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Advanced Programming

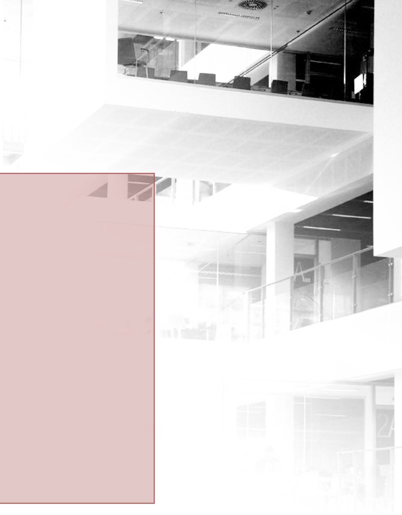
Partial Computations (Option)

IT UNIVERSITY OF COPENHAGEN

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"
}
```

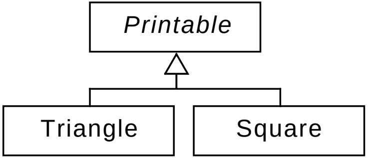
```java
class Person {
  private String name;
  private int age;
  public String name() { return name; }
  public int age() { return age; }

  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
- Known from F# and C# as well

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

Mentimeter: Dynamic Dispatch in Java

```java
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++

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)

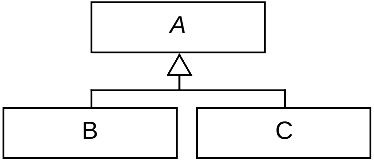
Variance of Type Parameters (condensed, in Scala)

- 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. 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

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`

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`)

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

Mentimeter: Variance of Type Parameters

```
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]
```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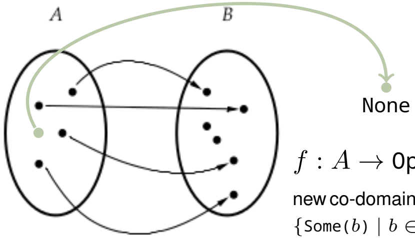
Partial Functions

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 $(a, b) \in f$.



$f : A \to$ `Option`$[B]$

new co-domain: `Option`$[B]$ = $\{$`Some`$(b) \mid b \in B\} \cup \{$`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**
- 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.

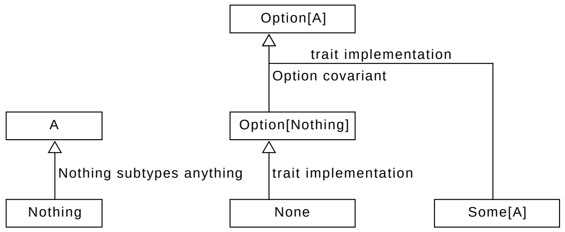
Example (Option)

```scala
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?

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

```scala
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)

Option in the Standard Library Methods (Examples)

How other types use Option

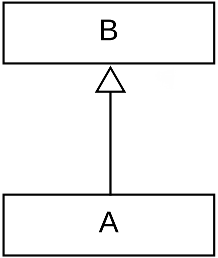
- `Option` is defined in the standard library
- In the course we make our own implementation for pedagogical purposes.
- `trait Map[K, +V]`
  - `def get(key: K): Option[V]`
    Optionally returns the value associated with a key
  - `def find(p: ((K, V)) =>Boolean): Option[(K, V)]`
    Finds the first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

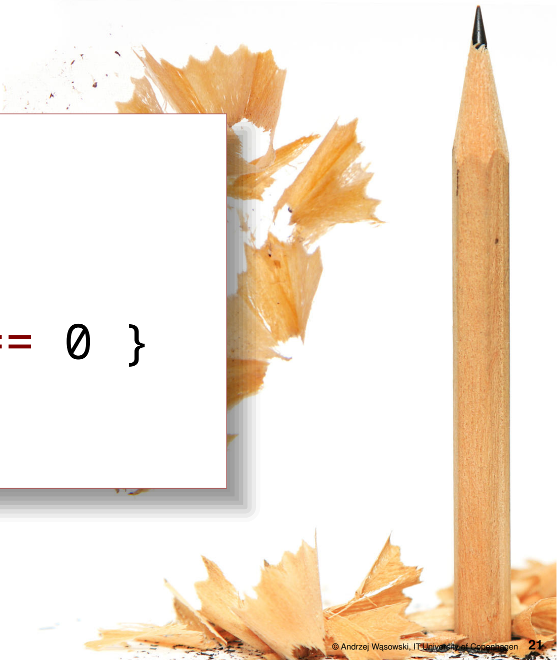
- A **failure** can occur in line 2 (or in line 5)
- The entire code is written **ignoring** a possible failure, like with exceptions
- All the computation steps are **in the Option monad** (informal for now)
- Handling the error is done **arbitrarily far** (maybe in a different function) by deciding 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

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

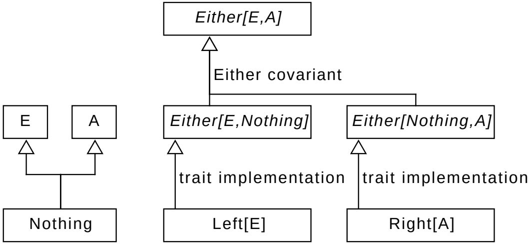


Either: Failures with diagnostic info

Recall that exceptions carry failure data objects

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

Mentimeter preparing for-yield discussion

For-Yield Comprehensions

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

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

```scala
// flush right
                              Some(4).flatMap (x1 =>
(if (x1%2 == 0) 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)

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

https://docs.scala-lang.org/tutorials/FAQ/yield.html

List is also a monad

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:** 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# has a limited form of for-yield

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

- Exercise: translate this to Scala using for-yield and 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 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.

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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!**