



 @AndrzejWasowski

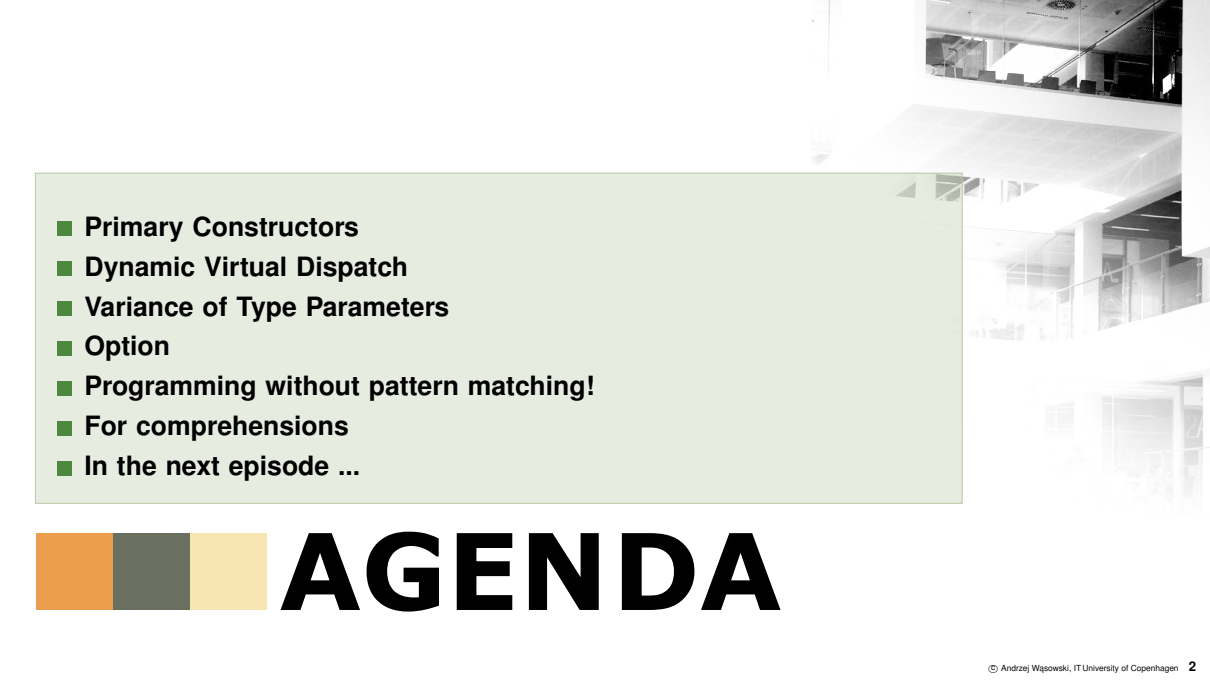
Andrzej Wąsowski

Advanced Programming

Partial Computations (Option)

IT UNIVERSITY OF COPENHAGEN

S SOFTWARE
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R RESEARCH

- 
- A background image showing a modern building interior with multiple levels, glass railings, and a bright, open space.
- **Primary Constructors**
 - **Dynamic Virtual Dispatch**
 - **Variance of Type Parameters**
 - **Option**
 - **Programming without pattern matching!**
 - **For comprehensions**
 - **In the next episode ...**

Three colored squares: orange, grey, and yellow.

AGENDA

The Primary Constructor

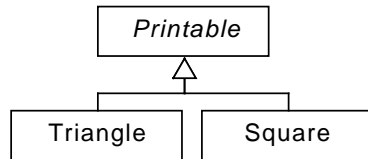
```
1 class Person (val name: String, val age: Int) {  
2   println ("Just constructed a person")  
3   def description = s"$name is $age years old"  
4 }
```

```
1 class Person {  
2   private String name;  
3   private int age;  
4   public String name() { return name; }  
5   public int age() { return age; }  
6  
7   public Person(String name, int age) {  
8     this.name = name;  
9     this.age = age;  
10    System.out.println("Just constructed a person");  
11  }  
12  
13  public String description ()  
14  { return name + "is " + age + " years old"; }  
15 }
```

- 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
- Known from F# and C# as well

Mentimeter: Dynamic Dispatch in Java

```
1 class Printable { void hello() { print ("printable "); }}
2 class Triangle extends Printable { void hello() { print ("triangle "); }}
3 class Square extends Printable { void hello() { print ("square "); }}
4 ...
5 Square x = new Square ()
6 Printable y = new Triangle ()
7 x.hello ();
8 ((Printable)x).hello ();
9 y.hello ();
10 ((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++**

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) { ... }
```

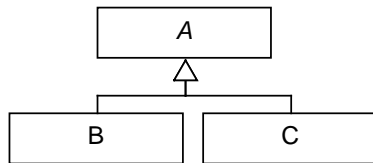
```
IEnumerable<Student> students = ...;  
PrintPeople(students);
```

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>

The Problem with Covariance of Java Arrays

```
1 class A {};  
2 class B extends A {};  
3 class C extends A {};  
4  
5 class Variance {  
6  
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?
- Not always covariance is desired.
- 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`

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 Bs 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. F# has no variance.
- 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


Contra-variance

```
1 class Cell[-T] (init: T) {  
2   private var current = init  
3   def get = current  
4   def set (x: T) { current = x }  
5 }  
6 object Cell {  
7   val c1: Cell[String] = new Cell[String] ("abc")  
8   val c2: Cell[Any] = c1  
9   c2.set (1)  
10  val s: String = c1.get  
11 }
```

- 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`)

Mentimeter: Variance of Type Parameters

```
1 abstract class A
2
3 abstract class B extends A
4
5 // Will the following code type check if T is
6 // (a) invariant,
7 // (b) covariant,
8 // (c) contravariant ?
9
10 val T[A] = new T[B]
```

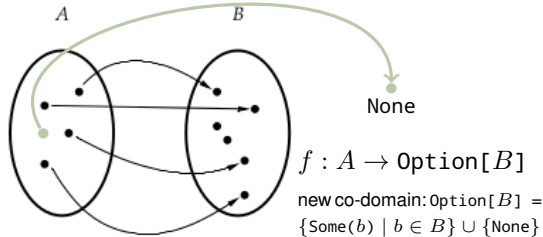
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Partial Functions

A **function** $f : A \rightarrow B$ 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 $(a, b) \in f$.



- 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**
- Object-oriented languages handle partiality with **exceptions**
- Advantage: handle the missing values **separately**, not mixing with the main logics implementation. This is valuable
- 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.

Example (Option)

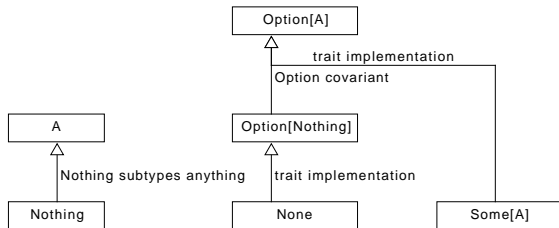
```
1 def mean (xs: List[Double]): Double = xs match {  
2   case Nil => throw new ArithmeticException ("empty list")  
3   case _   => xs.sum / xs.length  
4 }
```

// _.sum and _.length are standard library methods on sequences

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

```
5 sealed trait Option[+A]  
6 case class Some[+A] (get: A) extends Option[A]  
7 case object None extends Option[Nothing]
```

```
8 def mean (xs: List[Double]): Option[Double] =  
9   xs match {  
10     case Nil => None  
11     case _   => Some (xs.sum / xs.length)  
12   }
```



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

Option in the Standard Library Methods (Examples)

How other types use Option

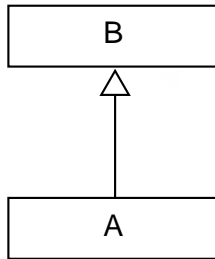
- `Option` is defined in the standard library
- In the course we make our own implementation for pedagogical purposes.
- `trait Map[K, +V]`
 - `def get(key: K): Option[V]`
Optionally returns the value associated with a key
 - `def find(p: ((K, V)) => Boolean): Option[(K, V)]`
Finds the first element 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

```
1 trait Option[+A] {  
2   def map[B] (f :A => B) :Option[B]  
3   def flatMap[B] (f :A => Option[B]) :Option[B]  
4   def filter(f: A => Boolean) :Option[A]  
5   def getOrElse[B >: A] (default: => B) :B  
6 }
```

- Implement these functions in **homework** exercises
- Let's try using them (Mentimeter)
 - `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 2 (or in line 5)
- 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?

Mentimeter

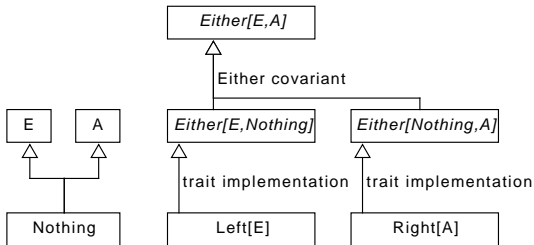
```
1 List(2,3,4)
2   .headOption
3   .filter { _ % 2 == 0 }
4   .map { _ / 2 }
```

Either: Failures with diagnostic info

Recall that exceptions carry failure data objects

```
1 sealed trait Either[+E,+A]
2 case class Left[+E](value :E) extends Either[E,Nothing]
3 case class Right[+A](value: A) extends Either[Nothing, A]
```

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



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.

Mentimeter preparing for-yield discussion

For-Yield Comprehensions

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

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

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

- For-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)

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


List is also a monad

For-comprehensions work on lists, too

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

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

F# has a limited form of for-yield

```
1 seq {  
2   for x in 1..10 do  
3     yield x  
4     yield! seq { for i in 1..x -> i }  
5 }
```

- Can we try to do some **collaborative programming** and translate this to Scala? Using for yield? Using just map/flatmap?
- Key difference: F# only supports this **only for sequences**,
- 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 programming (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.

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AGENDA

In the next episode ...

- A very **nice week**, **beautiful** ideas, **simple** but **powerful** API
- We learn **call-by-name** and **laziness**
- We implement a **stream library** (the lazy parallel of Lists)
- **Happy reading!** and **See you next week!**