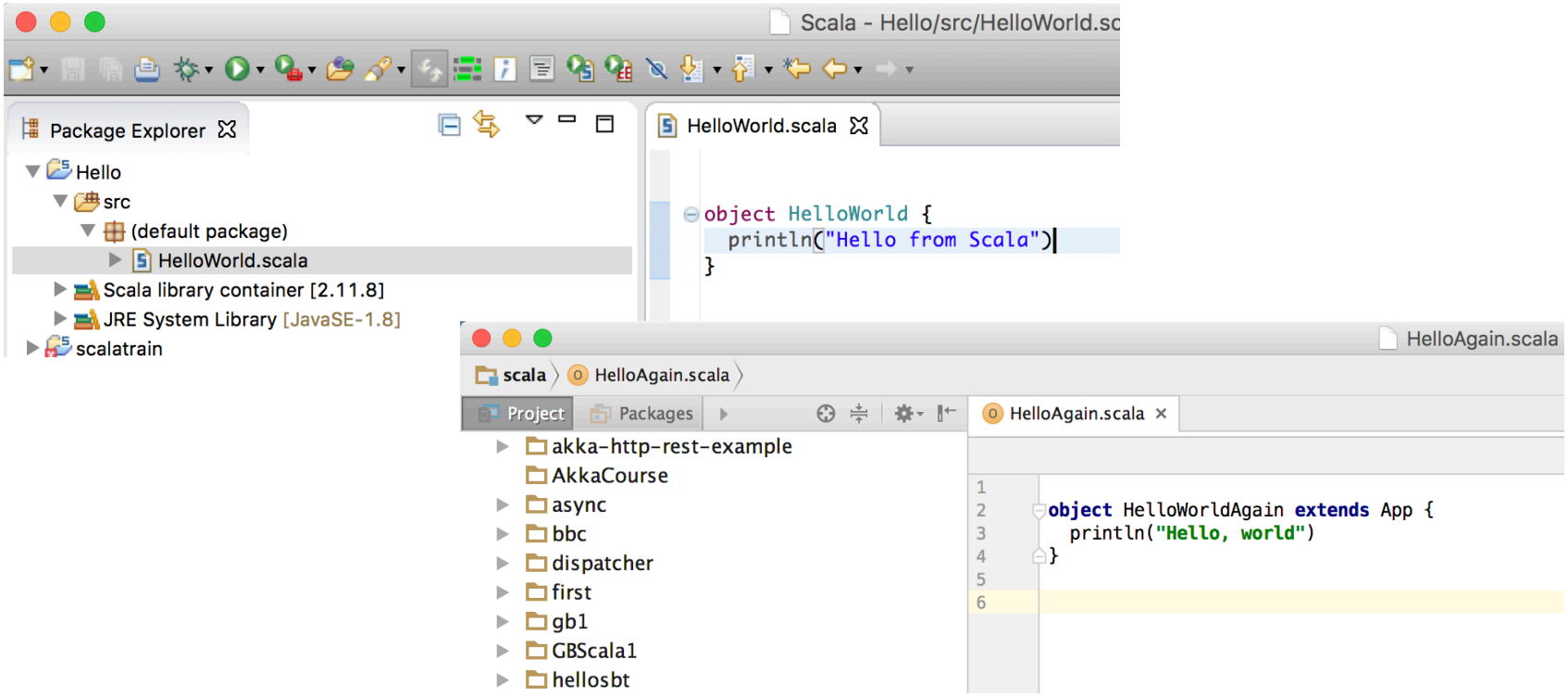
Running the Program

- Standard Scala compile/execution tools available
  - similar to JDK

```
$ scalac Hello.scala
$ ls –l
-rw-r--r--   1 george  staff   604 18 Sep 09:27 HelloWorld$.class
-rw-r--r--   1 george  staff   632 18 Sep 09:27 HelloWorld.class
$ scala HelloWorld
Hello from scala
```

Using an IDE

- Plugins available for common IDEs



The Scala REPL

- An interactive mode for experimenting with Scala

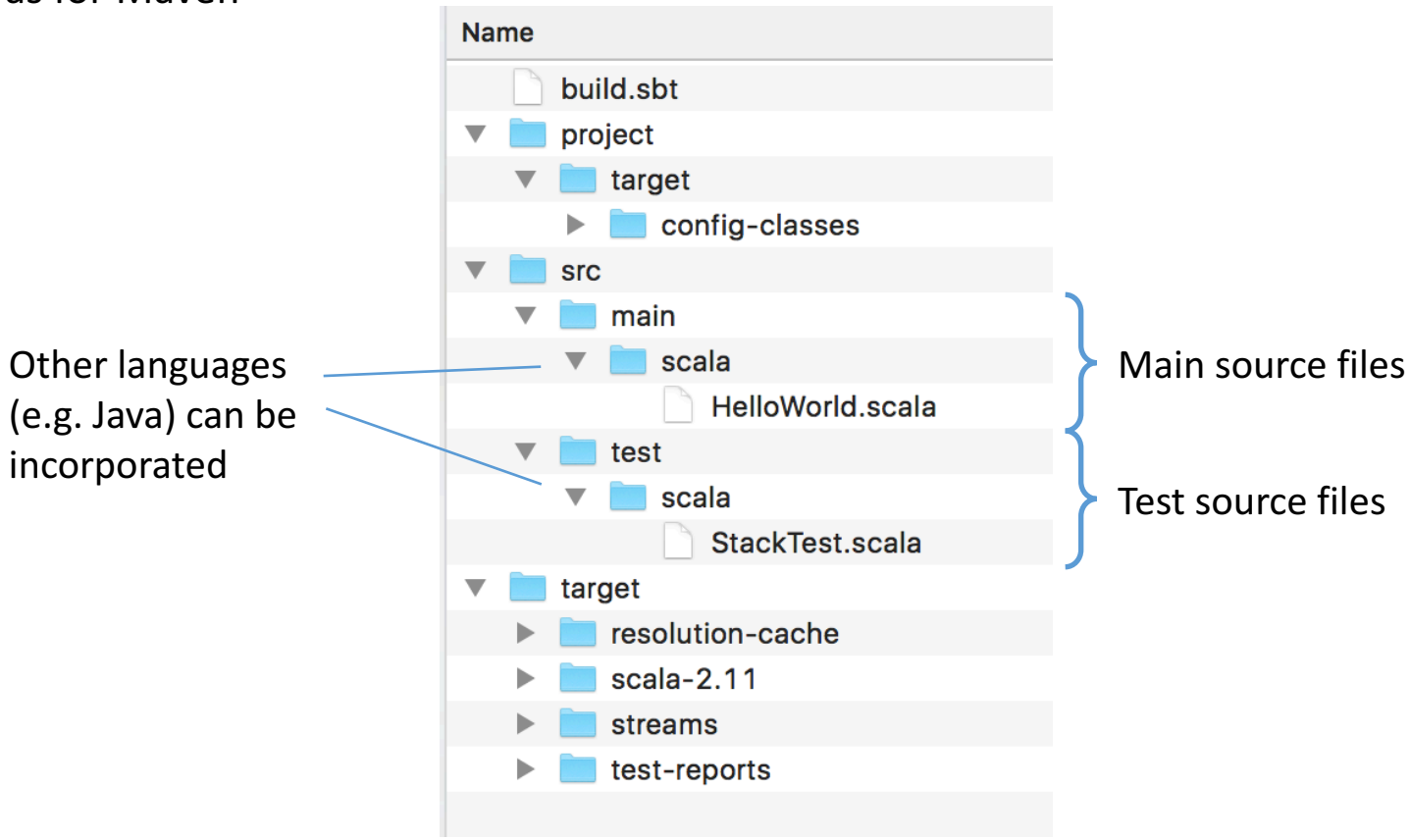
```
$ scala
Welcome to Scala 2.11.8 (Java HotSpot(TM) 64-Bit Server VM, Java 1.8.0_51).
Type in expressions for evaluation. Or try :help.

scala> println("Hello to all...")
Hello to all...

scala> :help
All commands can be abbreviated, e.g., :he instead of :help.
…
:load <path>                interpret lines in a file
:paste [-raw] [path]        enter paste mode or paste a file
:quit                       exit the interpreter
:replay [options]           reset the repl and replay all previous commands
:require <path>             add a jar to the classpath
:type [-v] <expr>           display the type of an expression without evaluating it
…
```

sbt: The Scala Build Tool

- Like Gradle
- Build files use Scala based DSL
  - Unlike Maven which uses XML
- Leverages Ivy for dependencies
- Incremental compilation reduces build times
  - Also server mode of operation
- Basis of Lightbend Activator tool

sbt Project Layout

- sbt has a basic structure for projects
  - Same as for Maven



Working with sbt

```
$ sbt
…
> run
[info] Compiling 1 Scala source to .../target/scala-2.11/classes...
[info] Running HelloWorld
Hello all
[success] Total time: 2 s, completed 08-Aug-2016 15:42:10
>
```

```
…
> test
…
[info] Run completed in 324 milliseconds.
[info] Total number of tests run: 2
[info] Suites: completed 1, aborted 0
[info] Tests: succeeded 2, failed 0, canceled 0, ignored 0, pending 0
[info] All tests passed.
[info] Passed: Total 2, Failed 0, Errors 0, Passed 2
[success] Total time: 1 s, completed 08-Aug-2016 15:50:41
>
```

The sbt Build File

- build.sbt
  - Written using a Scala DSL

Possible to manage build for several Scala versions

```
name := "Hello World"

version := "1.0"

scalaVersion := "2.11.8"

libraryDependencies += "org.specs2" %% "specs2-core" % "3.8.4" % "test"

libraryDependencies ++= Seq( "org.scalatest" % "scalatest_2.11" % "3.0.0" % "test",
                             "org.scalactic" %% "scalactic" % "3.0.0" )
```

Dependencies can be specified individually or as a list

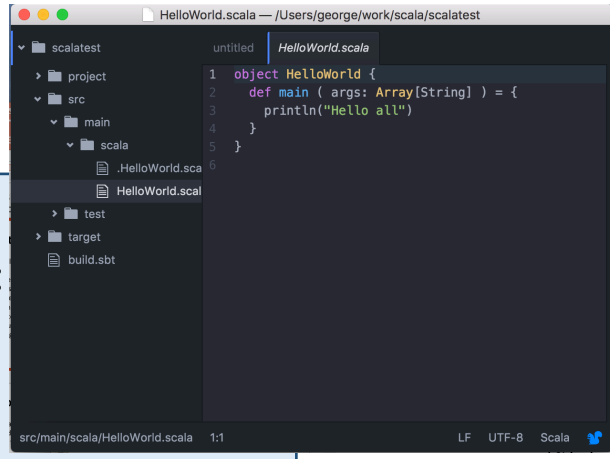
The sbt Console

- Allows Scala REPL interaction with dependencies resolved

```
$ sbt
[info] Set current project to Hello World (in build file:../latest/)
> console
[info] Starting scala interpreter...
[info]
Welcome to Scala 2.11.8 (Java HotSpot(TM) 64-Bit Server VM, Java 1.8.0_51).
Type in expressions for evaluation. Or try :help.

scala> println("Hello there")
Hello there

scala> :quit

[success] Total time: 4 s, completed 08-Aug-2016 16:17:33
>
```

Continuous Mode

- sbt can monitor for changes to files in the build
  - rerun the task if any change is detected
  - prepend ~ to task




```
$ sbt
[info] Set current project to Hello World (in build file:
> ~run
[info] Running HelloWorld
Hello all
[success] Total time: 0 s, completed 08-Aug-2016 16:18:46
1. Waiting for source changes... (press enter to interrupt)
[info] Running HelloWorld
Hello all
[success] Total time: 0 s, completed 08-Aug-2016 16:19:11
2. Waiting for source changes... (press enter to interrupt)

>
```

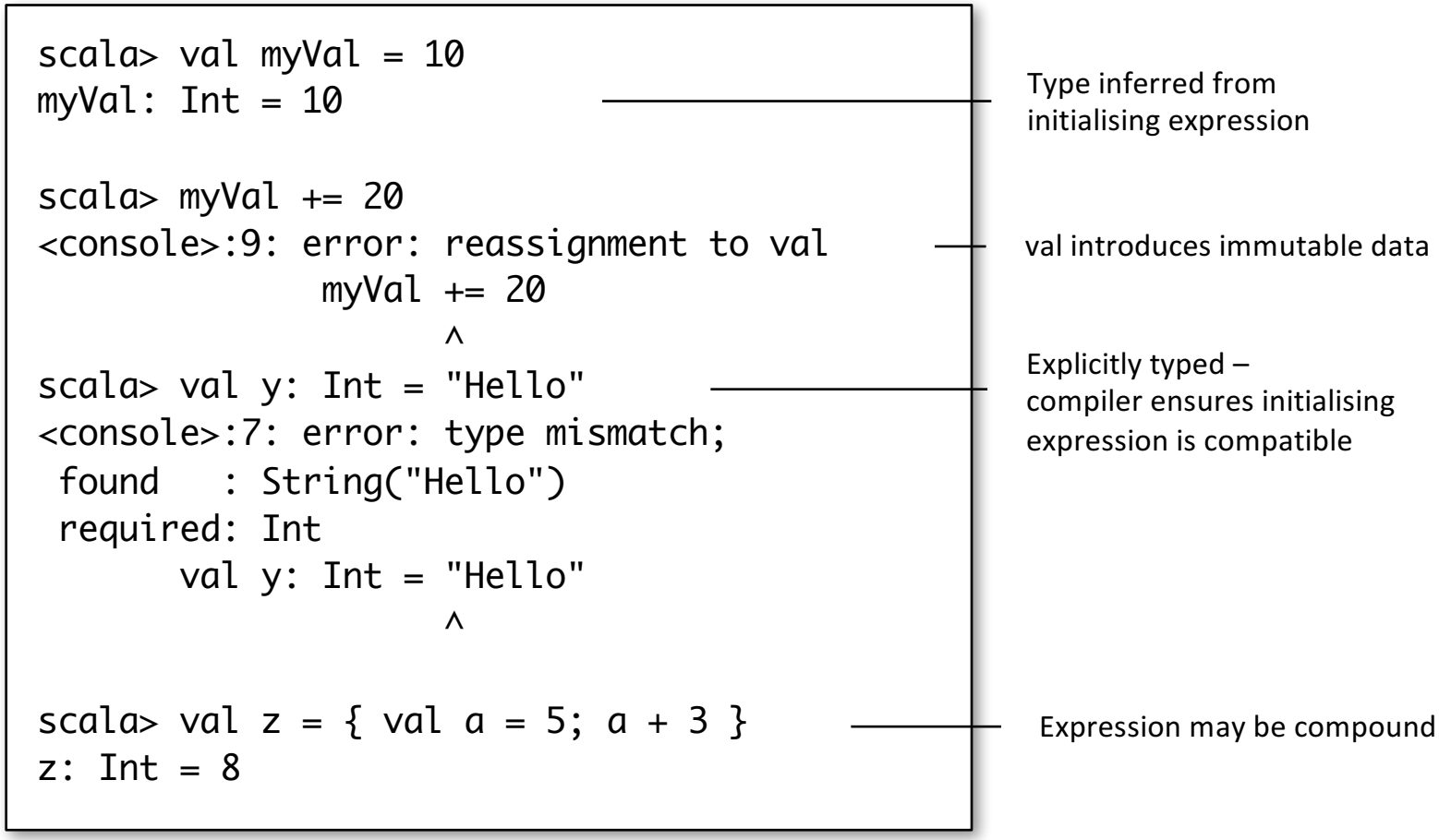
Introducing the Scala Language

Basic Principles

- Three language "rules"
- Everything is an expression
  - Should yield a value
  - If no value returned, expression is known as a *statement*
- Every value is an object
  - Compiler optimises to use JVM primitive types when appropriate
- Every operation is a method call

Values

- Named pieces of *immutable* storage



Variables

- Named pieces of *mutable* storage
  - may be initialised after definition
  - must be initialised before use

- Use of mutable data is discouraged in Scala

```
scala> var myVar: Int = 20
myVar: Int = 20

scala> myVar += 10

scala> myVar
res3: Int = 30

scala> myVar + myVal
res4: Int = 40
```

`var` and `val` may be mixed in expressions

Methods/Functions

- Use def keyword

```
scala> def times2 ( i: Int ) = i * 2
times2: (i: Int)Int

scala> times2 ( 3 )
res17: Int = 6

scala> def upper ( strings: String* ) = strings.map( _.toUpperCase() )
upper: (strings: String*)Seq[java.lang.String]

scala> upper ( "one", "two" )
res18: Seq[java.lang.String] = ArrayBuffer(ONE, TWO)

scala> def sayHello = println( "Hello everyone" )
sayHello: Unit

scala> sayHello
Hello everyone
```

* means variable number of parameters

Unit similar to Java void type

No args so () not required

About Strings

- Scala String type based on java.lang.String
  - Some additional capabilities
- String interpolation allows Scala expressions to be evaluated inside String literals

```
scala> val a = 1
a: Int = 1

scala> val b = 3
b: Int = 3

scala> s"$a + $b = ${a + b}"
res2: String = 1 + 3 = 4

scala> f"$a%2d + $b%2d = ${a + b}%3.2f"
res3: String = " 1 +  3 = 4.00"
```

Simple substitution

Formatted substitution

Regular Expressions

- Powerful notation for working with Strings

```
scala> val s1 = "I like coffee before lunch, and Tea after lunch"
s1: String = I like coffee before lunch, and Tea after lunch

scala> s1.matches( raw".*[Tt]ea.*" )
res14: Boolean = true

scala> s1.replaceAll( raw"[tT]ea", "coffee" )
res16: String = I like coffee before lunch, and coffee after lunch

scala> s1.replaceAll( raw"[tT]ea", "coffee" ).replaceFirst( raw"[Cc]offee", "tea" )
res12: String = I like tea before lunch, and coffee after lunch
```

raw string interpolator prevents expansion of \... sequences in string.

Regular Expressions

- RE Capture groups may be accessed
  - Slightly unusual syntax

```
scala> val s1 = "I like coffee before lunch, and Tea after lunch"
s1: String = I like coffee before lunch, and Tea after lunch

scala> val drink = raw".*([tT]ea|[Cc]offee) before.*([tT]ea|[cC]offee) after.*".r
drink: scala.util.matching.Regex = .*([tT]ea|[Cc]offee) before.*([tT]ea|[cC]offee) after.*

scala> val drink(morningDrink, afternoonDrink) = s1
morningDrink: String = coffee
afternoonDrink: String = Tea
```

Conditional Expressions

- `if` expression
  - Similar syntax to Java/C/C++
  - Similar semantics to ?: operator
  - Yields a value

```
scala> val amount = 25000
amount: Int = 25000

scala> val taxRate = if ( amount < 41000 ) 0.25 else 0.4
taxRate: Double = 0.25

scala> val x = 10
x: Int = 10

scala> if ( x % 2 == 0 ) println("even") else println("odd")
even
```

Pattern Matching

- `match` expression
  - similar to switch statement
  - each branch is an expression

```
scala> val month = 5
month: Int = 5

scala> month match {
     |   case 1  => println("January")
     |   case 2  => println("February")
     |   case 3  => println("March")
     |   case 4  => println("April")
     |   case 5  => println("May")
     |   …
     |   case 12 => println("December")
     |   case _  => println("Ooops")
     | }
May
```

No automatic fall-through, so no need for break

Default case represented using _ wildcard

Pattern Matching

- `match` is an operator (method)
  - Part of expression yielding a value

```
scala> def season ( m: Int ) =
     |   m match {
     |     case 1 | 2 | 3    => "Winter"
     |     case 4 | 5 | 6    => "Spring"
     |     case 7 | 8 | 9    => "Summer"
     |     case 10 | 11 | 12 => "Autumn"
     |     case _            => "Weird"
     |   }
season: (m: Int)java.lang.String

scala> season(2)
res5: java.lang.String = Winter
```

- Example also shows matching multiple values

Pattern Matching

- Case options can have guards associated
  - Allows continuous ranges of values to be matched

```
scala> def state ( t: Int ) =
     |   t match {
     |     case i if ( i < 0 )              => "ice"
     |     case i if ( i >= 0 && i < 100 ) => "water"
     |     case i if ( i >= 100 )           => "steam"
     |   }
state: (t: Int)java.lang.String

scala> state (120)
res9: java.lang.String = steam

scala> state (-10)
res10: java.lang.String = ice
```

While Loop

- Conventional behaviour
  - Imperative style

```
scala> var j = 1
j: Int = 1

scala> var tot = 0
tot: Int = 0

scala> while ( j <= 5 ) {
     |   tot += j
     |   j += 1
     | }

scala> tot
res10: Int = 15
```

Note var used as variables are mutable

```
scala> var j = 1
j: Int = 1

scala> while ( j <= 5 ) {
     |   if ( j % 2 == 0 )
     |     println(j + ": even")
     |   else
     |     println(j + ": odd")
     |   j += 1
     | }
1: odd
2: even
3: odd
4: even
5: odd
```

Basic for Loop

- Special case of for comprehension
- Body is a statement
  - Evaluated for its side effects
  - Control variable is immutable
- Equivalent to foreach on input Seq

```
scala> for ( a <- 1 to 5 ) println(a)
1
2
3
4
5
```

```
scala> 1 to 5 foreach ( println(_) )
1
2
3
4
5
```

Exercises

1. Write a function that converts a Celsius temperature to Fahrenheit

   ```
   f = ( c * 9 / 5 ) + 32
   ```

2. Write a function that converts a String containing a date in the form dd/mm/yy into a full representation of the date. For example, 01/02/15 would be 1st February 2015. Assume dates will not go back further than needed to convert a 2 digit year into a 4 digit year.

3. Lines in a Unix password file have a well defined format:

   ```
   username:password:uid:gid:description:home directory:shell
   ```

   An example line would be

   ```
   root:x:0:0:The SuperUser:/root:/bin/sh
   ```

   Using regular expressions, write code to extract the fields from such lines

Object Oriented Scala

Object Oriented Scala

- Scala supports the OO paradigm
- Every value is an object
  - Compiler uses JVM primitive types when appropriate
- Scala follows the Java approach to OO
  - Classes and traits define object types
  - Singleton objects available
  - Single inheritance of classes
  - Mixin inheritance provided through traits

```
scala> 350.toString
res0: String = 350

scala> :type 350
Int

scala> 350 + 1
res1: Int = 351

scala> (350).+(1)
res2: Int = 351
```

Defining a Class

- Easy to define a new class
  - Instantiate using new
  - REPL provides :javap command to examine bytecodes

```
scala> class MyClass
defined class MyClass

scala> val myObj = new MyClass
myObj: MyClass = MyClass@14bf9759

scala> myObj.toString
res3: String = MyClass@14bf9759
```

```
scala> :javap -c MyClass
Compiled from "<console>"
public class MyClass {
  public MyClass();
    Code:
       0: aload_0
       1: invokespecial #9                  // Method java/lang/Object."<init>":()V
       4: return
}
```

Constructor

- Every class has a "primary" constructor
  - Code embedded between { … }

```
class MyClass {
  println("Building a MyClass")
}

scala> val myObj = new MyClass
Building a MyClass
myObj: MyClass = MyClass@5db45159
```

- Class parameters may be defined
  - Accessible in constructor code

```
class Message( head: String, body: String ) {
  println(s"$head $body")
}

scala> val myMsg = new Message("Hello", "world")
Hello world
myMsg: Message = Message@5c669da8
```

Constructor

- Other constructors may be defined
  - Specify as method called this
  - Allows chaining, as per Java
  - Must eventually execute primary constructor

```
class Message( head: String, body: String ) {
  def this( bd: String ) = this( "Hello", bd )
  println( s"Primary: $head $body")
 }

scala> val myMsg = new Message("Class")
Primary: Hello Class
myMsg: Message = Message@ff6077
```

Class Properties

- Class may have immutable or mutable data properties
    - Use val or var as appropriate

```
class Message ( head: String, body: String ) {
  val msg = s"$head $body"
}


scala> val myMsg = new Message("Hello", "world")
myMsg: Message = Message@6f9ad11c

scala> myMsg.msg
res9: String = Hello world

scala> myMsg.msg = "Goodnight everyone"
<console>:13: error: reassignment to val
       myMsg.msg = "Goodnight everyone"
                 ^
```

Class Parameters and Properties

- Class parameters are not stored as properties
  - Only available in primary constructor

```
class Message ( head: String, body: String ) {
  val msg = s"$head $body"
}


scala> val myMsg = new Message("Hello", "world")
myMsg: Message = Message@6f9ad11c

scala> myMsg.head
<console>:14: error: value head is not a member of Message
       myMsg.head
             ^
```

Class Parameters and Properties

- Use val or var to promote parameters to properties

```
class Message( val head: String, val body: String ) {
  val msg = s"$head $body"
}


scala> val myMsg = new Message("Hello", "world")
myMsg: Message = Message@5f59ea8c

scala> myMsg.head
res12: String = Hello

scala> myMsg.msg
res14: String = Hello world
```

Adding Methods

- Methods define calculations on instances of the class
  - Use def to define methods

```
class Arith ( val i: Int, val j: Int ) {
  def add = i + j
  def sub: Int = i - j
  def addAndMult( by: Int ) = (i + j) * by
}


scala> val arith = new Arith( 5, 2 )
arith: Arith = Arith@6ac4c3f7

scala> arith.add
res15: Int = 7

scala> arith.addAndMult(2)
res16: Int = 14
```

Compiler infers return type

Explicit return type (recommended for public interface)

Parameter types must be specified

val and def – the Uniform Access Principle

- val and def are similar syntactically
  - If def has no parameters

```
class VClass {
  val now = new java.util.Date().toString
}


scala> val vObj = new VClass
vObj: VClass = VClass@16d07cf3

scala> vObj.now
res17: String = Wed Aug 10 11:45:46 CST 2016

scala> vObj.now
res18: String = Wed Aug 10 11:45:46 CST 2016
```

val and def – the Uniform Access Principle

- val causes expression to be evaluated *eagerly*
  - def causes expression to be evaluated *lazily*
  - Caller should not notice different syntax

```
class DClass {
  def now = new java.util.Date().toString
}


scala> val dObj = new DClass
dObj: DClass = DClass@7b53b1ad

scala> dObj.now
res20: String = Wed Aug 10 11:46:09 CST 2016

scala> dObj.now
res21: String = Wed Aug 10 11:46:16 CST 2016
```

A Complete Example

- Complex numbers:
  - A simple (sic) implementation

Default value for property

```
class Complex ( val re: Int, val im: Int = 0 ) {

  def + ( that: Complex ) =
                new Complex( this.re + that.re, this.im + that.im )

  def - ( that: Complex ) =
                new Complex ( this.re - that.re, this.im - that.im )

  override def toString = s"${re} + ${im}i"

}
```

Keyword is mandatory when overriding method from base class

A Complete Example

- Single argument methods can be invoked as operators
  - "Normal" precedence applies for methods named using operator characters

```
scala> val c1 = new Complex(1,2)
c1: Complex = 1 + 2i

scala> val c2 = new Complex(3)
c2: Complex = 3 + 0i

scala> c1.+(c2)
res23: Complex = 4 + 2i

scala> c1 + c2
res24: Complex = 4 + 2i
```

REPL uses toString method for display

A Complete Example

- Method with no arguments can be written as postfix

```
scala> val c1 = new Complex(1,2)
c1: Complex = 1 + 2i

scala> c1 toString
res25: String = 1 + 2i
```

- Define unary_... methods for prefix +, -, !, ~

```
...
  def unary_- = new Complex( -re, -im )
...

scala> -c1
res26: Complex = -1 + -2i
```

Equality

- Scala == and != operators check state equality
  - Compiler translates to call equals() method for compatibility with Java
- Use eq and ne methods to check identity equality
  - For reference types (see later)

```
scala> 3 == 3
res27: Boolean = true

scala> new String("foobar") == new String("foobar")
res28: Boolean = true

scala> new String("foobar") eq new String("foobar")
<console>:12: warning: comparing a fresh object using `eq' will always yield false
       new String("foobar") eq new String("foobar")
                            ^
res29: Boolean = false
```

Singleton Objects

- Class and single automatically created instance
  - Cannot create further instances

```
object MessageObj {
  val hd = "Hello"
  val bd = "World"
  def showMessage = s"$hd $bd"
}


scala> MessageObj.hd
res34: String = Hello

scala> MessageObj.showMessage
res35: String = Hello World
```

```
scala> new MessageObj
<console>:12: error: not found: type MessageObj
       new MessageObj
           ^
```

Companion Objects

- Singleton object compiled in same unit as a class is called a Companion Object
  - Has access to all private items in the class
  - Can be viewed as a container for static data and methods

```
class Message ( val hd: String, val bd: String ) {
  Message.count += 1
}
object Message {
  var count = 0
}
```

```
scala> val m1 = new Message ( "hello", "world" )
m1: Message = Message@3292eff7

scala> val m2 = new Message("I see", "no ships")
m2: Message = Message@59014efe

scala> Message.count
res37: Int = 2
```

- Use :paste mode to have REPL compile both together

Object Factories

- Uses companion object and associated apply() method
  - Compiler rewrites () "operator" to call this method

```
class Message private ( val hd: String, bd: String )

object Message {
  var count = 0
  def apply( h: String, b: String ): Message = {
    count += 1
    new Message(h, b)
  }
}
```

```
scala> val m1 = new Message("from", "the constructor")
<console>:13: error: constructor Message in class Message
                                        cannot be accessed in object $iw
       val m1 = new Message("from", "the constructor")
                ^

scala> val m1 = Message("from", "the factory")
m1: Message = Message@18b45500
```

Case Classes

- Useful for representing types that present "value" semantics
- Compiler provides boilerplate implementation of methods
  - equals, hashcode, toString, copy
- Class parameters are automatically promoted to properties
- Companion object and apply method provided for construction

```
scala> case class Complex ( re: Int, im: Int )
defined class Complex

scala> val c1 = Complex(1,2)
c1: Complex = Complex(1,2)

scala> c1 == Complex(1,2)
res39: Boolean = true
```

Case Classes

- Copy method provides safe copying
  - Possibly altering properties

- Case classes not universally applicable
  - Additional bytecode generated
  - Case class cannot inherit from another case class
  - Normally used for value objects, not service objects

```
scala> c1.copy() == c1
res41: Boolean = true

scala> c1.copy() eq c1
res42: Boolean = false

scala> val c3 = c1.copy( re = 4 )
c3: Complex = Complex(4,2)
```

Named parameter passing

Packages

- Define namespaces, as in Java
- More flexible
  - Can be nested
  - Many packages per source file

```
package myPackage {
  class AA

  package mySubPackage {
    class AB1
    class AB2
  }
}

class C

object foo extends App {
  val a = new myPackage.AA
  val b = new myPackage.mySubPackage.AB1
  val c = new C
}
```

Package Objects

- Allow definition of package-global data and methods

package.scala

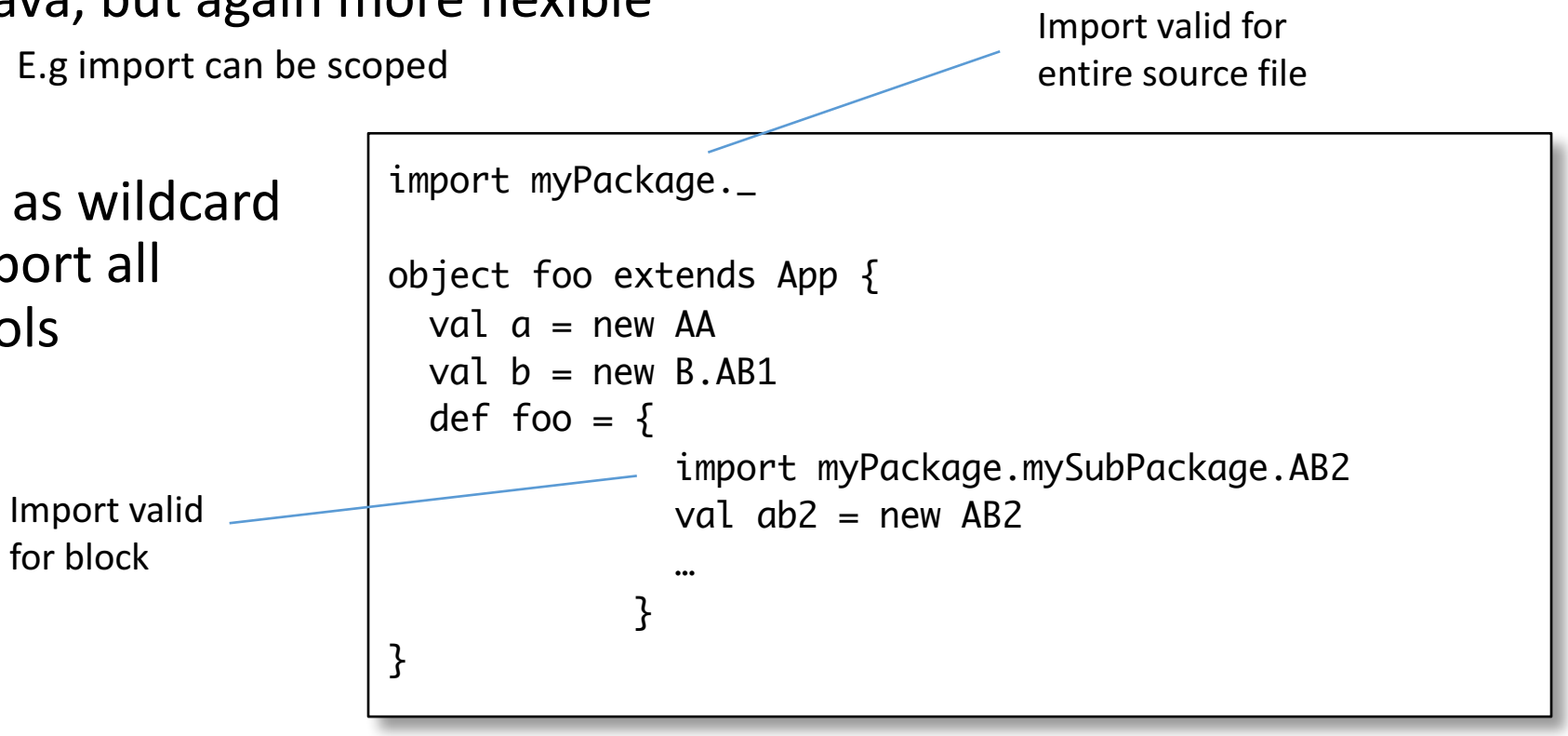
```
package object myPackage {
  val packageGlobalVal = 100;
  def packageGlobalDef = "Hello There"
}
```

- Use like any other package members

```
object MyProg extends App {
  val myVal = myPackage.packageGlobalVal
  println(myPackage.packageGlobalDef)
}
```

Import

- Allows symbols to be used without package qualification
- Like Java, but again more flexible
  - E.g import can be scoped
- Use _ as wildcard to import all symbols



Import

- Import multiple symbols at one time

```
import java.io.{ InputReader, OutputWriter }
```

- Import symbol and create alias
  - Helps deal with name clashes

```
import java.util.Date
import java.sql.{ Date => SqlDate }
```

- Import allowed from entities other than packages
  - package objects
  - singleton objects

Import

- Default imports performed by the compiler

```
import java.lang._
import scala._
import scala.Predef._
```

- scala.Predef defines many useful functions
  - println
  - printf
  - Various read… functions
  - assert
  - require

```
scala> require ( 1 == 0, "WTF???" )
java.lang.IllegalArgumentException: requirement
failed: WTF???
        at
scala.Predef$.require(Predef.scala:233)
        at .<init>(<console>:8)
        at .<clinit>(<console>)
…
```

Visibility

- By default all class members (properties and methods) are public
- Can be restricted to private
  - Visible in containing type only
- …or protected
  - Visible in containing type and subtypes

```
class Person ( val firstName: String,
               val lastName: String,
               private val age: Int ) {

  protected val name = s"${firstName} ${lastName}"
}
```

Visibility

- Visibility restriction can be qualified

- Restricted to package

```
package myPackage

class Person ( val firstName: String,
               val lastName: String,
               private [myPackage] val age: Int ) {

   protected val name = s"${firstName} ${lastName}"
}
```

- Restricted to instance

```
class Person ( val firstName: String,
               val lastName: String,
               private [this] val age: Int ) {

   protected val name = s"${firstName} ${lastName}"
}
```

Inheritance in OO Scala

Inheritance

- Scala classes may inherit from one other class
  - Standard JVM model
  - Non-private members inherited
  - Non-final members may be overridden

```
class Animal ( val name: String ) {
  def eat = println("Hungry....")
  private def mySecret = println("This is my secret")
}

class Lion (n: String ) extends Animal( n ) {
  def roar = println(name + " says Grrr")
  override def eat = println("Rare steak please")
}
```

Invoke superclass constructor with arg

Preventing Subclassing or Overriding

- Use final to prevent a class from being extended

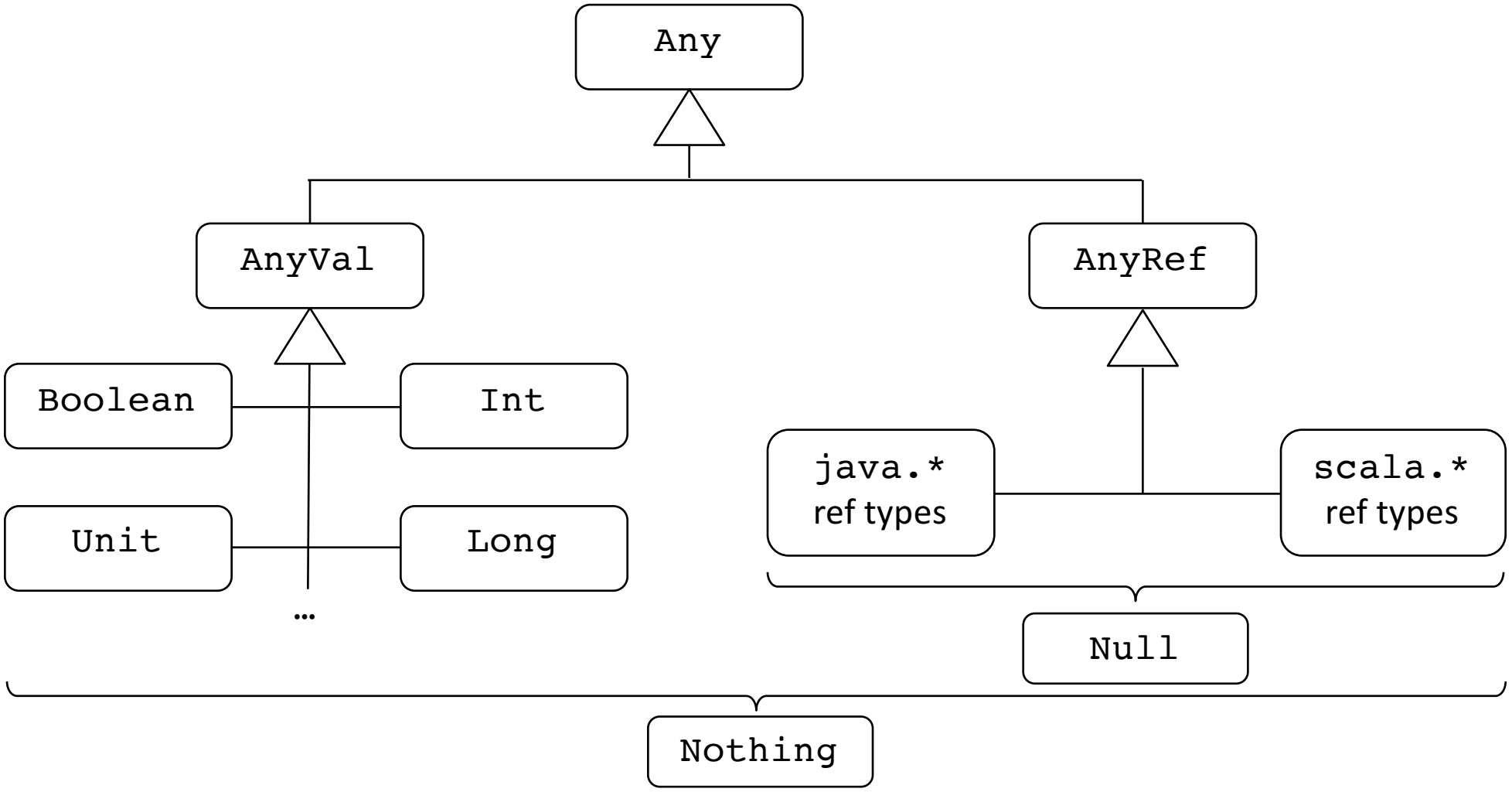
```
scala> final class Animal
defined class Animal

scala> class Lion extends Animal
<console>:12: error: illegal inheritance from final class Animal
       class Lion extends Animal
```

Preventing Subclassing or Overriding

- …or to prevent a member being overridden

```
scala> class Animal { final def eat = println("Hungry") }
defined class Animal

scala> class Lion extends Animal {
     |   override def eat = println("WTF??")
     | }
<console>:13: error: overriding method eat in class Animal of type => Unit;
 method eat cannot override final member
         override def eat = println("WTF??")
```

Scala Class Inheritance Hierarchy



Value Types

- Subtypes of AnyVal
- Present as objects
  - Act as wrappers around JVM primitive types
  - Compiler removes object wrapper when possible
  - Balances efficiency with object capabilities
- New value types may be defined
  - Must wrap a single JVM primitive type
  - Must extend AnyVal

```
class Foo ( i: Int ) {

  def bar = i + 1

}
```

```
scala> :javap -c Foo
Compiled from "<console>"
public class Foo {
  public int bar();
    Code:
       0: aload_0
       1: getfield      #11  // Field i:I
       4: iconst_1
       5: iadd
       6: ireturn

  …
}
```

Abstract Classes

- Class need not provide full implementation of all properties
- Such a class must be marked as abstract
  - Cannot be instantiated

```
abstract class Animal {
  def eat: String
}

scala> new Animal
<console>:13: error: class Animal is abstract; cannot be instantiated
       new Animal
       ^
```

Argument types and result type should be specified

```
class Lion extends Animal {
  override def eat = "Yum"
}

scala> new Lion().eat
res48: String = Yum
```

Keyword not mandatory but advised

Overriding and the Uniform Access Principle

- def may be overridden with a val
  - Subclass causes the property value to become stable
- val may *not* be overridden by a def

```
class Person {
  def age: Int = // Some calculation
}

scala> val p = new Person
p: Person = Person@1c59d3ae

scala> p.age
res23: Int = 22
```

```
class DorianGray extends Person {
  override val age: Int = 21
}
```

Traits

- Trait is similar to Java 8 interface
  - May include implementation
  - May not define construction parameters
  - Use trait to interact with Java interfaces
- Scala class may "inherit" or "mix in" several traits
- Use trait to
  - Advertise public interface
  - Add behaviour to existing type

Why Traits?

- The case for multiple inheritance is normally based on mixins
  - Can help produce a more accurate model

```
scala> abstract class Animal
defined class Animal

scala> class Bird extends Animal { def fly = "wheee" }
defined class Bird

scala> class Fish extends Animal { def swim = "splash" }
defined class Fish

scala> class Seagull extends ?????????

scala> class Penguin extends ?????????
```

Why Traits?

- Start with (abstract) base class
  - Mix in required functionality

```
scala> abstract class Animal
defined class Animal

scala> trait CanSwim { def swim = "Splash" }
defined trait CanSwim

scala> trait CanFly { def fly = "Wheeee" }
defined trait CanFly

scala> class Fish extends Animal with CanSwim
defined class Fish

scala> class Seabird extends Animal with CanFly with CanSwim
```

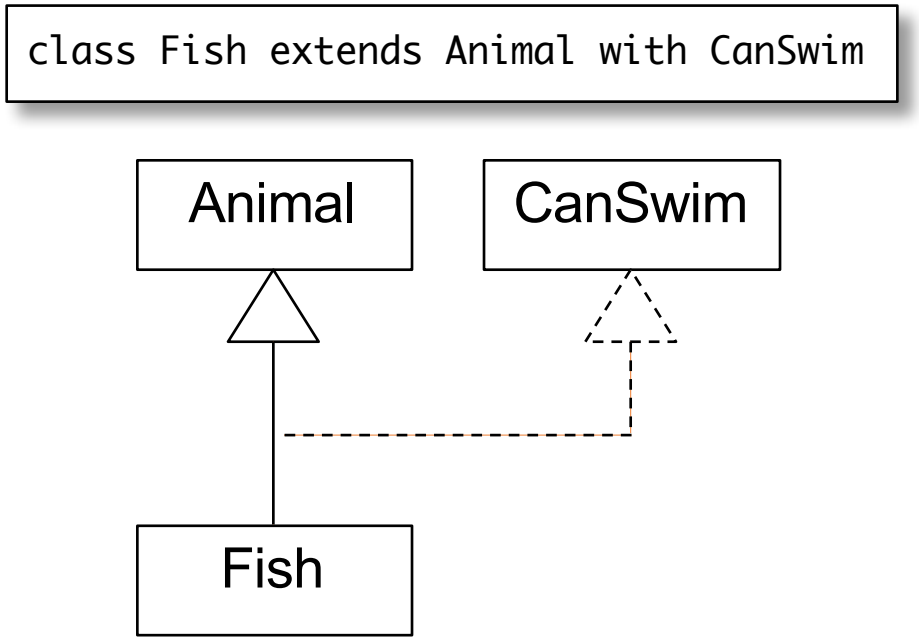
First supertype can be class or trait

Use "with" for subsequent supertypes

Mixins and the super Reference

- Multiple inheritance must resolve the meaning of "super" in the derived class
- Scala's mixin inheritance based on traits forms a single chain of supertypes:

- `Fish`, `CanSwim`, `Animal`, `AnyRef`, `Any`



Mixins and the super Reference

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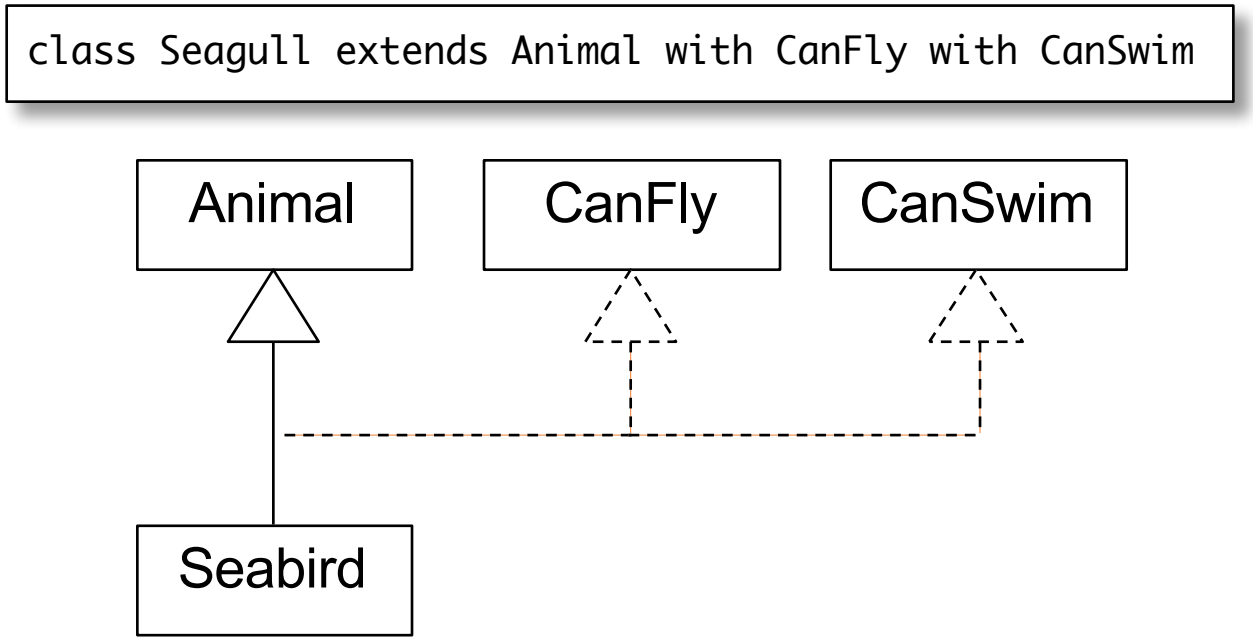

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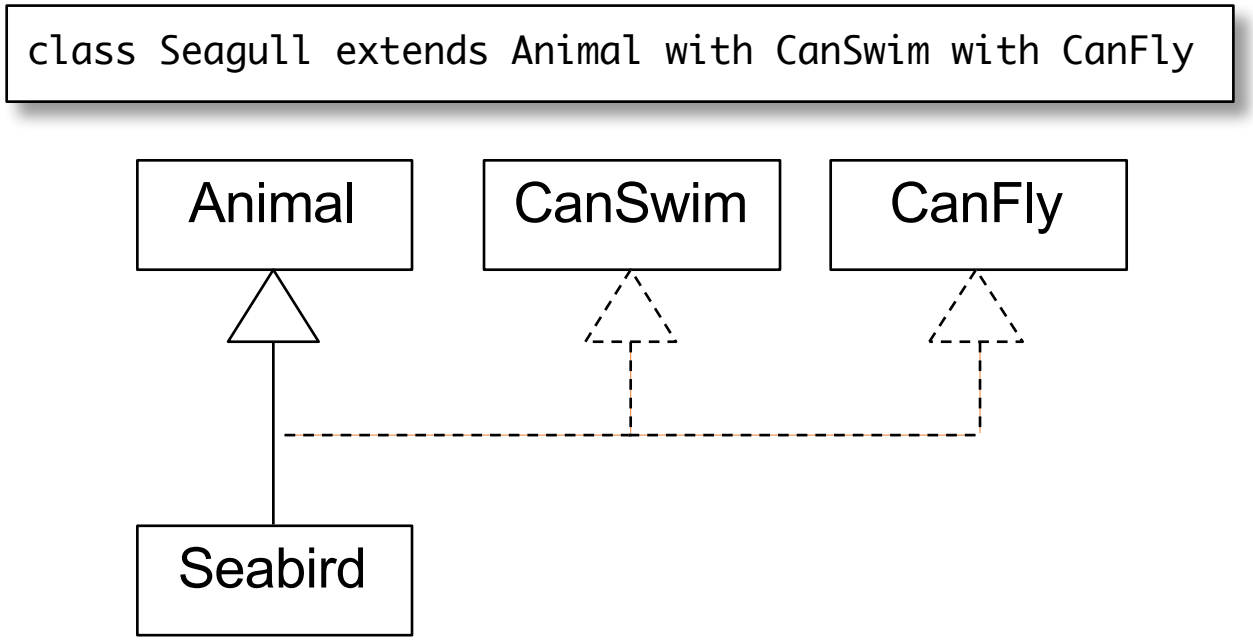


Multiple Implementations in Supertypes

- Ambiguity must be removed

(new C).bar???

```
scala> trait Foo { def bar = "FooBar" }
defined trait Foo

scala> trait Bar { def bar = "BarBar" }
defined trait Bar

scala> class C extends Foo with Bar
<console>:13: error: class C inherits conflicting members:
  method bar in trait Foo of type => String  and
  method bar in trait Bar of type => String
(Note: this can be resolved by declaring an override in class C.)
       class C extends Foo with Bar

scala> class C extends Foo with Bar {
     |   override def bar = super[Foo].bar
     | }
defined class C

scala> (new C).bar
res49: String = FooBar
```

Trait Example

- Add ordering to the Complex class
  - with our own definition of "ordering" of complex numbers!!
- Trait extends java.lang.Comparable
  - provides compareTo() method
  - use [ ] instead of < > for type parameters
- Define two "operator" methods

```
trait Ordered[A] extends java.lang.Comparable[A] {

  def < ( that: A ) = compareTo(that) < 0
  def > ( that: A ) = compareTo(that) > 0

}
```

Using the Trait

- New type – Ordered Complex Numbers
- Extends basic class with capabilities of trait
    - provides implementation of abstract method compareTo() so that trait provided operators will work

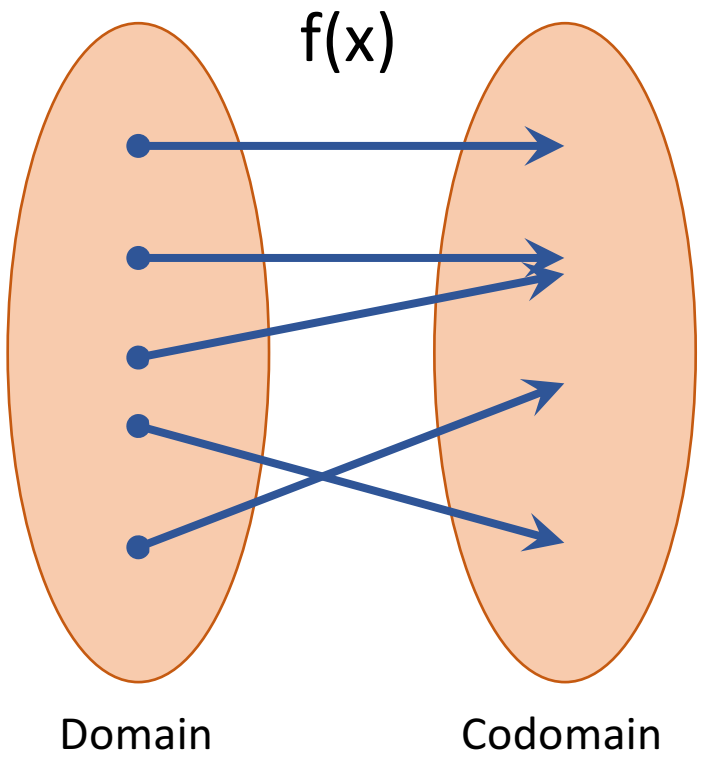
```
class OrdComplex (r: Int = 0, i: Int = 0 )
             extends Complex ( r, i ) with Ordered[OrdComplex] {
  def compareTo(that: OrdComplex): Int = this.re - that.re
}
```

```
scala> val oc1 = new OrdComplex(2,3)
oc1: OrdComplex = OrdComplex@69cab16f

scala> val oc2 = new OrdComplex(3,4)
oc2: OrdComplex = OrdComplex@19db0a1d

scala> oc1 < oc2
res37: Boolean = true
```

Functional Programming in Scala

What is Functional Programming?

- Functional Programming views computation as function evaluation
  - in the mathematical sense
  - avoiding state and mutable data
- FP started with Lisp in the 1950s
  - but the ideas are much older than that…
- Today, many languages support FP
  - Haskell
  - Clojure
  - Scala
  - Java
  - C#
  - C++
  - Python
  - …



What is Functional Programming?

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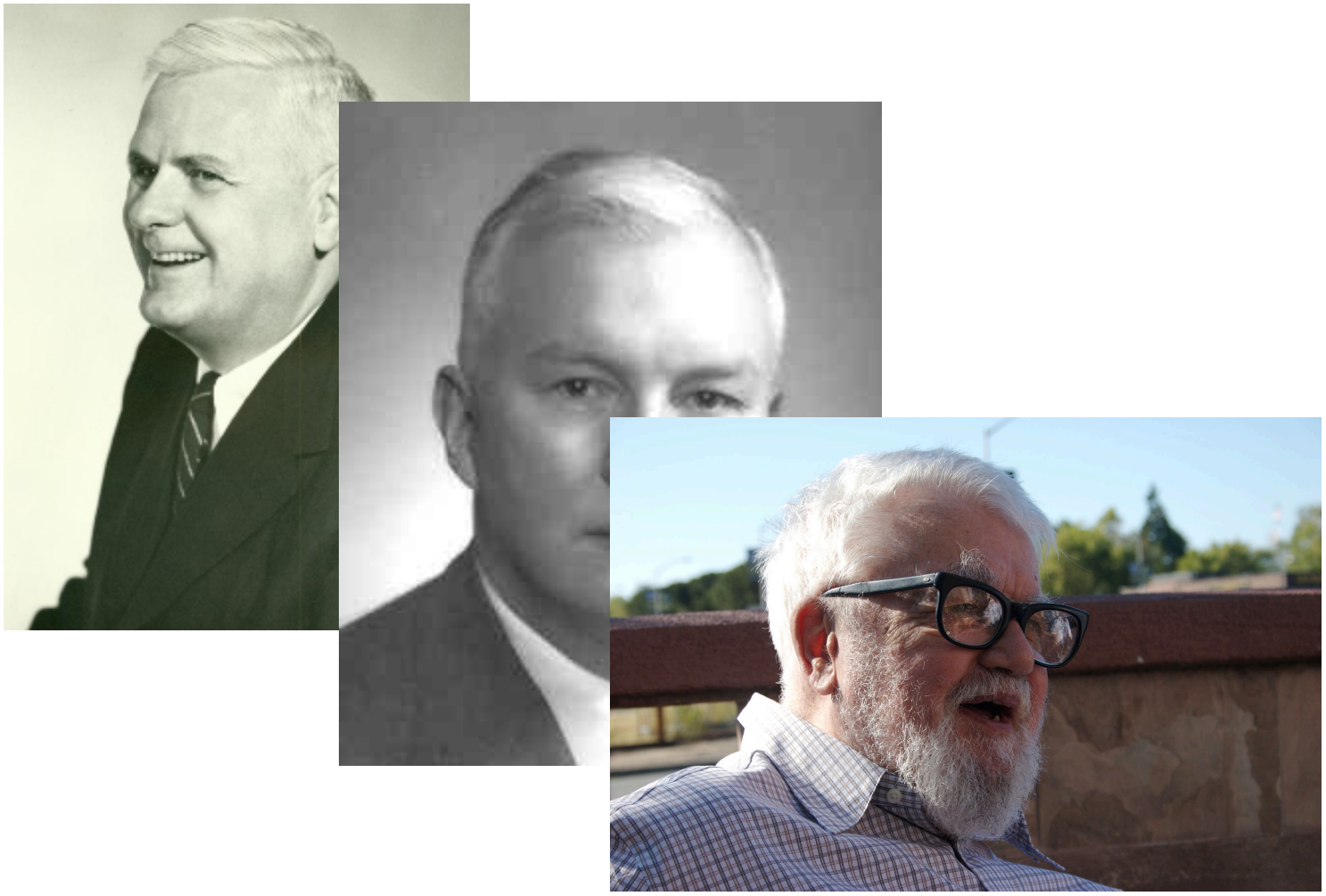


What is Functional Programming?

What is Functional Programming?

What Characterises Functional Programming?

- First-class and higher-order functions
  - lambdas
  - closures
- Immutable state
- Use of recursion
- Declarative style
- Lazy evaluation
- Type inference

What are FP's Strong Points?

- Higher-order functions and declarative style
  - concise expression of algorithms
  - efficient implementation
- Immutable state
  - less concern with concurrency problems
  - easy parallelization
- Especially well suited to Big Data processing
  - declarative style allows flexibility of implementation
  - thanks to ease of parallelization

Functional Programming in Scala

- We have already seen "functions" in Scala

```
scala> def twice ( i: Int ) = i * 2
twice: (i: Int)Int

scala> twice(3)
res59: Int = 6
```

- These are not strictly speaking first class functions
    - E.g. cannot be assigned

```
scala> val doubleIt = twice
<console>:12: error: missing argument list for method twice
…
```

Functional Programming in Scala

- First class functions are objects

```
scala> val doubleIt = (n: Int) => n * 2
doubleIt: Int => Int = <function1>

scala> doubleIt(3)
res60: Int = 6
```

- doubleIt is an instance of a type that extends Function1[Int, Int]
  - trait
  - How does the function get called?

- Many other Function*n* types – up to Function22[…]

Function Literals

- AKA Lambda Expressions

```
scala> (n: Int) => n * n
res61: Int => Int = <function1>

scala> ( (n:Int) => n * n )(10)
res62: Int = 100

scala> val squareIt = (n: Int) => n * n
squareIt: Int => Int = <function1>

scala> (a: Int, b: Int) => a + b
res65: (Int, Int) => Int = <function2>

scala> ((a: Int, b: Int) => a + b)(4,3)
res66: Int = 7
```

Higher Order Functions

- Functions that take other functions as arguments

```
scala> val doIt = ( i: Int, f: Int => Int ) => f(i)
doIt: (Int, Int => Int) => Int = <function2>

scala> doIt(10, doubleIt)
res63: Int = 20

scala> doIt(10, squareIt)
res64: Int = 100
```

Function Composition

- Chaining function invocations, building a pipeline of processing
  - Fundamental principle of functional programming

```
scala> val f = (x: Int) => x + 1
f: Int => Int = <function1>

scala> val g = (x: Int) => x * 2
g: Int => Int = <function1>
```

```
scala> f(2)
res199: Int = 3

scala> g(2)
res200: Int = 4
```

Function Composition

- Chaining function invocations, building a pipeline of processing
  - Fundamental principle of functional programming

```
scala> val f = (x: Int) => x + 1
f: Int => Int = <function1>

scala> val g = (x: Int) => x * 2
g: Int => Int = <function1>

scala> val h = f compose g
h: Int => Int = <function1>
```

```
scala> f(2)
res199: Int = 3

scala> g(2)
res200: Int = 4

scala> h(2)
res202: Int = 5
```

Function Composition

- Chaining function invocations, building a pipeline of processing
  - Fundamental principle of functional programming

```
scala> val f = (x: Int) => x + 1
f: Int => Int = <function1>

scala> val g = (x: Int) => x * 2
g: Int => Int = <function1>

scala> val j = g compose f
j: Int => Int = <function1>
```

```
scala> f(2)
res199: Int = 3

scala> g(2)
res200: Int = 4

scala> j(2)
res203: Int = 6
```

Function Composition

- Chaining function invocations, building a pipeline of processing
  - Fundamental principle of functional programming

```
scala> val f = (x: Int) => x + 1
f: Int => Int = <function1>

scala> val g = (x: Int) => x * 2
g: Int => Int = <function1>

scala> val k = f andThen g
k: Int => Int = <function1>
```

```
scala> f(2)
res199: Int = 3

scala> g(2)
res200: Int = 4

scala> k(2)
res201: Int = 6
```

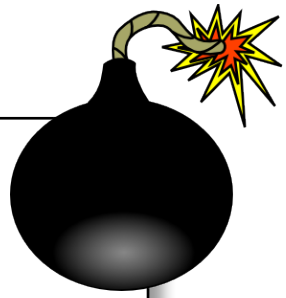
Higher Order Functions

- Functions that return functions

```
scala> val multBy = (n: Int) => ( (x: Int) => x * n )
multBy: Int => (Int => Int) = <function1>

scala> val double = multBy(2)
double: Int => Int = <function1>

scala> val triple = multBy(3)
triple: Int => Int = <function1>

scala> double(4)
res67: Int = 8

scala> triple(4)
res68: Int = 12
```

Closures

- Function definition may refer to external values
- Function "captures" or "closes over" these external values
- Beware closing over mutable state!



```
scala> var extVal = 100
extVal: Int = 100

scala> def foo(n: Int): Int = n * extVal
foo: (n: Int)Int

scala> foo(2)
res0: Int = 200

scala> extVal = 200
extVal: Int = 200

scala> foo(2)
res1: Int = 400
```

Methods and Functions

- Method can be converted to a function object
  - "lifting"
- Use explicit type

```
def myMethod(a: Int) = a + 10
```

```
scala> val myMethod3: Int => Int = myMethod
myMethod3: Int => Int = <function1>

scala> myMethod3(10)
res10: Int = 20
```

- Use special syntax

```
scala> val myMethod2 = myMethod _
myMethod2: Int => Int = <function1>

scala> myMethod2(10)
res8: Int = 20
```

Collections

Tuples

- Aggregate type containing elements of possibly different types
  - Like struct

```
scala> val myTuple = ( 1, "One" )
myTuple: (Int, String) = (1,One)

scala> val myData = ( 3.5, 2, new java.util.Date )
myData: (Double, Int, java.util.Date) = (3.5,2,Thu Aug 11 22:04:28 CST 2016)
```

- Instances of a range of types
  - Tuple1, Tuple2,… Tuple22
  - Tuple2 aliased to Pair
- Known as Product Types
  - Cartesian product

Tuples

- Syntactic sugar available for Pair (Tuple2)

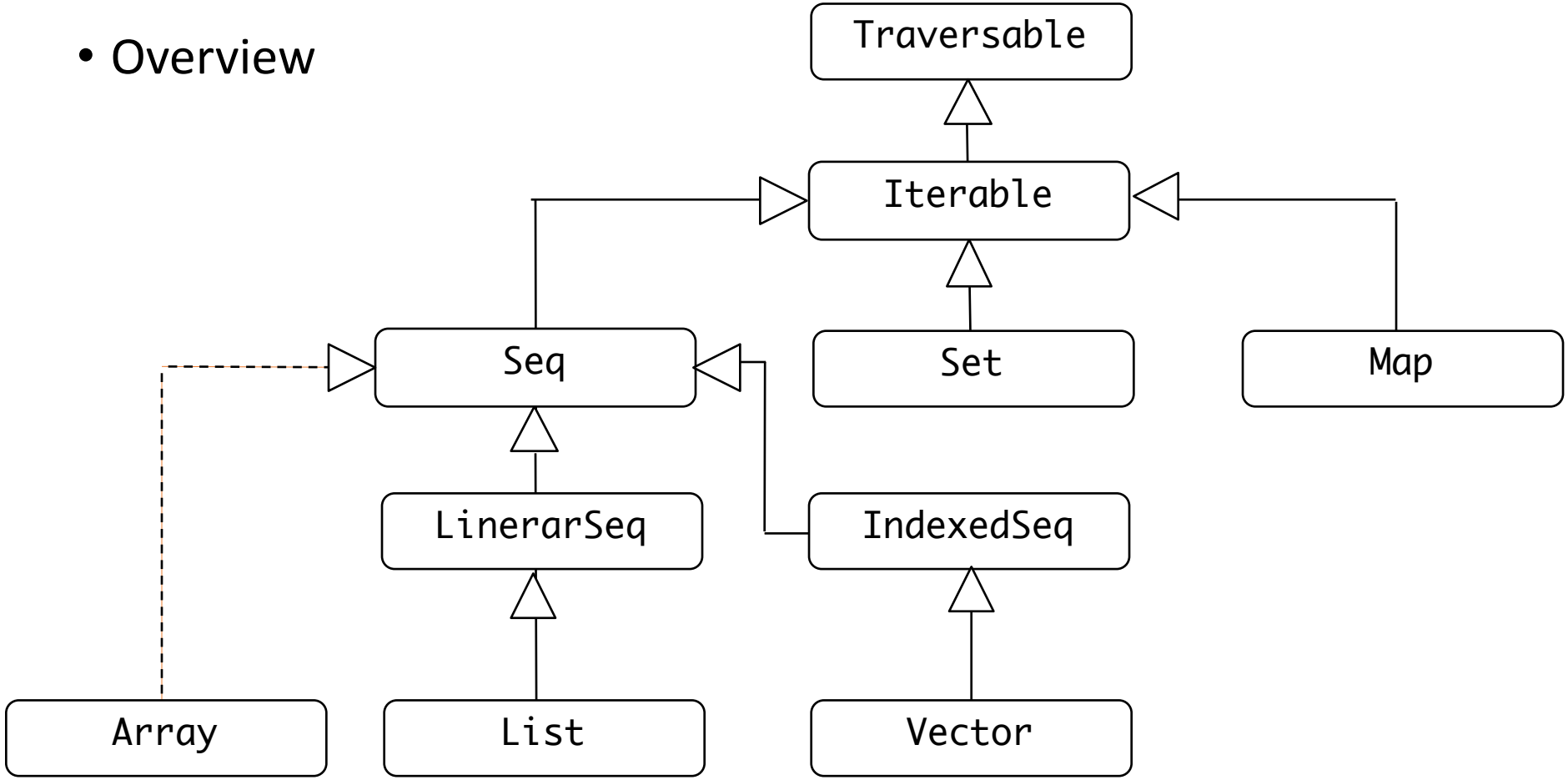
```
scala> val myPair = "George" -> 21
myPair: (String, Int) = (George,21)
```

- Elements of tuple can be accessed using special names
  - _1 for first element
  - *Compiler* checks for "range"

```
scala> myPair._1
res87: String = George

scala> myPair._4
<console>:13: error: value _4 is not a member of (String, Int)
       myPair._4
              ^
```

Collections Types

- Overview



Collections Packages

- Based on implementation characteristics
- Immutable
  - Package scala.collection.immutable
  - Cannot be changed in place (may generate new copies if updates allowed)
  - scala.Predef defines type aliases so default collection types are immutable
  - (Except for Seq, to allow for Arrays)
- Mutable
  - Package scala.collecton.mutable
  - Collections may be changed in place
- Beware – this is not related to val / var

Working with Collections

- Syntactic sugar allows convenient notation to be used
  - Companion object and factory methods

```
scala> val mySeq = List(1,2,3)
mySeq: List[Int] = List(1, 2, 3)

scala> val s1 = Set(1, "Hello")
s1: scala.collection.immutable.Set[Any] = Set(1, Hello)
```

- Note collection types are parameterised
  - Type inference engine can deduce element type from initialisation
  - Can specify element type if extra checking required

```
scala> val v1 = Vector[Int](12, 13, 14)
v1: scala.collection.immutable.Vector[Int] = Vector(12, 13, 14)
```

Seq

- Ordered collection of items
  - Indexed using Int expressions
- Subtypes differ in implementation approach
  - Array – use JVM array types and associated bytecodes
  - IndexedSeq (Vector) – constant time access to elements
  - LinearSeq (List) – Fast head/tail, length functions
- All collection types are parameterised
  - Even Array

```
scala> val a = Array(1, 2, 3)
a: Array[Int] = Array(1, 2, 3)

scala> a(2)
res91: Int = 3

scala> a(1) = 0

scala> a
res93: Array[Int] = Array(1, 0, 3)
```

Seq

- Many methods and properties available

```
scala> val s = Seq( 1, 2, 3, 4 )
s: Seq[Int] = List(1, 2, 3, 4)

scala> s.length
res94: Int = 4

scala> s.indices
res95: scala.collection.immutable.Range = Range(0, 1, 2, 3)

scala> s.reverse
res96: Seq[Int] = List(4, 3, 2, 1)

scala> s.contains(2)
res97: Boolean = true
```

Seq

```
scala> s :+ 5
res98: Seq[Int] = List(1, 2, 3, 4, 5)

scala> 0 +: s
res99: Seq[Int] = List(0, 1, 2, 3, 4)

scala> s ++ Seq(4, 5, 6, 7)
res100: Seq[Int] = List(1, 2, 3, 4, 4, 5, 6, 7)

scala> s.count ( _ == 4 )
res101: Int = 1

scala> val names = Seq("tom", "dick", "harry")
names: Seq[String] = List(tom, dick, harry)

scala> names.sorted
res103: Seq[String] = List(dick, harry, tom)

scala> names.sortWith((a,b) => a.length.compareTo(b.length) < 0)
res105: Seq[String] = List(tom, dick, harry)
```

Right binding operator

Note List is immutable type

Set

- Unordered collection, no duplicates
  - Smaller number of methods

```
scala> val odds = Set( 1, 3, 5, 7, 9 )
odds: scala.collection.immutable.Set[Int] = Set(5, 1, 9, 7, 3)

scala> odds.contains(3)
res110: Boolean = true

scala> odds & Set( 3, 4, 5 )
res109: scala.collection.immutable.Set[Int] = Set(5, 3)

scala> odds | Set( 3, 4, 5 )
res111: scala.collection.immutable.Set[Int] = Set(5, 1, 9, 7, 3, 4)

scala> odds &~ Set( 3, 4, 5 )
res113: scala.collection.immutable.Set[Int] = Set(1, 9, 7)

scala> odds + 4
res115: scala.collection.immutable.Set[Int] = Set(5, 1, 9, 7, 3, 4)

scala> odds + 11
res116: scala.collection.immutable.Set[Int] = Set(5, 1, 9, 7, 3, 11)
```

Map

- Collection of (key, value) pairs
  - Can be constructed out of a collection of Pair(Tuple2) objects

```
scala> val capitals = Map( "Denmark" -> "Copenhagen",
                           "Sweden" -> "Stockholm",
                           "Norway" -> "Oslo" )
capitals: scala.collection.immutable.Map[String,String] = Map(Denmark ->
Copenhagen, Sweden -> Stockholm, Norway -> Oslo)

scala> capitals.keys
res117: Iterable[String] = Set(Denmark, Sweden, Norway)

scala> capitals.values
res118: Iterable[String] = MapLike(Copenhagen, Stockholm, Oslo)
```

Map

- Lookup operation through apply method
  - "Associative Array"
  - Exception if no such key, alternative approaches available

```
scala> capitals("Norway")
res120: String = Oslo

scala> capitals("Finland")
java.util.NoSuchElementException: key not found: Finland
  at scala.collection.MapLike$class.default(MapLike.scala:228)
  at scala.collection.AbstractMap.default(Map.scala:59)
  at scala.collection.MapLike$class.apply(MapLike.scala:141)
  at scala.collection.AbstractMap.apply(Map.scala:59)
  ... 32 elided

scala> capitals.getOrElse("Finland", "I have no idea")
res123: String = I have no idea
```

Map

- Use MutableMap type to add or change entries

```
scala> val mCapitals = collection.mutable.Map() ++ capitals
mCapitals: scala.collection.mutable.Map[String,String] = Map(Norway -> Oslo,
Denmark -> Copenhagen, Sweden -> Stockholm)

scala> mCapitals("Finland") = "Helsinki"

scala> mCapitals += "Iceland" -> "Reykjavik"
res131: mCapitals.type = Map(Norway -> Oslo, Denmark -> Copenhagen, Iceland ->
Reykjavik, Sweden -> Stockholm, Finland -> Helsinki)

scala> val capitals2 = mCapitals toMap
capitals2: scala.collection.immutable.Map[String,String] = Map(Denmark ->
Copenhagen, Iceland -> Reykjavik, Finland -> Helsinki, Sweden -> Stockholm,
Norway -> Oslo)
```

Change back to immutable Map

Dealing With Optional Values

- What should be returned when we use a non-existent key to retrieve value from a Map?
    - Throw Exception…
    - Return special value (e.g null)
- Neither of these is type safe
    - What is the type of null in Java???
- Need an equivalent to SQL's NULL
    - Representation of "no value"

Dealing With Optional Values

- Option[T] is the type of a value that may or may not be present
  - If present, the value will have type T
- Represented by a sealed type hierarchy
  - Two case class subtypes of Option[T]
  - Some[T] is a container for a value of type T
  - None represents no value

```
scala> capitals.get("Denmark")
res0: Option[String] = Some(Copenhagen)

scala> capitals.get("Finland")
res1: Option[String] = None
```

Success and failure cases both have the same type

Dealing With Optional Values

- Retrieve the actual value using the get mathod
  - Returns value of type T if present
  - Throws NoSuchElementException if no value

- Use getOrElse to return "default" value in case where no value is present

```
scala> capitals.get("Denmark").get
res2: String = Copenhagen

scala> capitals.get("Finland").get
java.util.NoSuchElementException: None.get
  at scala.None$.get(Option.scala:347)
  at scala.None$.get(Option.scala:345)
  ... 32 elided

scala> capitals.get("Finland").getOrElse("I don't know")
res4: String = I don't know
```

Dealing With Optional Values

- Pattern matching can also be used

```
scala> val capitalOf = ( country: String ) => capitals.get(country) match {
     |   case Some(city) => city
     |   case None => "Unknown"
     | }
capitalOf: String => String = <function1>

scala> capitalOf("Norway")
res5: String = Oslo

scala> capitalOf("Iceland")
res6: String = Unknown
```

- Further possibilities (see later)

Functional Programming and Collections

- Conventional approach based on Iterator pattern
  - Process each element in turn
  - "External" iteration
- Collections lend themselves to functional programming style
  - Algorithms can elegantly be specified
  - "Internal" iteration
- Based on Higher Order Functions
  - map
  - flatMap
  - filter
  - …

Using Higher Order Functions

- Large range of methods defined on collections

```
scala> val range1 = 1 to 5
range1: scala.collection.immutable.Range.Inclusive = Range(1, 2, 3, 4, 5)

scala> range1.foreach( i => print(s"$i ") )
1 2 3 4 5

scala> range1 forall ( i => i <= 5 )
res133: Boolean = true

scala> range1 exists ( i => i == 10 )
res134: Boolean = false
```

Using map

- Return a new collection
  - Apply function to elements in source to generate elements in result

```
scala> val range1 = 1 to 5
range1: scala.collection.immutable.Range.Inclusive = Range(1, 2, 3, 4, 5)

scala> val plusOne = range1.map( i => i + 1 )
plusOne: scala.collection.immutable.IndexedSeq[Int] = Vector(2, 3, 4, 5, 6)

scala> val sList = List("one", "two", "three")
sList: List[String] = List(one, two, three)

scala> sList.map( s => s.toUpperCase )
res135: List[String] = List(ONE, TWO, THREE)
```

Combining Elements from a Collection

- foldLeft and foldRight
  - Function argument determines how elements are combined
  - Notice functions are defined in "curried" form – two argument lists
  - foldRight scans elements right to left

```
val theSum = range1.foldLeft(0)( (i, j) => i + j )
```

Initial Value

Accumulating "Total"

Element to process

```
scala> val pathName = sList.foldLeft("")( (a, b) => s"$a/$b" )
pathName: String = /one/two/three

scala> val pathName = sList.foldRight("")( (a, b) => s"$a/$b" )
pathName: String = one/two/three/
```

Initial Value

Element to process

Selecting Elements from a Collection

- filter
  - Elements placed into new collection based on supplied predicate function

```
scala> val oddNumbers = range1.filter ( _ % 2 != 0 )
oddNumbers: scala.collection.immutable.IndexedSeq[Int] = Vector(1, 3, 5)

scala> val strings = sList.filter( s => s.length > 3 )
strings: List[String] = List(three)

scala> val word = "fortunately"
word: String = fortunately

scala> word.seq
res139: scala.collection.immutable.WrappedString = fortunately

scala> word.seq.filter("aeiou".contains(_) )
res140: scala.collection.immutable.WrappedString = ouae
```

Partitioning a Collection

- partition method
  - Return a Tuple2 of collections

```
scala> range1.partition( _ % 2 == 0 )
res141: (scala.collection.immutable.IndexedSeq[Int],
scala.collection.immutable.IndexedSeq[Int]) = (Vector(2, 4),Vector(1, 3, 5))

scala> word.seq.partition ( "aeiou".contains(_) )
res142: (scala.collection.immutable.WrappedString,
scala.collection.immutable.WrappedString) = (ouae,frtntly)
```

- groupBy gives more general grouping/partitioning capability

```
scala> 1 to 10 groupBy ( _ % 3 )
res143:
scala.collection.immutable.Map[Int,scala.collection.immutable.IndexedSeq[Int]]
= Map(2 -> Vector(2, 5, 8), 1 -> Vector(1, 4, 7, 10), 0 -> Vector(3, 6, 9))
```

Joining Collections

- Zip
  - Combines Seq[A] and Seq[B] objects into Seq[Tuple2[A,B]]

```
scala> 1 to 3 zip sList
res145: scala.collection.immutable.IndexedSeq[(Int, String)] =
        Vector((1,one), (2,two), (3,three))
```

- Also zipWithIndex

```
scala> val colours = List("Red", "Green", "Blue")
colours: List[String] = List(Red, Green, Blue)

scala> colours zipWithIndex
warning: there was one feature warning; re-run with -feature for details
res146: List[(String, Int)] = List((Red,0), (Green,1), (Blue,2))
```

Nested Collections

- Collections can contain other collections
  - Often the result of call to map

```
scala> val text = List("Here is the first line", "this is the second line")
text: List[String] = List(Here is the first line, this is the second line)

scala> val splitlines = text.map( _.split(" ") )
splitlines: List[Array[String]] =
List(Array(Here, is, the, first, line), Array(this, is, the, second, line))
```

- Flatten method removes one level of nesting

```
scala> splitlines flatten
res150: List[String] =
List(Here, is, the, first, line, this, is, the, second, line)
```

Combining map and flatten

- flatMap
  - Very important function
  - Forms basis of many idioms in Scala and functional programming
  - Used with many types, not just collections
  - E.g. Option[T], Future[T], Try{T]
  - Monads

```
scala> val words = text.flatMap( _.split(" ") )
words: List[String] =
         List(Here, is, the, first, line, this, is, the, second, line)
```

Option[T] and the Higher Order Functions

- map, flatMap, foreach, etc all defined on Option[T] type
  - Allow processing on results of operations without forcing null check

```
scala> capitals.get("Norway").map(_.toUpperCase)
res10: Option[String] = Some(OSLO)

scala> capitals.get("Finland").map(_.toUpperCase)
res11: Option[String] = None

scala> capitals.get("Norway").foreach( println(_) )
Oslo

scala> capitals.get("Iceland").foreach( println(_) )

scala>
```

The for Comprehension

- Used to generate a new instance of a container type
  - E.g. collections
  - Yield operator specifies how elements are generated

```
scala> val squares = for ( i <- 1 to 5 ) yield i * i
squares: scala.collection.immutable.IndexedSeq[Int] = Vector(1, 4, 9, 16, 25)
```

- Equivalent to map
  - Compiler rewrites for comprehension to use map

```
scala> val squares = 1 to 5 map ( i => i * i )
squares: scala.collection.immutable.IndexedSeq[Int] = Vector(1, 4, 9, 16, 25)
```

The for Comprehension

- Can also specify nested for comprehensions

```
scala> val coordinates = for ( x <- 1 to 3;
     |                         y <- 6 to 9 )
     |                    yield (x,y)
coordinates: scala.collection.immutable.IndexedSeq[(Int, Int)] =
             Vector((1,6), (1,7), (1,8), (1,9), (2,6), (2,7), (2,8), (2,9),
                    (3,6), (3,7), (3,8), (3,9))
```

- Equivalent to combination of flatMap and map

```
scala> val coordinates = 1 to 3 flatMap ( x => 6 to 9 map ( y => (x,y) ) )
coordinates: scala.collection.immutable.IndexedSeq[(Int, Int)] =
             Vector((1,6), (1,7), (1,8), (1,9), (2,6), (2,7), (2,8), (2,9),
                    (3,6), (3,7), (3,8), (3,9))
```

The for Comprehension

- for comprehension can include guard

```
scala> val coordinates = for ( x <- 1 to 3 if x % 2 != 0;
     |                         y <- 6 to 9 if y %2 == 0 )
     |                     yield ( x, y )
coordinates: scala.collection.immutable.IndexedSeq[(Int, Int)] =
             Vector((1,6), (1,8), (3,6), (3,8))
```

- Equivalent to use of filter

```
scala> val coordinates = 1 to 3 filter ( _ % 2 != 0 ) flatMap (
                            x => 6 to 9 filter ( _ % 2 == 0 ) map (
                                    y => (x,y) ) )
coordinates: scala.collection.immutable.IndexedSeq[(Int, Int)] = Vector((1,6),
(1,8), (3,6), (3,8))
```

The for Loop

- Special case of for comprehension
  - Function argument returns Unit

```
scala> for ( i <- 1 to 5 ) print (s"$i ")
1 2 3 4 5
```

- Equivalent to foreach higher order function

```
scala> 1 to 5 foreach { i => print(s"$i ") }
1 2 3 4 5
```

- Can also be used with guards

Option[T] with for Comprehensions

- Recall that for comprehension is rewritten as combinations of map, flatMap and filter
    - Option[T] supports these methods

```
scala> val countries = List("Denmark", "USA", "Sweden")
countries: List[String] = List(Denmark, USA, Sweden)

scala> for ( c <- countries;
     |       cap <- capitals.get(c) )
     |     yield(c, cap)
res14: List[(String, String)] = List((Denmark,Copenhagen), (Sweden,Stockholm))
```

```
scala> countries flatMap ( c => capitals.get(c) map ( cap => (c,cap) ) )
res15: List[(String, String)] = List((Denmark,Copenhagen), (Sweden,Stockholm))
```

More About Functional Programming in Scala

Recursion

- Functional programming paradigm prefers recursion to iteration
  - Less dependency on mutable state
  - Supports declarative style
- Many algorithms can be expressed in a recursive way

```
scala> def factorial ( i: Int ): BigInt = i match {
     |   case 0 => 1
     |   case _ => i * factorial(i - 1)
     | }
factorial: (i: Int)BigInt

scala> factorial(0)
res163: BigInt = 1

scala> factorial(10)
res168: BigInt = 3628800

scala> factorial(10000)
java.lang.StackOverflowError
...
```

Tail Recursion and Tail Call Elimination

- Every recursive call needs a new stack frame
  - Deep recursion can cause stack overflow error
- Tail recursion occurs when
  - Recursive call is last action of a function
  - Result of the function call is returned directly

```
scala> def gcd ( a: Int, b: Int ): Int = if ( b == 0 ) a else gcd( b, a % b )
gcd: (a: Int, b: Int)Int

scala> gcd(14,35)
res170: Int = 7
```

- Tail call elimination is an optimisation that can be used here
  - Reuse current stack frame for recursive call
  - Recursion effectively becomes iteration

Tail Recursion and Tail Call Elimination

- Not all algorithms are tail recursive by default
  - Scala compiler will generate tail call elimination code when possible
  - Otherwise normal recursion
- @tailrec annotation causes compilation failure if no tail recursion in annotated function

```
scala> @tailrec
     | def factorial( i: Int ): BigInt = i match {
     |    case 0 => 1
     |    case _ => i * factorial(i-1)
     | }
<console>:16: error: could not optimize @tailrec annotated method factorial:
                     it contains a recursive call not in tail position
         case _ => i * factorial(i-1)
                       ^
```

Tail Recursion and Tail Call Elimination

- Non tail-recursive function can often be transformed into tail-recursive
  - Introduce argument to pass accumulated value to next call

```
scala> def factorial( n: Int ): BigInt = {
     |   @tailrec def fact( n: Int, accum: BigInt ): BigInt = n match {
     |     case 0 => accum
     |     case _ => fact ( n-1, n * accum )
     |   }
     |   fact(n,1)
     | }
factorial: (n: Int)BigInt

scala> factorial(10000)
res176: BigInt = 284625968091705451890641321211986889014805140170279923079417999427
441134000376444377299078675778477581588406214231752883004233994015351873905242 1
...
```

Use nested method to avoid changing external interface

Currying

- Currying is a technique to transform a function taking 2 or more arguments into a composition of functions taking 1 argument

Function that takes one Int parameter and returns another function from Int to Int

Function that adds 2 to its Int argument

```
scala> val add = ( a: Int, b: Int ) => a + b
add: (Int, Int) => Int = <function2>

scala> add.curried
res182: Int => (Int => Int) = <function1>

scala> add.curried(2)
res183: Int => Int = <function1>

scala> add.curried(2)(3)
res184: Int = 5
```

Partial Function Application

- Currying a function allows partial application
  - Generate a function that effectively fixes the first argument(s)
  - Use this generated function further

```
scala> val add2 = add.curried(2)
add2: Int => Int = <function1>

scala> add2(3)
res185: Int = 5
```

```
scala> val foo = (a: Int, b: Int, c: Int) => a + b + c
foo: (Int, Int, Int) => Int = <function3>

scala> def add23 = foo.curried(2)(3)
add23: Int => Int

scala> add23(4)
res186: Int = 9
```

Lazy Parameter Evaluation

- AKA Pass By Name
- Suppresses evaluation of actual parameter expression until parameter is used in the function

```
def showTheTime ( t: java.util.Date ) = {
  println(s"The time is $t")
  Thread.sleep(1000)
  println(s"The time is $t")
}


scala> showTheTime( new java.util.Date )
The time is Sat Aug 13 20:52:49 CST 2016
The time is Sat Aug 13 20:52:49 CST 2016
```

Evaluated on call
Value used inside function

Lazy Parameter Evaluation

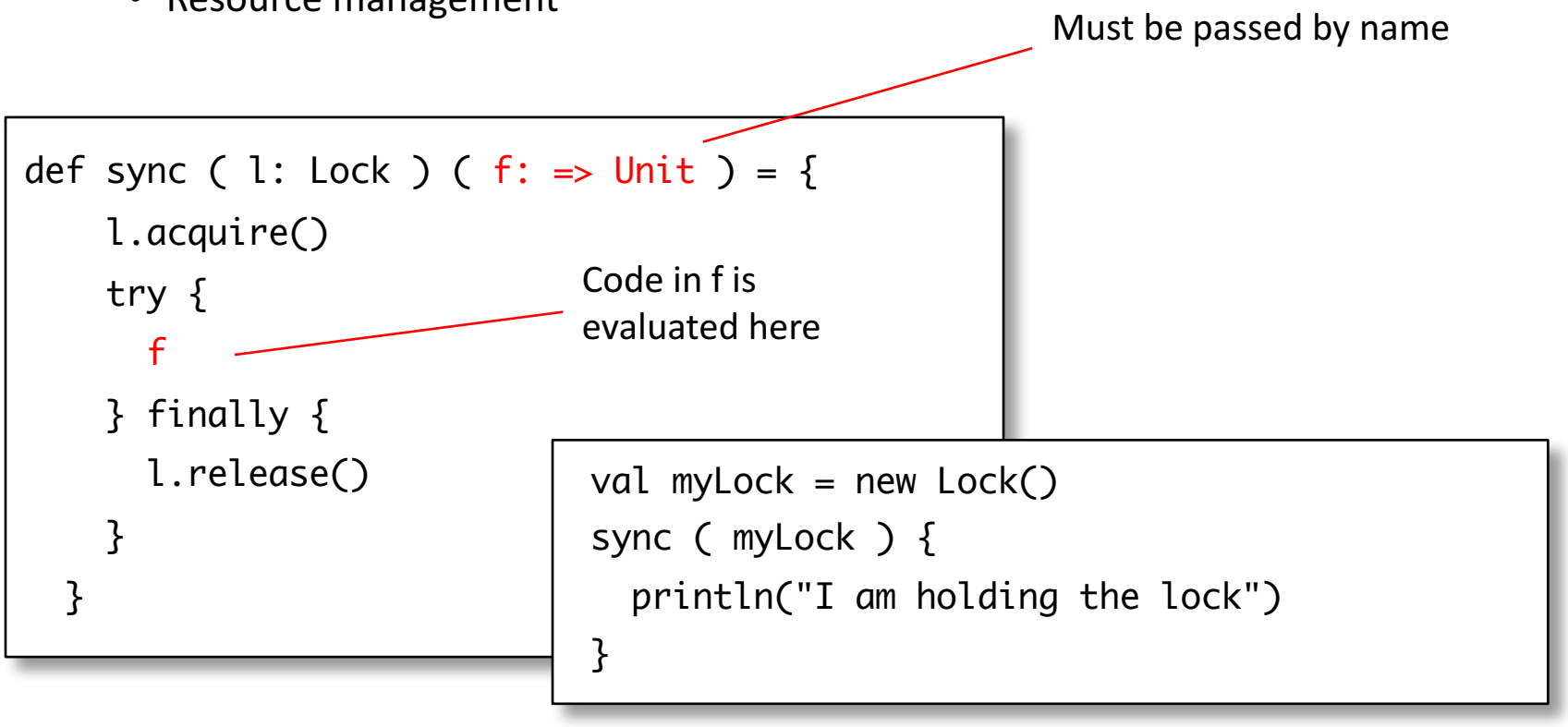
- Parameter passing is normally by value
- Actual parameter expression is evaluated as part of call

```
def showTheTime ( t: => java.util.Date ) = {
  println(s"The time is $t")
  Thread.sleep(1000)
  println(s"The time is $t")
}


scala> showTheTime(new java.util.Date)
The time is Sat Aug 13 21:23:56 CST 2016
The time is Sat Aug 13 21:23:57 CST 2016
```

Evaluated each time parameter is used during the function call

Managing Resources

- Curried function/method definition and pass by name parameters allow definition of powerful structures within a program
  - Resource management



Partial Functions

- Partially defined, not partially evaluated (curried)
- Function not defined over its entire domain
  - E.g sqrt over Int
- Scala provides type level support for partial functions
- PartialFunction type is subtype of Function1
  - Defines two additional methods
  - `def isDefinedAt(a: A): Boolean`
  - `def orElse(that: PartialFunction[A,B]): PartialFunction[A,B]`

Defining a Partial Function

- Case alternatives

```
scala> val pf: PartialFunction[Int, String] = {
     |   case 1 => "one"
     |   case 2 => "two"
     |   case 3 => "three"
     | }
pf: PartialFunction[Int,String] = <function1>

scala> pf isDefinedAt(2)
res55: Boolean = true

scala> pf(2)
res56: String = two

scala> pf isDefinedAt(4)
res57: Boolean = false

scala> pf(4)
scala.MatchError: 4 (of class java.lang.Integer)
  at
scala.PartialFunction$$anon$1.apply(PartialFunction.scala:248)
  …
```

Defining a Partial Function

- Implement the required methods

```
scala> object SquareRoot extends PartialFunction[Int, Double] {
     |  def apply ( i: Int ) = if ( i >= 0 ) Math.sqrt(i) else
     |         throw new IllegalArgumentException("…")
     |  def isDefinedAt(i: Int ) = ( i >= 0 )
     | }
defined module SquareRoot

scala> SquareRoot isDefinedAt(4)
res62: Boolean = true

scala> SquareRoot(4)
res63: Double = 2.0

scala> SquareRoot isDefinedAt(-1)
res64: Boolean = false

scala> SquareRoot(-1)
java.lang.IllegalArgumentException: Negative sqrt not cool
        at SquareRoot$.apply$mcDI$sp(<console>:17)
```

Map as a Partial Function

- Map type is a mapping from keys to values
  - Not every value from the key type may have a mapping
  - Hence Map is a partial function

```
scala> val squares = Map( 1->1, 2->4, 3->9)
squares: scala.collection.immutable.Map[Int,Int] = Map(1 -> 1, 2 -> 4, 3 -> 9)

scala> squares isDefinedAt(2)
res190: Boolean = true

scala> squares isDefinedAt(4)
res191: Boolean = false

scala> squares(2)
res192: Int = 4

scala> squares(4)
java.util.NoSuchElementException: key not found: 4
  at scala.collection.MapLike$class.default(MapLike.scala:228)
  …
```

Composing Partial Functions

- Composition of partial functions means providing mappings for previously undefined values
  - orElse method
  - Does not overwrite existing values if key already present

```
scala> val moreSquares = squares orElse Map( 4-> 16, 5->25 )
moreSquares: PartialFunction[Int,Int] = <function1>

scala> moreSquares isDefinedAt(4)
res195: Boolean = true

scala> moreSquares(4)
res196: Int = 16
```

Dealing with Exceptions in Scala

Scala and Exceptions

- Scala designed to run on the JVM
  - Exceptions are a basic feature of the JVM
  - Many Java methods will throw exceptions
- Scala does not support checked exceptions
  - Handling is not enforced
- try { … } catch { … } syntax supported
  - But with some differences

```
scala> val s = "123"
s: String = 123

scala> try {
     |   s.toInt
     | } catch {
     |   case e: Exception => println("oops")
     | }
res0: AnyVal = 123
```

Scala and Exceptions

- try { … } catch { … } is an expression
  - Yields a value, but what is the type of this value?

```
scala> val i = try {
     |   s.toInt
     | } catch {
     |   case e: Exception => println("oops")
     | }
i: AnyVal = 123
```

- Could return special value (e.g. -1)
  - Defeats the point of exceptions!!

```
scala> val s = "Foobar"
s: String = xxx

scala> val i = try {
     |   s.toInt
     | } catch {
     |   case e: Exception => println("oops")
     | }
oops
i: AnyVal = ()
```

Using Option[T]

- Encapsulate result in Option[T] type

```
scala> val s = "123"
s: String = 123

scala> val i = try {
     |   Some(s.toInt)
     | } catch {
     |   case e: Exception => None
     | }
i: Option[Int] = Some(123)
```

```
scala> val s = "Foobar"
s: String = Foobar

scala> val i = try {
     |   Some(s.toInt)
     | } catch {
     |   case e: Exception => None
     | }
i: Option[Int] = None
```

- Further processing of result can take place

```
scala> i map ( _ + 4 )
res1: Option[Int] = Some(127)
```

```
scala> i map ( _ + 4 )
res2: Option[Int] = None
```

Using Option[T]

- Use of Option[T] may lead to loss of information
  - Details of exceptions

```
scala> val data = List ( "0", "1", "blah", "2" )
data: List[String] = List(0, 1, blah, 2)

scala> for (
     |   a <- data;
     |   b <- try { Some(a.toInt) }
     |        catch { case ex: Exception => None };
     |   c <- try { Some( 12 / b ) }
     |        catch { case ex2: Exception => None } )
     | yield ( a, c )
res3: List[(String, Int)] = List( (1,12), (2,6) )
```

"blah" fails here

"0" fails here

The Try[T] Type

- Sealed ADT like Option[T]
  - Captures details of non-fatal exceptions
  - Serious faults (e.g. Errors) will still be thrown
  - scala.util.control.NonFatal used to determine if Fatal or Nonfatal

```
scala> import scala.util.{Try, Success, Failure}
import scala.util.{Try, Success, Failure}

scala> Try("123".toInt)
res4: scala.util.Try[Int] = Success(123)

scala> Try("Foobar".toInt)
res5: scala.util.Try[Int] = Failure(java.lang.NumberFormatException:
                                    For input string: "Foobar")
```

Working with Try[T]

- Higher order functions can be used

```
scala> val result = Try { "123".toInt } map { n => n * 2 }
result: scala.util.Try[Int] = Success(246)

scala> val result = Try { "blah".toInt } map { n => n * 2 }
result: scala.util.Try[Int] = Failure(java.lang.NumberFormatException:
                                                    For input string: "blah")

scala> val result = Try { "0".toInt } flatMap { i => Try { 12 / i } }
result: scala.util.Try[Int] = Failure(java.lang.ArithmeticException: / by zero)
```

Working with Try[T]

- Use get method to retrieve value
  - Throws exception if one exists
- Allows "effect" to be exposed at appropriate stage

```
scala> val result = Try { "123".toInt } map { n => n * 2 } get
result: Int = 246

scala> val result = Try { "blah".toInt } map { n => n * 2 } get
java.lang.NumberFormatException: For input string: "blah"
  at java.lang.NumberFormatException.forInputString(NumberFormatException.java:65)
  …

scala> val result = Try { "0".toInt } flatMap { i => Try { 12 / i } } get
java.lang.ArithmeticException: / by zero
  at $anonfun$2$$anonfun$apply$1.apply$mcI$sp(<console>:14)
  …
```

Chaining Calls Using Try[T]

- Common Scala idiom
  - Follow the "happy path"
  - Keep track of failure details

```
scala> val dividend = "15"
dividend: String = 15

scala> val divisor = "3"
divisor: String = 3

scala> for ( x <- Try { dividend.toInt };
     |       y <- Try { divisor.toInt } )
     | yield ( x / y )
res7: scala.util.Try[Int] = Success(5)
```

```
scala> val dividend = "foobar"
dividend: String = foobar

scala> val divisor = "3"
divisor: String = 3

scala> for ( x <- Try { dividend.toInt };
     |       y <- Try { divisor.toInt } )
     | yield ( x / y )
res8: scala.util.Try[Int] = Failure(java.lang.NumberFormatException:
                                    For input string: "foobar")
```