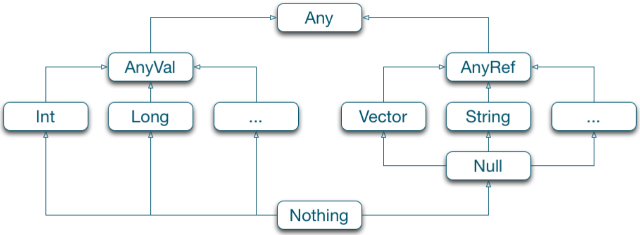
Mastering the type system

Scala training, 2016

Outline

Recap



- most of our custom types extend `AnyRef`
- since Scala 2.10 we can define value types

Outline

Adding value classes

```scala
class MyInteger(val underlying: Int) extends AnyVal {
  def +(that: MyInteger): MyInteger =
    new MyInteger(this.underlying + that.underlying)
}
```

Value types:

- are wrappers over a single value
- extend AnyVal
- have only one class parameter
- the class parameter is a `val`

Outline

The Scala "generics"

```
// parameterized trait
trait Set[A] {
  // parameterized method
  def map[B](f: A => B): Set[B]
}
```

You may

- declare (one or more) type params in square brackets
- add type parameters to *classes, traits or methods*

Outline

"Generics" and subtyping

Given the `Animal` and `Cat (extends Animal)` types:

- should a list of Cats also be a list of Animals...
  - if I just *read* it?
  - if I want to *add* to it?
- if I can feed an Animal, should I also be able to feed a Cat?

"Generics" and subtyping

Given the `Animal` and `Cat (extends Animal)` types:

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  - if I just *read* it?
    (yes - *covariant*)
  - if I want to *add* to it?

- if I can feed an Animal, should I also be able to feed a Cat?

"Generics" and subtyping

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  - if I just *read* it?
    (yes - *covariant*)
  - if I want to *add* to it?
    (no - *invariant*: what if I add a Horse to it?)
- if I can feed an Animal, should I also be able to feed a Cat?

"Generics" and subtyping

Given the `Animal` and `Cat (extends Animal)` types:

- should a list of Cats also be a list of Animals...
  - if I just *read* it?
    (yes - *covariant*)
  - if I want to *add* to it?
    (no - *invariant*: what if I add a Horse to it?)
- if I can feed an Animal, should I also be able to feed a Cat?
  (yes - *contravariant*; we'll explain shortly)

Variance

Example (the question of variance in the List type)

Let B extend A.
Should List[B] extend List[A]?

We have 3 options:

- covariance = List[B] extends List[A]
- invariance = no relationship and no substitution
- contravariance = List[A] extends List[B]

Variance = relationshtip between parameterized types, given the relationship of their components

Variance syntax

- invariant is default

```
class Container[A]
```

- + is covariant

```
class CovariantContainer[+A]
```

- - is contravariant

```
class ContravariantContainer[-A]
```

A contravariance example

```
class FeedAction[-T] {
   def apply(t : T): Unit = {
      println(t.toString + " eating")
   }
}

// this feeds the Cat
def feedCat(action: FeedAction[Cat], c: Cat): Unit = {
   action(c)
}

val f = new FeedAction[Animal]
// I can feed an Animal, so I can also feed a Cat
feedCat(f, new Cat)
```

Variance positions

Assume we have types Animal, Cat, Dog.
Cat and Dog inherit from Animal.

```
class Cage[-A] {
   val underlying: A
}

val w: Cage[Cat] = new Cage[Animal]
println(w.underlying)
```

Everything OK with this code?

Variance positions

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```
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Everything OK with this code?
(no - what type is w.underlying?!)

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println(w.underlying)
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Everything OK with this code?
(no - what type is w.underlying?!)

- `val`s can't have contravariant types

Rule

Types of `val`s are in *covariant* position.

(same for `var`s)

Variance positions (2)

Same hierarchy with types Animal, Cat, Dog.

```
class Cage[+A] {
   var underlying: A
}

def process(w: Cage[Animal]) {
   w.underlying = new Dog
}
process(new Cage[Cat])
```

Everything OK with this code?

Variance positions (2)

Same hierarchy with types Animal, Cat, Dog.

```
class Cage[+A] {
   var underlying: A
}

def process(w: Cage[Animal]) {
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process(new Cage[Cat])
```

Everything OK with this code?
(no - we're polluting a Cage[Cat] with a Dog)

Variance positions (2)

Same hierarchy with types Animal, Cat, Dog.

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class Cage[+A] {
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process(new Cage[Cat])
```

Everything OK with this code?
(no - we're polluting a Cage[Cat] with a Dog)

Rule

Types of `var`s are in *covariant AND contravariant* position.

Variance positions in methods

Same hierarchy with types Animal, Cat, Dog.

```
class Cage[+A] {
   def method(a: A): Unit = ...
}

val w: Cage[Animal] = new Cage[Cat]
w.method(new Dog)
```

Everything OK with this code?

Variance positions in methods

Same hierarchy with types Animal, Cat, Dog.

```
class Cage[+A] {
   def method(a: A): Unit = ...
}

val w: Cage[Animal] = new Cage[Cat]
w.method(new Dog)
```

Everything OK with this code?

(no - we're messing up *declared* and *used* types)

Rule

Types of *method parameters* are in *contravariant* position.

Variance positions in methods (2)

```
class Cage[-A] {
   def get: A = ...
}

val w: Cage[Cat] = new Cage[Animal]
val getResult = w.get
```

Everything OK with this code?

Variance positions in methods (2)

```
class Cage[-A] {
   def get: A = ...
}

val w: Cage[Cat] = new Cage[Animal]
val getResult = w.get
```

Everything OK with this code?
(no - w.get must be a Cat, is originally an Animal, might be a Dog)

Rule

Method return types **are in** ***covariant*** **position.**

Variance positions in methods (3)

Big rule.

Methods are

- contravariant in argument types and
- covariant in return types.

Variance positions in methods (3)

Big rule.

Methods are

- contravariant in argument types and
- covariant in return types.

Actually, methods have their own types (remember?) declared as:

```
trait Function1[-T1, +R] {

  def apply(t : T1) : R

}
```

Now you know why...

Outline

Variance is good, but...

```
class List[+A] {
   def add(a: A): List[A]
}
```

Variance is good, but...

```
class List[+A] {
   def add(a: A): List[A]
}
```

Error: Covariant type A occurs in contravariant position

- covariance makes sense
- but we cannot add covariant methods

Solution: lower bounded types

```
class List[+A] {
   def add[B >: A](b: B): List[B]
}
```

Notice the `[B >:A]` syntax:

- B is a type parameter to the method
- B is a *supertype* of A
- the result type List[B] is thus widened

Upper bounded types

```scala
class Car
class SuperCar extends Car

class Garage[A <: Car] (car: A)

// OK
new Garage(new SuperCar)
// error: inferred type arguments [String]
// do not conform to type parameter bounds [A <: Car]
new Garage("supercar")
```

- A is a subtype of Car (*is a* Car)
- A *has to be* a (subtype of) Car
- otherwise it doesn't compile

Outline

Declaring type members

Classes, traits and singleton objects can have *type* members:

```
class MyClass {
   // an abstract type
   type MyType
   // a bounded abstract type
   type MagicList <: List
   // a type alias
   type LL = java.util.LinkedList

   //...
}
```

Outline

Inner types

Classes, traits and singleton objects can have *inner types*:

```
class OuterClass {
   class InnerClass
   trait InnerTrait
   type InnerType

   //...
}
```

Referring and using inner types

```
class Outer {
   class Inner
}

val o = new Outer

// notice the type and the instantiation syntax
val i1: o.Inner = new o.Inner

// error: value Outer not found
val i2: Outer.Inner = new o.Inner
```

To use an inner type, you must use an outer instance

Referring and using inner types (2)

```
class Outer {
   class Inner
   def print(i: Inner): Unit = println(i)
}

val o1 = new Outer
val o2 = new Outer

val i2: o2.Inner = new o2.Inner

// error: type mismatch:
// found o2.Inner, required o1.Inner
o1.print(i2)
```

Different outer instances $\Rightarrow$ different inner types

Referring and using inner types (3)

All inner types have a common supertype - `Outer#Inner`

```
class Outer {
   class Inner
   def print(i: Outer#Inner): Unit = println(i)
}

val o1 = new Outer
val o2 = new Outer

val i2: o2.Inner = new o2.Inner

// OK
o1.print(i2)
```

Outline

Enhancing existing types

We can add definitions/declarations to existing types

```
// assume this is in some library
class Printer {
   def print(o: Any): Unit
}

// in our code
type VerbosePrinter = Printer {
   // this is called structural definition
   // we don't override any existing member
   def printVerbose(o: Any): Unit
}
```

- structurally defined members are found via reflection

Outline

On duck typing

Q: What is duck typing?

On duck typing

Q: What is duck typing?
Q: What is the duck test?

On duck typing

Q: What is duck typing?
Q: What is the duck test?

The duck test

If something looks like a duck, swims like a duck and quacks like a duck, then it's probably a duck.

We want Scala to do the duck test *at compile time*.

Static duck typing in Scala

Omit the type to be refined/enhanced:

```
// a purely structural type declaration
type SoundMaker = { def makeSound(): Unit }

class Dog {
   def makeSound(): Unit = {...}
}

class Car {
   def makeSound(): Unit = {...}
}

val d: SoundMaker = new Dog
val c: SoundMaker = new Car
```

- no relationship between e.g. Dog and Soundmaker...
- ...but Scala is OK
- ...and will use `dog` as a `SoundMaker`

Recap

A little more about the type hierarchy

- Adding value classes

Type parameters and variance

- Type parameters
- Variance
- Bounded types

More about types

- Type members
- "Inner" types
- Type refinements
- Static duck typing