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# Advanced Programming

## Partial Computations: The Option Type

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SOFTWARE QUALITY RESEARCH

- Primary Constructors
- Dynamic Virtual Dispatch
- Variance of Type Parameters
- Option
- Programming without pattern matching!
- For comprehensions
- In the next episode ...

# AGENDA

# The Primary Constructor

```scala
class Person(val name: String, val age: Int):
  println("Just constructed a person")
  def description =
    s"$name is $age years old"
```

```java
class Person {
  private String name;
  private int age;
  public String name() { return name; }
  public int age() { return age; }

  public Person(String name, int age) {
    this.name = name;
    this.age = age;
    System.out.println("Just constructed a person");
  }

  public String description ()
  { return name + "is " + age + " years old"; }
}
```

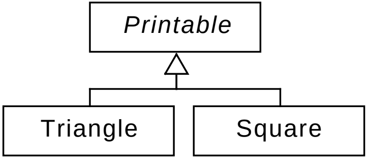
- Parameters become fields
- 'val' parameters become values, 'var' become variables
- If no parameter list, primary constructor takes none
- Constructor initializes fields and executes top-level statements of the class
- Like for all functions, parameters can take default values, reducing the need for overloading
- Note: primary constructors are used with case classes
- In F# and C# 12 as well

[Horstmann 2012, Chpt. 5.7] explains the primary constructors in Scala

# Mentimeter: Dynamic Dispatch in Java

7152 5570

```
class Printable                  { void hello() { print ("printable "); }}
class Triangle extends Printable{ void hello() { print ("triangle ");}}
class Square extends Printable  { void hello() { print ("square "); }}
...
Square x = new Square ()
Printable y = new Triangle ()
x.hello ();
((Printable)x).hello ();
y.hello ();
((Printable)y).hello ();
```




- printable printable printable printable
- square printable triangle printable
- square printable printable printable
- square square triangle triangle
- square square printable printable
- The program will crash, or fail to type check

**In Scala,**
**like in Java*,**
**all instance methods are virtual**
**(dynamically dispatched)**
**unlike in C# and C++**

***and Python and JavaScript**

# Programs as data
## Higher-order functions, polymorphic types, and type inference

Niels Hallenberg

Thursday 2019-09-17

Originally by Peter Sestoft

# Variance in type parameters

- Assume Student subtype of Person

```
void PrintPeople(IEnumerable<Person> ps) { ... }
```

```
IEnumerable<Student> students = ...;
PrintPeople(students);
```

Java and C# 3 say NO: Ill-typed!

- C# 3 and Java:
  - A generic type is *invariant* in its parameter
  - I<Student> is *not* subtype of I<Person>
- Co-variance (co=with):
  - I<Student> is subtype of I<Person>
- Contra-variance (contra=against):
  - I<Person> is subtype of I<Student>

# Co-/contra-variance is unsafe in general

- Co-variance is unsafe in general

```
List<Student> ss = new List<Student>();
List<Person> ps = ss;
ps.Add(new Person(...));
Student s0 = ss[0];
```

Wrong!

Because would allow writing Person to Student list

- Contra-variance is unsafe in general

```
List<Person> ps = ...;
List<Student> ss = ps;
Student s0 = ss[0];
```

Wrong!

Because would allow reading Student from Person list

- But:
  – co-variance OK if we *only read (output)* from list
  – contra-variance OK if we *only write (input)* to list

# Co-variance in interfaces (C# 4)

- When an I<T> only produces/*outputs* T's, it is safe to use an I<Student> where an I<Person> is expected
- This is co-variance
- Co-variance is declared with the **`out`** modifier

```
interface IEnumerable<out T> {
  IEnumerator<T> GetEnumerator();
}
interface IEnumerator<out T> {
  T Current { get; }
}
```

- Type T can be used only in *output* position; e.g. not as method argument (input)

# Contra-variance in interfaces (C# 4)

- When an I<T> only consumes/*inputs* T's, it is safe to use an I<Person> where an I<Student> is expected
- This is contra-variance
- Contra-variance is declared with **`in`** modifier

```
interface IComparer<in T> {
  int Compare(T x, T y);
}
```

OK! – a Compare method working on Persons will also work on Students.

- Type T can be used only in *input* position; e.g. not as method return type (output)

# Variance of Type Parameters (condensed, in Scala)

- Write `A <: B` to say that `A` is a **subtype of** `B` (values of `A` fit where `B`s are expected)
- **Example**: if class `A` extends a class `B` then `A <: B`. Same for traits.
- Assume a generic type `T[B]`;
  `B` is a **covariant** parameter of `T` if for each `A <: B` we have that `T[A] <: T[B]`
  So we can use `T[A]` values where `T[B]`s are expected
- In Scala write `T[+B]` to specify that B is a covariant type parameter (so `+` is `out` in C#).
- Covariance common in pure programs. Scala lists are covariant (`List[+B]`).
- `A` is a **contra-variant** parameter of `T` if whenever `A <: B` we have that `T[B] <: T[A]`
- Contra-variance is needed if `A` is send in subsequently.
  In Scala, write `T[-A]` to specify contra-variance (`-` is `in` of C#)
- **Invariance** means that there is no automatic subtypes of generic type T;
  Invariance is default in Scala (when you omit the -/+), like in C#
- Java and C# generics **also** support variance of type parameters. In F# : type parameter constraints.
- Java has covariant arrays (problem). Scala has invariant arrays.

Why arrays shouldn't be covariant: http://stackoverflow.com/questions/6684493/why-are-arrays-invariant-but-lists-covariant

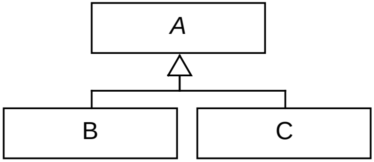
[Odersky et al. 2014, Chpt. 19] explains variance annotations in Scala in detail

# The Problem with Covariance of Java Arrays

```
1 class A {};
2 class B extends A {};
3 class C extends A {};

5 class Variance {

7   static void problem () {
8     B[] b = { new B() };
9     A[] a = b;
10    a[0] = new C();
11  }
12 };
```




- All type checks compile
- Runtime type error in line 11. Why?
- Covariance is not always covariance desirable.
- Covariance is good for **immutable containers** storing elements of the parameter type.

Code in `option/src/main/java/adpro/variance/Variance.java` and the corresponding test in `option/src/test/scala/adpro/variance/VarianceSpec.scala`

# Contra-variance

```scala
1 class Cell[-T](init: T):
2   private var current = init
3   def get = current
4   def set(x: T) { current = x }

6 object Cell:
7   val c1: Cell[String] = Cell[String]("abc")
8   val c2: Cell[Any] = c1
9   c2.set(1)
10  val s: String = c1.get
```

- **If `Cell` covariant**: l. 9 would assign a string to integer (like with our Java example)
- Can do things to `Cell[Any]` that we cannot do to `Cell[String]` (assigning a number)
- Scala compiler detects this in l. 4 (`T` used in a contravariant position, on a value that will be assigned). It detects the **wrong design** of the Cell (if covariant).
- So `Cell` **contravariant**, note the `[-T]` annotation.
- Compiler flags the assignment in l. 8 (**wrong use** of the `Cell`)

Example from Odersky. Spoon. Venners. **Programming in Scala**. 2nd Edition, chapter 19

# Mentimeter: Variance of Type Parameters

7152 5570

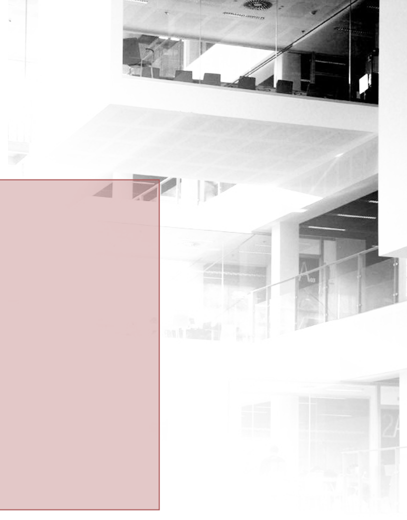
```
abstract class A

abstract class B extends A

// Will the following code type check if T is
// (a) invariant,
// (b) covariant,
// (c) contravariant ?

val T[A] = new T[B]
```



- Primary Constructors
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- Programming without pattern matching!
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# AGENDA

# A Partial Function

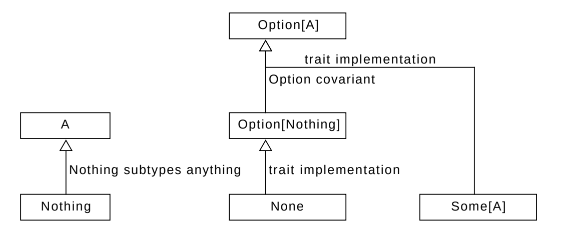
## (and how to fix it)

```
def mean(xs: List[Double]): Double = xs match
  case Nil => throw new ArithmeticException ("empty list")
  case _   => xs.sum / xs.length
              // _.sum and _.length are standard library methods on sequences
```

What is the domain and co-domain of the function above?

```
enum Option[+A]:
  case Some(get: A)
  case None
```

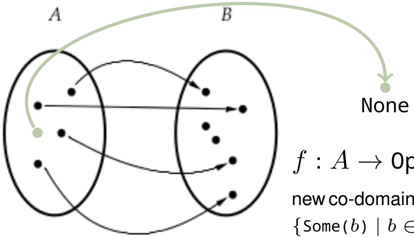
```
def mean (xs: List[Double]): Option[Double] =
  xs match
    case Nil => None
    case _   => Some(xs.sum / xs.length)
```




Referentially transparent (!), but we still need to figure out how to **defer** error processing (like with exception handling)

# Partial and Total Functions: Definitions

A **function** $f : A \to B$ is a binary relation on sets $A$ and $B$ such that for every $a \in A$ there exists precisely one such $b \in B$ that $(a, b) \in f$.




$f : A \to \texttt{Option}[B]$

new co-domain: $\texttt{Option}[B] = \{\texttt{Some}(b) \mid b \in B\} \cup \{\texttt{None}\}$

- A function $f$ is **total**, if for each $a \in A$ there exists a $b \in B$ such that $f(a) = b$
- A function is **partial** otherwise.

- **Computations are functions**
- If an argument value for a call is **illegal** (crash, exception) then **partial function**
- Non-FP languages handle partiality with **exceptions**
- Advantage: handle the missing values **separately**, do not confuse errors with results.
- Scala has exceptions, but we don't use them in this course. **Why?**
- Need another way to handle partiality, but **keep the main advantage of exceptions**
- Idea: store the result in a special value by **growing the domain**, to contain the failure, and provide an API for handling failures non-locally.

# Option in the Standard Library Methods (Examples)

## How other types use Option

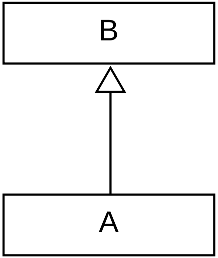
- `Option` is defined in the standard library
- In the course we make our own implementation for pedagogical purposes.
- `trait Map[K, +V]`
  - `def get(key: K): Option[V]`
    Optionally returns the value associated with a key
  - `def find(p: ((K, V)) =>Boolean): Option[(K, V)]`
    Finds the first element of the collection satisfying a predicate, if any
- `class List[+A]`
  - `def headOption: Option[A]` — Optionally selects the first element.
  - `def lastOption: Option[A]` — Optionally selects the last element.

# Option API

## What Option itself offers

```scala
enum Option[+A]:
    def map[B](f: A => B): Option[B]
    def flatMap[B](f: A => Option[B]): Option[B]
    def filter(f: A => Boolean): Option[A]
    def getOrElse[B >: A](default: => B): B
```

- Implement these functions in **homework** exercises
- Let’s try using them (2 × Mentimeter 7152 5570)
  - `List(1,2,3).headOption.map {_ /10.0}` ?
  - `List().headOption.map {_ /10.0}` ?
- An interesting type parameter on `getOrElse`, with a **constraint** on `B`
  - Get a value of **any type** `B` from an `Option[A]`, if `B` is a **super-type** of `A` (so implicit upcasting, as needed)
  - Another case of interesting interplay between object-oriented and functional programming type systems




`getOrElse` type constraint

# Localized Error Handling in the Option Monad

```
1 list.headOption
2     .map { _ / 10.0 }
3     .map { _ + 2 }
4     .flatMap { something that can fail }
5     .map { something that cannot fail }
6     ...
```

- A **failure** can occur in line 1 (or in line 4)
- The entire code is written **ignoring** a possible failure, like with exceptions
- All the computation steps are **in the Option monad** (informal for now)
- Handling the error is done **arbitrarily far** (maybe in a different function) by deciding what to do, if `None` is received.
- A default or error value (like -1 in C) can be injected with `getOrElse`:

```
6     ...
7     .getOrElse(-1)
```

# What does this compute?

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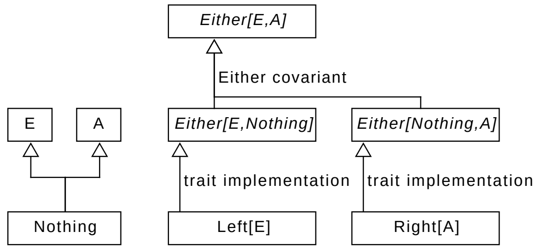
```scala
List(2,3,4)
    .headOption
    .filter { _ % 2 == 0 }
    .map { _ / 2 }
```

# Either: Failures with diagnostic info

## Recall that exceptions carry failure data objects

```
enum Either[+E,+A]:
  case Left(value: E)
  case Right(value: A)
```

- Two time parameters: left (error, `E`) and right (aka correct, value, `A`)
- Mnemonic: right is synonym for correct, which is a synonym for succesful




If you need to **grow the failure** info along the call-stack fashion, then `E` should be a **collection**, for instance a `Either[List[Msg]]`, where `Msg` is the error message type.

# For-Yield Comprehensions

```
// the original input
Some(4)
 .flatMap { x1 => (if x1%2==0 then Some(x1/2) else None)
   .flatMap { x2 => Some(x2 + 1)
     .map { x3 => x3.toString } } }
```

```
// break lines differently
Some(4).flatMap { x1 =>
 (if x1%2==0 then Some(x1/2) else None).flatMap { x2 =>
   Some(x2 + 1).map { x3 =>
     x3.toString } } }
```

```
// flush right
                                Some(4).flatMap { x1 =>
(if x1%2==0 then Some(x1/2) else None).flatMap { x2 =>
                                Some (x2+1).map { x3 =>
                                      x3.toString } } }
```

- For-yield comprehensions correspond to Haskell's do-notation or F# computation expressions.
- Work for any type with `map` and `flatMap`
- Other functions (like filter) also integrated
- Not to be confused with other uses of `for` in Scala (mostly impure loops iterating over collections)

```
for
  x1 <- Some(4)
  x2 <- if x1%2==0 then Some(x1/2) else None
  x3 <- Some(x2+1)
yield x3.toString
```

https://docs.scala-lang.org/scala3/book/control-structures.html#for-expressions

# List is also monadic

## For-comprehensions work on lists, too

```
for
  x <- List(3, 4, 5)
  incremented = x + 1
  duplicated <- List(incremented, incremented)
                if incremented % 2 == 0
yield duplicated // map identity
```

- **Mentimeter 7152 5570:** What is the result of the above?
- **Exercise:** Rewrite the above code using map and flatMap.
- `'<-'` translates to `flatMap`
- `'='` translates to `map`
- `if` translates to `filter`
- `'yield'` translates to `map`

# F# uses Computation Expressions

```
// F#
seq {
  for x in 1..10 do
    yield x                          // map
    yield! seq { for i in 1..x -> i} // flatMap
}
```

- Exercise: translate this to Scala using for-yield and using just map/flatmap?
- Key difference: implemented **explicitly**,
- Scala for–yield is **general**, for any **user defined type** that supports monadic API (flatMap and map, and ...)
- **Generators** are a similar construct in Python; Also the **with** blocks resemble monadic progamming (but are not strictly such)

Source of the example: `https://docs.microsoft.com/en-us/dotnet/fsharp/language-reference/sequences`, where you will also find more about F# sequences.

# Our For-Yield Example in F#

```
type OptionBuilder() =
    member _.Yield(x : 'a) : 'a option =
        Some x

    member _.Bind(m : 'a option, f : 'a -> 'b option) : 'b option =
        Option.bind f m

let option = OptionBuilder ()

option {
    let! x1 = Some 4
    let! x2 = if x1 % 2 = 0 then Some (x1 / 2) else None
    let! x3 = Some (x2 + 1)
    yield x3.ToString()
}
```

Implemented **explicitly**! Not inferred from type as in Scala.

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# AGENDA

# In the next episode . . .

- We implement a **lazy list library**
- A very **nice week**, **beautiful** ideas, **simple** but **powerful** API
- We learn **call-by-name** and **laziness**
- **Happy reading! and See you next week!**