Functional programming with Scala

Collections

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CY TECH – ING2

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Scala collection library

Definition

Container of an arbitrary number of elements **with same type**

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Example (kinda) from already seen types : `Option`

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In this course

- **New design will be presented.**
- Some remarks about previous design may be adressed.

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Two main packages

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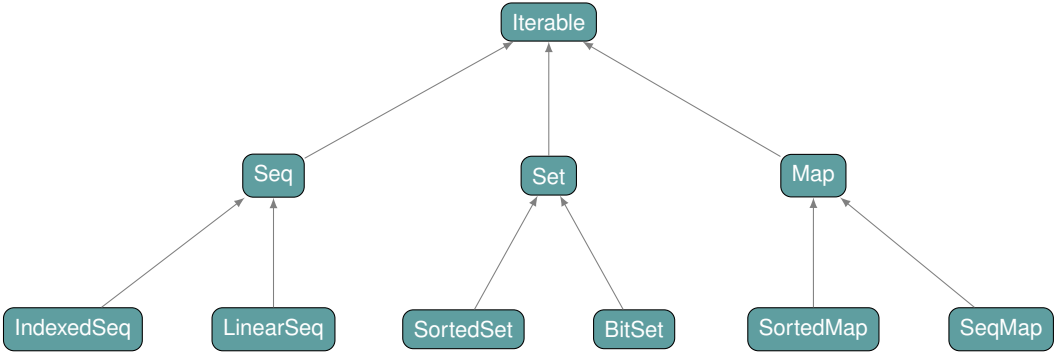
Rich set of. . .

- collection types (classes and traits)
- common methods for most collections
- methods for specific collections

Top of hierarchy

Scala collection library



(Source : Scala 2.13 Collection API Charts)

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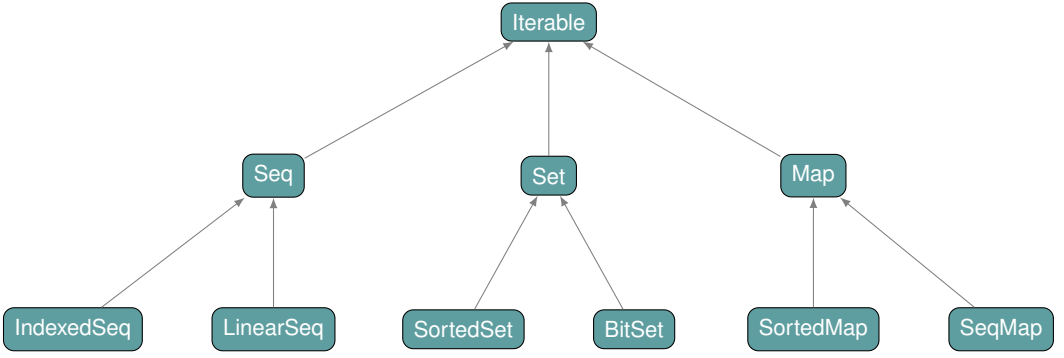

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Prior versions : **`Traversable`** at top of hierarchy

- introduced `foreach[U](f : A => U) : Unit`
  (now available in **`Iterable`** via **`IterableOnceOps`**)
- *removed in 2.13 due to underuse*

Scala collection hierarchy : **`Iterable`**

Any **`Iterable`** has an *iterator*

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scala> List(1, 3, 5) foreach { x => println(s"Current element is $x") }
Current element is 1
Current element is 3
Current element is 5
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scala> val it = List(1, 3, 5).iterator
it: Iterator[Int] = non-empty iterator

scala> while (it.hasNext) println(s"Current element is ${it.next()})
Current element is 1
Current element is 3
Current element is 5
```

Specific collections

Specific collections

Seq

Scala collection hierarchy : **Seq**[**+T**]

Base trait for *sequences*

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- Main methods : `head`, `tail`, `apply`, `length`
  + `update` (for mutable sequences)

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  - *Other implementations* : `Queue[T]`, `LazyList[T]`

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*NB: In Scala, any **`String`** object is implicitly seen as a **`Seq[Char]`**.*

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Example

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scala> Seq.empty(ou Seq())
res0: Seq[Nothing] = List()
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scala> val s = Seq(5, 1, 3, 1)
s: Seq[Int] = List(5, 1, 3, 1)
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scala> s == Seq(1, 1, 3, 5)
res5: Boolean = false
```

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scala> Seq(5, 1, 3).reverse
res2: Seq[Int] = List(3, 1, 5)
```

Specific collections

Set

Scala collection hierarchy : `Set[T]`

Base trait for *sets*

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Set operators

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- `&` : set intersection

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- `apply` : equivalent for `contains`

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Example

```
scala> val s = Set(5, 1, 3, 1)
s: scala.collection.immutable.Set[Int] = Set(5, 1, 3)
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scala> s contains 4
res0: Boolean = false
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scala> emptySet + 1
<console>:13: error: type mismatch;
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- Main methods : `get`, `removed`
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Scala collection hierarchy : `Map[K, +V]`

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  - *Default implementation* : `TreeMap[K, V]`

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Example

```
scala> val m = Map("dze" -> "Cergy", "rdl" -> "Pau")
m: scala.collection.immutable.Map[String, String]
   = Map(dze -> Cergy, rdl -> Pau)
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  at scala.collection.immutable.Map$Map2.apply(Map.scala:298)
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res2 : scala.collection.immutable.Map[String, String]
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```

Scala collection hierarchy : `Map[K, +V]`

Empty map `Map.empty`

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Example

```
scala> val emptyMap = Map.empty(ou Map())
emptySet: scala.collection.immutable.Map[Nothing,Nothing] = Map()

scala> emptyMap + ("test" -> "failed")
<console>:13: error: type mismatch;
 found   : (String, String)
 required: (Nothing, ?)
       emptyMap + ("test" -> "failed")
                           ^
```

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                           ^

scala> val emptyMap = Map.empty[String, String]
(ou Map[String, String]())
emptySet: scala.collection.immutable.Map[String] = Map()

scala> emptyMap + ("test" -> "success")
res0: scala.collection.immutable.Map[String, String] = Map(test -> success)
```

Specific collections

Conversions

Scala collection hierarchy : conversions with `to(_)`

Conversion `Seq[T]` $\leftrightarrow$ `Set[T]`

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Syntax introduced in version 2.13

- Old syntax : `to[Seq]`, `to[Set]`, `to[Map]`, etc...
- Other available syntax : `toSeq`, `toSet`, `toMap`, etc...

Common methods

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Basic methods and search methods

Common methods on `Iterable[T]`

Simple methods

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- `isEmpty` and `nonEmpty` $\equiv$ `!isEmpty`

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  Checks if at least one element `x` satisfies `p(x) == true`

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- `count(p : T => Boolean) : Boolean`
  Counts number of elements satisfying `p(x) == true`
- `find(p : T => Boolean) : Option[T]`
  Find first element x satisfying `p(x) == true`
  *(returns **`None`** if no such element is found)*

Common methods

Filter methods

Filter methods on `Iterable[T]`

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  Drop elements while elements x satisfies `p(x) == true`
- `span(p : T => Boolean)`
  $\equiv$ `(takeWhile p, dropWhile p)`
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Transformation methods on `Iterable[T]`

Transformation methods

- `flatten` "flattens" a collection of collections
- `map(f : T => U)`
  Returns the collection of results of `f` for all elements
- `flatMap(f : T => Iterable[U])` ≡ `map(f).flatten`

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Transformation methods on `Iterable[T]`

Example

```
scala> Seq(Seq(5, 1, 1), Seq(1)).flatten
res0: Seq[Int] = List(5, 1, 1, 1)
```

Transformation methods on `Iterable[T]`

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scala> Seq(Seq(5, 1, 1), Seq(1)).flatten
res0: Seq[Int] = List(5, 1, 1, 1)

scala> Set(Seq(5, 1, 1), Seq(1)).flatten
res1: scala.collection.immutable.Set[Int] = Set(5, 1)
```

Transformation methods on `Iterable[T]`

Example

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scala> Set(Seq(5, 1, 1), Seq(1)).flatten
res1: scala.collection.immutable.Set[Int] = Set(5, 1)

scala> Seq(Set(5, 1, 1), Set(1)).flatten
res2: scala.collection.immutable.Set[Int] = Seq(5, 1, 1)
```

Transformation methods on `Iterable[T]`

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res1: scala.collection.immutable.Set[Int] = Set(5, 1)

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res2: scala.collection.immutable.Set[Int] = Seq(5, 1, 1)

scala> Seq(5, 1, 2) map { 1.0 / _ }
res3: Seq[Double] = List(0.2, 1.0, 0.5)
```

Transformation methods on `Iterable[T]`

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res3: Seq[Double] = List(0.2, 1.0, 0.5)

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res4: scala.collection.immutable.Set[Double] = Set(0.2, 1.0, 0.5)

scala> Seq(5, 1, 2) flatMap { x => List(x, x) }
res5 : Seq[Int] = List(5, 5, 1, 1, 2, 2)
```

Transformation methods on `Iterable[T]`

Example

```
scala> Seq(Seq(5, 1, 1), Seq(1)).flatten
res0: Seq[Int] = List(5, 1, 1, 1)

scala> Set(Seq(5, 1, 1), Seq(1)).flatten
res1: scala.collection.immutable.Set[Int] = Set(5, 1)

scala> Seq(Set(5, 1, 1), Set(1)).flatten
res2: scala.collection.immutable.Set[Int] = Seq(5, 1, 1)

scala> Seq(5, 1, 2) map { 1.0 / _ }
res3: Seq[Double] = List(0.2, 1.0, 0.5)

scala> Set(5, 1, 2) map { 1.0 / _ }
res4: scala.collection.immutable.Set[Double] = Set(0.2, 1.0, 0.5)

scala> Seq(5, 1, 2) flatMap { x => List(x, x) }
res5 : Seq[Int] = List(5, 5, 1, 1, 2, 2)

scala> Set(5, 1, 2) flatMap { x => List(x, x) }
res6 : scala.collection.immutable.Set[Int] = Set(5, 1, 2)
```

`for`-comprehensions by example

`for (x <- c) yield f(x)` ≡ `c map f`

```
scala> for (x <- Seq(5, 1, 2)) yield 1.0 / x
res0: Seq[Double] = List(0.2, 1.0, 0.5)

scala> Seq(5, 1, 2) map { x => 1.0 / x }
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scala> Seq(5, 1, 2) map { x => 1.0 / x }
res1: Seq[Double] = List(0.2, 1.0, 0.5)
```

```
for (x <- c if cond(x)) yield f(x) ≡ (c filter cond) map f
```

```
scala> for (x <- Seq(5, 1, 2) if x > 1) yield 1.0 / x
res2: Seq[Double] = Seq(0.2, 0.5)

scala> (Seq(5, 1, 2) filter {x => x > 1}) map { x => 1.0 / x }
res3: Seq[Double] = Seq(0.2, 0.5)
```

`for`-comprehensions by example

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for (x <- c) yield f(x) ≡ c map f
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scala> for (x <- Seq(5, 1, 2)) yield 1.0 / x
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for (x <- c if cond(x)) yield f(x) ≡ (c filter cond) map f
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scala> for (x <- Seq(5, 1, 2) if x > 1) yield 1.0 / x
res2: Seq[Double] = Seq(0.2, 0.5)

scala> (Seq(5, 1, 2) filter {x => x > 1}) map { x => 1.0 / x }
res3: Seq[Double] = Seq(0.2, 0.5)
```

```
for (x <- c1 ; y <- c2) yield f(x, y) ≡ c1 flatMap (x => c2 map (y => f(x, y)))
```

```
scala> for (x <- Seq(5, 1, 2) ; y <- Seq(2, 3)) yield x + y
res4: Seq[Int] = List(7, 8, 3, 4, 4, 5)

scala> Seq(5, 1, 2) flatMap (x => Seq(2, 3) map (y => x + y))
res4: Seq[Int] = List(7, 8, 3, 4, 4, 5)
```

`for`-comprehensions by example

Do not forget the `yield` keyword !

`for`-comprehensions by example

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Example

```
scala> def couplesWithSum(n : Int) =
         for (i <- 0 to n ;
              j <- 0 to n if i + j == n)
           yield (i, j)
couplesWithSum(n: Int): IndexedSeq[(Int, Int)]

scala> couplesWithSum(4)
res1: IndexeqSeq[(Int, Int)] = Vector((0,4), (1,3), (2,2), (3,1), (4,0))
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`for`-comprehensions by example

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- Object $\equiv$ Item in database

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Think DBMS...

- Object ≡ Item in database
- Collection ≡ Table in database
- `for (x <- table)` ≡ `SELECT * FROM table`
- `if cond(x)` ≡ `WHERE cond(x)`

Common methods

Aggregation methods

Aggregation methods on `Iterable[T]`

`fold`-like aggregation methods

Aggregation methods on `Iterable[T]`

`fold`-like aggregation methods

- `foldLeft[U](z : U)(op : (U, T) => U) : U`
  ≡ `op(...(op(op(z, a_1), a_2) ...), a_n)`

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  behaves like above **if op is associative**

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- If collection is empty, result is always `z`.

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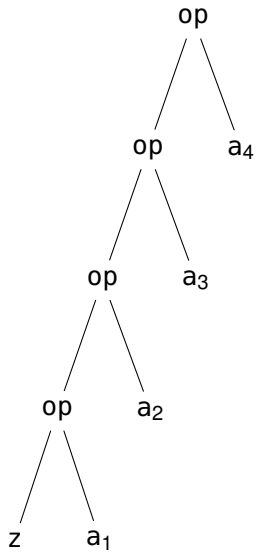
  behaves like above **if op is associative**

Features

- If collection is empty, result is always `z`.
- When called on unordered collections, **method is not guaranteed to be pure**
  (except `fold` if `op` is associative AND commutative)

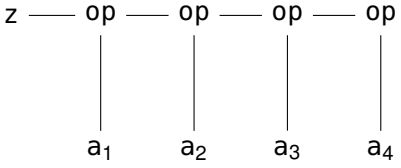
Folding process for `foldLeft`

Example on 4-element list `List(a1, a2, a3, a4)`



Folding process for `foldLeft`

```
(List(a1, a2, a3, a4) foldLeft z)(op)
```



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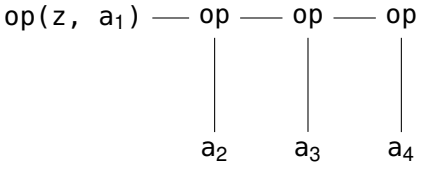

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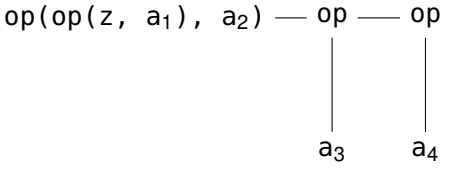
$(\texttt{List}(a_1, a_2, a_3, a_4)\ \texttt{foldLeft}\ z)(op)$



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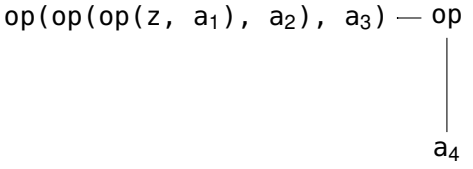

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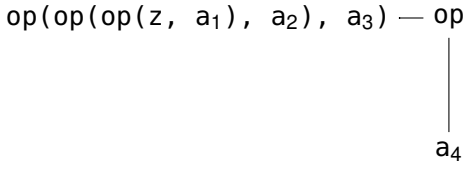
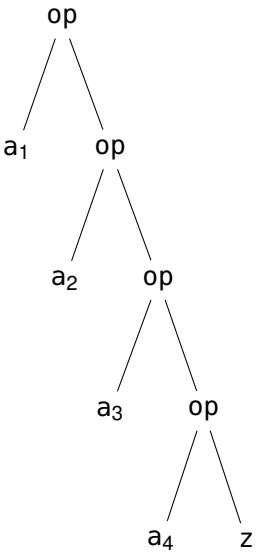


Résultat final

```
op(op(op(op(z, a1), a2), a3), a4)
```

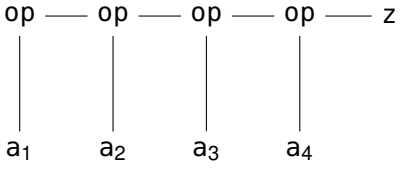
Folding process for `foldRight`

Example on 4-element list `List`(a_1, a_2, a_3, a_4)



Folding process for `foldRight`

```
(List(a1, a2, a3, a4) foldRight z)(op)
```



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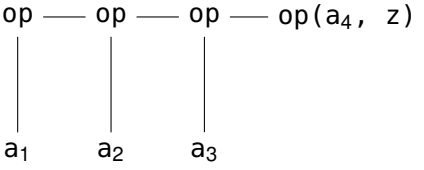

Folding process for `foldRight`

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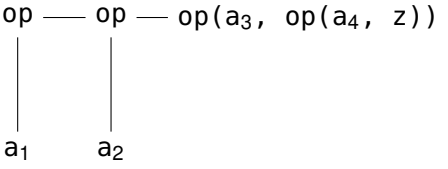
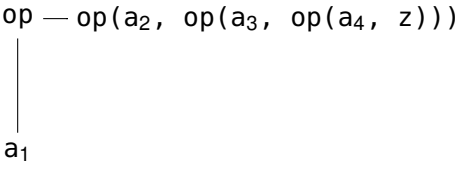


Folding process for `foldRight`

$$(\texttt{List}(a_1, a_2, a_3, a_4)\ \texttt{foldRight}\ z)(op)$$



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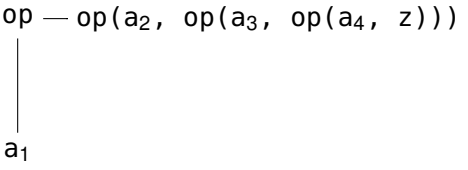

Résultat final

```
op(a1, op(a2, op(a3, op(a4, z))))
```

`foldLeft` vs `foldRight`

How to tell `foldLeft` from `foldRight` ?

`foldLeft` vs `foldRight`

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- `foldLeft` is inherently tail-recursive.

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Both are inherently recursive

- `foldLeft` is inherently tail-recursive.
- `foldRight` is not.

Aggregations methods on `Iterable[T]`

Compute all combinations of elements of a set

```
scala> def combinations[T](s : Set[T]) =
         (s foldLeft Set(Set[T]())) { case (z, x) => z ++ (z map { _ + x }) }
combinations: [T](s: Seq[T])Seq[Seq[T]]
```

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scala> combinations((1 to 3).to(Set))
res0: Set[Set[Int]] = HashSet(Set(), Set(1, 3), Set(2), Set(2, 3), Set(3),
                              Set(1, 2), Set(1), Set(1, 2, 3))
```

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Find corresponding existing methods

- `fold(0)(_ + _)`

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```

Find corresponding existing methods

- `fold(0)(_ + _)`
- `foldLeft(0){ case (z, x) => z + 1 }`

Aggregations methods on `Iterable[T]`

Compute all combinations of elements of a set

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```

Find corresponding existing methods

- `fold(0)(_ + _)`
- `foldLeft(0){ case (z, x) => z + 1 }`
- `foldLeft(0){ case (z, x) => if (p(x)) z+1 else z }`

Aggregations methods on `Iterable[T]`

`reduce`-like aggregation methods

Aggregations methods on `Iterable[T]`

reduce-like aggregation methods

- `reduceLeft[T1 >: T](op : (T1, T) => T1) : T1`
  ≡ `(tail foldLeft head)(op)`

Aggregations methods on `Iterable[T]`

reduce-like aggregation methods

- `reduceLeft[T1 >: T](op : (T1, T) => T1) : T1`
  `≡ (tail foldLeft head)(op)`
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  `≡ (init foldLeft last)(op)`

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- `reduceRight[T1 >: T](op : (T, T1) => T1) : T1`
  $\equiv$ `(init foldLeft last)(op)`
- `reduce[T1 >: T](op : (T1, T1) => T1) : T1`
  behaves like above **if op is associative**

Aggregations methods on `Iterable[T]`

`reduce`-like aggregation methods

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Features

- *If collection is empty, methods throw an exception.*
  `Option`-valued version are also defined.
- When called on unordered collections, **method is not guaranteed to be pure**
  (except `reduce` if `op` is associative AND commutative)

Aggregations methods on `Iterable[T]`

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scala> Set[Int]() reduceOption (_ + _)
res1: Option[Int] = None
```

Common methods

Grouping methods

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New in version 2.13 : `groupMap`, `groupMapReduce`

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Current list is not exhaustive !

Refer to official API documentation

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`Option`-valued collections

- `flatten` remove all `None`-valued elements.

Particular collections

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Already defined as a method in class ***LazyList***

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scala> def from(n : Int) : LazyList[Int] =
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def from(n: Int): LazyList[Int]
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How is infinity handled by methods ?

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Expected behaviour is documented in API.

LazyList[T]

Examples

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scala> val inverses = naturals.tail map { 1.0 / _ }
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4 is computed
5 is computed
... (endless !)
```

LazyList[T]

Erathostenes' sieve

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Before version 2.12 : Stream[T]

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Before version 2.12 : Stream[T]

- Head was not lazily evaluated.

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Make standard collections parallelizable : `.par`

- Version 2.13 requires specific import :

```
import scala.collection.parallel.CollectionConverters._
```

Parallel collections

Sequential vs parallel collections

```
import scala.collection.parallel.CollectionConverters._

object Parallel extends App
  {
    def elapsedNano[T](chunk : => T, times : Int = 1) : Long =
      {
        val start = System.nanoTime() // from Java
        for (i <- 0 until times) { val res = chunk }
        System.nanoTime() - start
      }

    val c = 0 to 1000000
    println(s"${elapsedNano(c     count { _ %3 == 0 }, 1000)/1000000.0} ms")
    println(s"${elapsedNano(c.par count { _ %3 == 0 }, 1000)/1000000.0} ms")
  }
```

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(At least, use mutable state as rarely as possible. . . !)

Parallel collections and (im)mutability

Immutability vs mutable state

```
import scala.collection.parallel._
import scala.collection.parallel.CollectionConverters._

object MutableIsEvil extends App
  {
    val c = 1 to 1000000
    def isPrime(n : Int) = (2 to math.sqrt(n).toInt) forall { n % _ != 0 }

    // Immutable case
    for (i <- 1 to 3) println(s"count isPrime = ${c.par count isPrime}")

    // Mutable case with a counter
    def countPrimes(c : ParSeq[Int]) = {
        var count = 0
        c foreach { n => if (isPrime(n)) count = count + 1 }
        count
      }
    for (i <- 1 to 3) println(s"countPrimes = ${countPrimes(c.par)}")
  }
```