About Scala Types

The Scala Type System

- Static, strong typing
  - Type safety checked at compile time
  - Every value has a type
  - Compiler can infer types in many cases

- Type model is based on Object Oriented principles
  - Concrete types are classes

- Types allow us to describe sets of values
  - At different levels of abstraction
  - Expressed in different ways

Classes

- A class contains a set of properties
  - Data
  - Functions (methods)

```
class Person ( f: String, l: String, val age: Int = 18 ) {
  override def toString = s"$f $l ($age)"
}

val p = new Person ( "John", "Doe" )

println("The person is " + p)   // The person is John Doe (18)
```

Singleton Objects

- Class and a single instance of the class
  - Approximation to Singleton pattern
  - Use object keyword

```
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
```

Companion Objects

- Object with same name as a class is a Companion Object
  - If part of the same compilation unit (ie same source file)
- Use to hold "static" members
- Access available to private properties of class
  - Can be used to implement factories

```
class Complex private ( val re: Int, val im: Int = 0 ) {
  …
}
object Complex {
  def apply( r,i)  = new Complex(r, i)
}
```

```
val c1 = Complex( 1, 2 )
```

Case Classes

- Convenience mechanism for defining classes
  - Especially those exhibiting value semantics

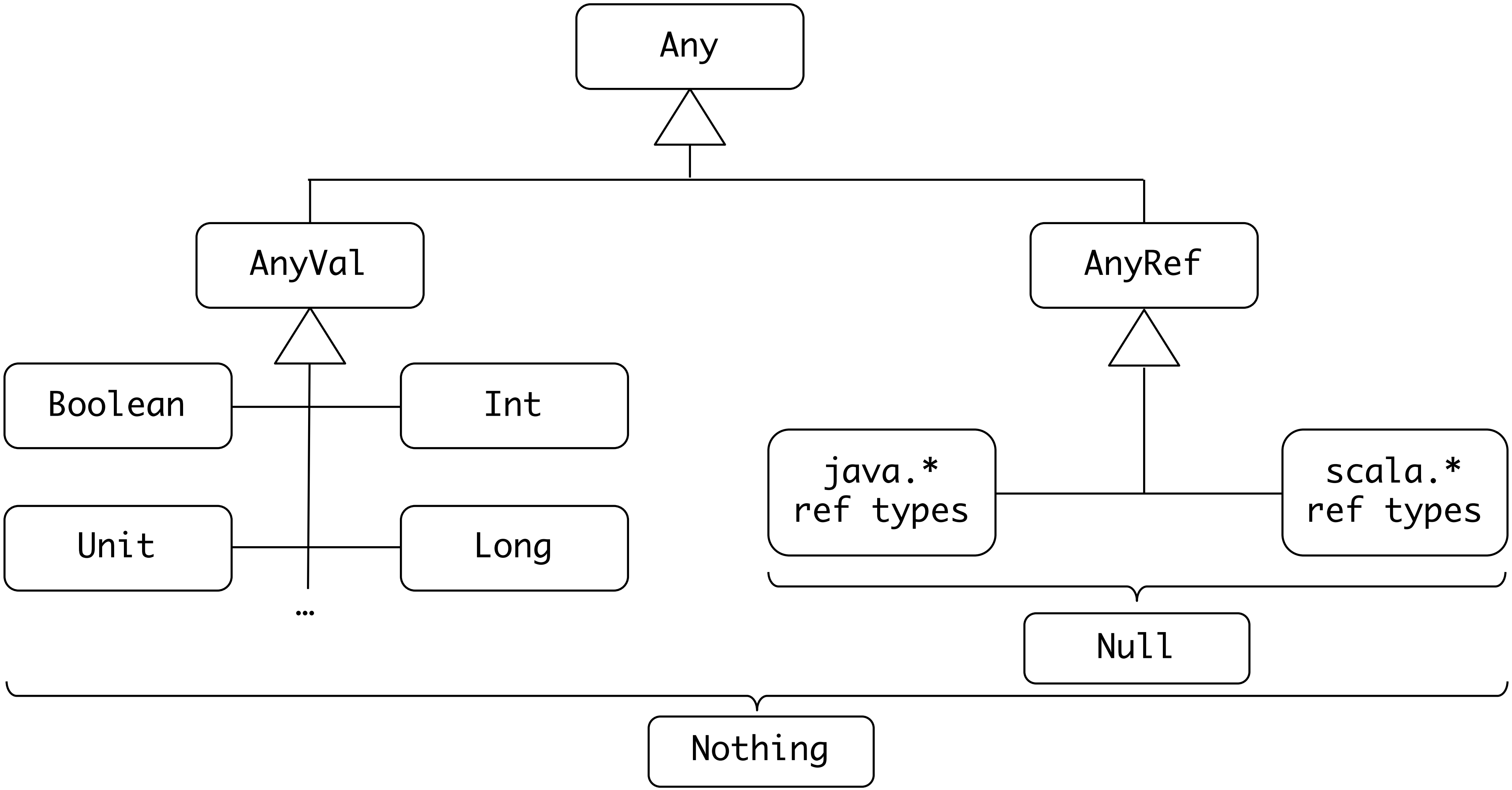
```
case class Money ( dollars: Int, cents: Int )
```

- Compiler generates for commonly used methods
  - toString
  - equals
  - copy / clone
  - Companion object with apply() method for use as factory

- If no class parameters, use case object

```
case object SingleVal
```

Scala Class Hierarchy



Value Classes

- Classes extending AnyVal
  - Intended to wrap JVM primitive types
  - Compiler generates code that operates on unwrapped (primitive) values

```
scala> class MyStuff {
     |    def doSomething ( i: Int ) = i.+(4)
     | }
defined class MyStuff

scala> new MyStuff().doSomething(3)
res6: Int = 7
```

```
scala> :javap -c MyStuff
Compiled from "<console>"
public class MyStuff {
  public int doSomething(int);
    Code:
       0: iload_1
       1: iconst_4
       2: iadd
       3: ireturn
     …
}
```

Value Classes

- Scala allows custom value classes to be defined
  - Builds in extra level of type safety
- Restrictions on new Value Classes:
  - Class must have exactly one parameter
  - Parameter must have public accessibility
  - Parameter must be val
  - No other vals allowed
  - No secondary constructors or initialisation statements
  - Must not be nested class

Value Classes

- Example

```
scala> case class Mile ( m: Double ) extends AnyVal {
     |    def + ( other: Mile ) = Mile( this.m + other.m )
     |    def - ( other: Mile ) = Mile( this.m - other.m )
     | }
defined class Mile

scala> val m1 = Mile (2.2)
m1: Mile = Mile(2.2)

scala> val m2 = Mile(4.2)
m2: Mile = Mile(4.2)

scala> m1 + m2
res8: Mile = Mile(6.4)
```

```
scala> m1 + 3.4
<console>:15: error: type mismatch;
 found    : Double(3.4)
 required: Mile
       m1 + 3.4
            ^

scala> m1 + Mile(3.4)
res10: Mile = Mile(5.6)
```

A Mile can only be added to another Mile, not an arbitrary Double value

Traits

- Abstract type representing properties of a type

```
trait HasId {
  def id: String
}
```

```
trait HasValue {
  def value: Double
}
```

- Properties are mixed in with class (and/or other traits)

```
class Stock ( val id: String ) extends HasId with HasValue {
  def id: String = ???
  def value: Double = ???
}
```

```
class Bond( val id: String ) extends HasId with HasValue {
  def id: String = ???
  def value: Double = ???
}
```

Sealed Types

- Sealed types are types that can only be extended in the same compilation unit (source file)
    - Normally abstract
    - Allows control over subtypes
    - Subtypes normally final
    - Used to create Algebraic Sum Data Types

```
sealed trait Expression

final case class Const(v: Int) extends Expression
final case class Neg(e: Expression) extends Expression
final case class Add ( l: Expression, r: Expression ) extends Expression
```

```
10 + ( - ( 3 + 4 ) )
```

```
scala> val expr = Add ( Const(10), Neg ( Add( Const(3), Const(4) ) )  )
```

Sealed Types

- Often used to define DSLs
  - Pattern Matching can be used to build an interpreter for the DSL

```
object ExpressionInterpreter {

  def eval ( e: Expression ): Int = e match {
    case Const(c) => c
    case Neg(e) => - eval(e)
    case Add(l, r) => eval(l) + eval(r)
  }

}
```

```
scala> val e1 = Add( Const(10), Neg( Add( Const(3), Const(4) ) ) )
e1: Add = Add(Const(10),Neg(Add(Const(3),Const(4))))

scala> ExpressionInterpreter.eval(e1)
res13: Int = 3
```

Sealed Types

- Sealed type hierarchy allows compiler to perform "exhaustiveness checking" in pattern match
    - Compiler knows all possible subtypes
    - Error not to include all possibilities in match
    - Alternative is MatchError exception at runtime

```
object ExpressionInterpreter {

  def eval ( e: Expression ): Int = e match {
    case Const(c) => c
    case Add(l, r) => eval(l) + eval(r)
  }

}
```

Match must include the Neg case otherwise MatchError exception may occur

Compound Types

- Represent intersections of types
  - Composed by mixing traits together

```
trait CanOpen { def open }
```

```
trait CanClose { def close }
```

```
class A extends CanOpen with CanClose {
  def open = println("A open")
  def close = println("A close")
}
```

```
class A extends CanOpen with CanClose {
  def open = println("B open")
  def close = println("B close")
}
```

```
def useIt ( it: CanOpen with CanClose ) = {
  it.open
  it.close
}
```

```
scala> useIt ( new A )
A open
A close

scala> useIt ( new B )
B open
B close
```

Structural Typing

- Specify types by required properties
  - Static "duck typing"

```
def useIt2 ( it: { def open: Unit; def close: Unit } ) = {
  it.open
  it.close
}
```

```
scala> useIt2 ( new A )
A open
A close

scala> object OpenOnly { def open = println("OpenOnly") }
defined object OpenOnly

scala> useIt2 ( OpenOnly )
<console>:14: error: type mismatch;
 found    : OpenOnly.type
 required: AnyRef{def open: Unit; def close: Unit}
       useIt2 ( OpenOnly )
```

OpenOnly does not define close method as required

Type Parameters

- Types can be defined using one or more parameters
    - Classes and traits

```
trait WorksWith[T]
```

```
class Box[T]
```

Type constructor

Type parameter

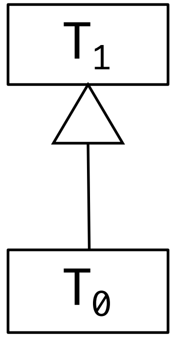
- Concrete types require parameters to be substituted
    - May be inferred by the compiler or explicitly provided

- Examples
    - List[T], Option[T], Map[K,V], Future[T], Try[T]

Variance

- Describes the effect on parameterised types of inheritance

- Assume T_1 is a subtype of T_0
    - What can we assume about (e.g.) List[T_1] and List[T_0]?



- Invariant
    - No relationship

```
List[A]
```

- Covariant
    - List[T1] is a subtype of List[T0]

```
List[+A]
```

- Contravariant
    - List[T1] is a supertype of List[T0]

```
List[-A]
```

Variance and Mutability

- Covariance implies read-only (immutable) type
  - Insertion of elements can break type safety
  - Collection types that offer covariance implement insert through defensive copying
  - E.g. List[T]
- Contravariance implies write-only types
  - Reading of elements can break type safety
  - E.g. Function types are contravariant in argument types, covariant in result type
- Invariance implies read and write

Type Bounds

- Allow type parameters to be restricted according to inheritance hierarchy

```
class Fruit
class Apple extends Fruit
class Banana extends Fruit
```

```
scala> class Bag [ A <: Fruit ]
defined class Bag

scala> val b1 = new Bag [Banana]
b1: Bag[Banana] = Bag@38f981b6

scala> val b2 = new Bag [String]
<console>:13: error: type arguments [String] do not conform to
class Bag's type parameter bounds [A <: Fruit]
       val b2 = new Bag [String]
```

A must be a subtype of Fruit

Type Bounds

- Allow type parameters to be restricted according to inheritance hierarchy

```
class Fruit
class Apple extends Fruit
class Banana extends Fruit
```

```
scala> class Bag [ A >: Fruit ]
defined class Bag

scala> val b1 = new Bag[Banana]
<console>:14: error: type arguments [Banana] do not conform
class Bag's type parameter bounds [A >: Fruit]
       val b1 = new Bag[Banana]
           ^

scala> val b1 = new Bag[AnyRef]
b1: Bag[AnyRef] = Bag@d13960e
```

A must be a supertype of Fruit

Type Parameters and Methods

- Methods can be parameterised by type
- Example: put method for covariant collection
    - Return copy with new element added
    - Need to infer type of new collection

```
class Bag[+A] ( val stuff: Seq[A] ) {
  def get:A = stuff.head
  def put [B >: A ] (n: B) = new Bag[B]( stuff :+ n )
}


val a = new Bag[Apple]( Seq( new Apple, new Apple ) )
val a2 = a.put(new Apple)     // OK, a2 is a Bag[Apple]
val a3 = a.put(new Banana)    // OK, but now a3 is a Bag[Fruit]
```

Type Aliases

- Provide a name for a type
  - Alternative name for class or trait
  - Name for structural or compound type
  - …
- Improves code readability

```
scala> type ID = String
defined type alias ID

scala> type Openable = { def open }
defined type alias Openable

scala> type CanOpenAndClose = CanOpen with CanClose
defined type alias CanOpenAndClose

scala> def useIt ( it: CanOpenAndClose ) {
     |   it.open
     |   it.close
     | }
useIt: (it: CanOpenAndClose)Unit
```

Type Members

- Types can be members of other types
  - Classes, traits, objects
- Type members can be abstract
  - Can provide alternative to type parameters in certain cases

```
class Box[A] {
  …
}
```

```
class Box {
  type A
  …
}
```

```
class Box {
  type A <: Fruit
  …
}
```

Nested Types

- Concrete types may be defined inside other types
  - Class, trait or object

```
scala> object OuterObj {
     |   class Inner
     | }
defined object OuterObj

scala> val x: OuterObj.Inner = new OuterObj.Inner
x: OuterObj.Inner = OuterObj$Inner@3387ab0
```

- Types nested in object similar to Java static inner types
  - Use import to simplify

```
scala> import OuterObj._
import OuterObj._

scala> val x = new Inner
x: OuterObj.Inner = OuterObj$Inner@342394b3
```

Path Dependent Types

- Types defined within class are defined relative to *instance*
  - Take care over type equivalence

```
class OuterClass {
  class InnerClass
}
```

```
scala> val o1 = new OuterClass
o1: OuterClass = OuterClass@38093ffe

scala> val o2 = new OuterClass
o2: OuterClass = OuterClass@3ba1f56e

scala> val oi1 = new o1.InnerClass
oi1: o1.InnerClass = OuterClass$InnerClass@1fd35a92

scala> val oi2 = new o2.InnerClass
oi2: o2.InnerClass = OuterClass$InnerClass@27b7204
```

These two objects do not have the same type

Path Dependent Types

- Compiler uses type path to ensure type correctness

```
scala> def foo ( a: o1.InnerClass ) = a
foo: (a: o1.InnerClass)o1.InnerClass

scala> foo(oi1)
res32: o1.InnerClass = OuterClass$InnerClass@1fd35a92

scala> foo(oi2)
<console>:21: error: type mismatch;
 found   : o2.InnerClass
 required: o1.InnerClass
       foo(oi2)
           ^
```

Path Dependent Types

- Use type projection to relax restriction if required

```
scala> def bar ( a: OuterClass#InnerClass ) = a
bar: (a: OuterClass#InnerClass)OuterClass#InnerClass

scala> bar(oi1)
res34: OuterClass#InnerClass =
OuterClass$InnerClass@1fd35a92

scala> bar(oi2)
res35: OuterClass#InnerClass =
OuterClass$InnerClass@27b7204
```

Path Dependent Types

- Example
- Represent a board for playing games
    - Board coordinates are dependent on dimensions

```
case class Board( len: Int, height: Int ) {

  case class Coordinate ( x: Int, y: Int ) {
    require ( 0 <= x && x < len && 0 <= y && y < height )
  }

  val occupied = scala.collection.mutable.Set[Coordinate]()
}
```

Path Dependent Types

```
scala> val b1 = Board(20, 20)
b1: Board = Board(20,20)

scala> val b2 = Board(30, 30)
b2: Board = Board(30,30)

scala> val c1 = b1.Coordinate(15, 15)
c1: b1.Coordinate = Coordinate(15,15)

scala> val c2 = b2.Coordinate(25, 25)
c2: b2.Coordinate = Coordinate(25,25)
```

```
scala> b1.occupied += c1
res36: b1.occupied.type =
              Set(Coordinate(15,15))

scala> b2.occupied += c2
res37: b2.occupied.type =
              Set(Coordinate(25,25))

scala> b1.occupied += c2
<console>:22: error: type mismatch;
 found    : b2.Coordinate
 required: b1.Coordinate
       b1.occupied += c2
                      ^
```