Implementing the Scala 2.13 collections

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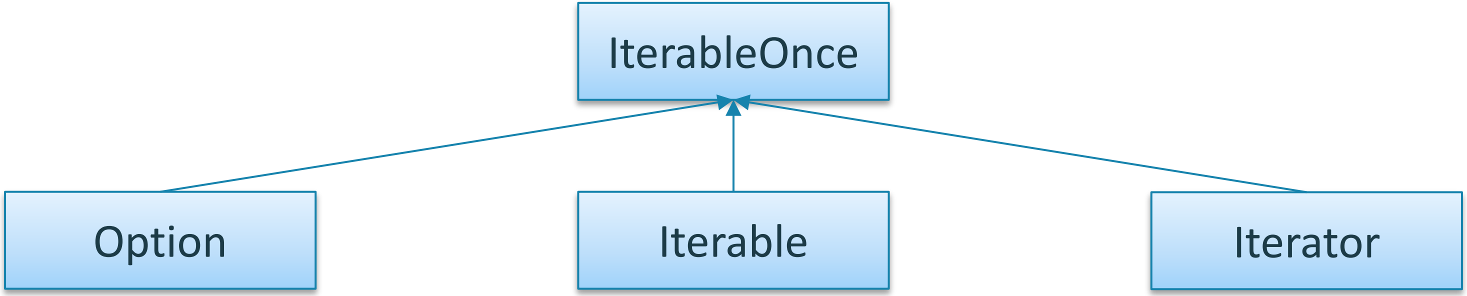
Scala 2.13

- Redesigned collection library
- Easier for users
  - Better discoverability
  - Better error messages
- Easier for collection implementers
  - More regular
  - But still plenty of necessary complexity

IterableOnce – Not Quite a Collection

IterableOnce

- "Has an `iterator` method"
  - Similar to `java.lang.Iterable`
  - But supports single-traversal implementations
- Lightweight interface
  - No unnecessary methods
  - Can be implemented by non-collection types
- Many collection methods accept `IterableOnce` values



IterableOnce

```
class MyIterableOnce extends IterableOnce[Int] {
  private[this] val data = Array(1, 2, 3)

  def iterator = data.iterator
}
```

IterableOnce

```
class MyIterableOnce extends IterableOnce[Int] {
  private[this] val data = Array(1, 2, 3)

  def iterator = data.iterator
  override def knownSize = data.length
}


val b = mutable.ArrayBuffer.empty[Int]
b.addAll(new MyIterableOnce)
```

IterableOnce

```
class MyIterableOnce extends IterableOnce[Int] {
  private[this] val data = Array(1, 2, 3)

  def iterator = data.iterator
  override def knownSize = data.length
  override def stepper[S <: Stepper[_]]
    (implicit shape: StepperShape[Int, S]): S = data.stepper[S]
}
```

Previously in *scala-java8-compat*
Like Java's `Spliterator`

- Parallel collections implement parallelizable Steppers

IterableOnce

```
class MyIterableOnce extends IterableOnce[Int] {
  private[this] val data = Array(1, 2, 3)

  def iterator = data.iterator
  override def knownSize = data.length
  override def stepper[S <: Stepper[_]]
    (implicit shape: StepperShape[Int, S]): S = data.stepper[S]
}


val st: IntStepper = (new MyIterableOnce).stepper
val it: PrimitiveIterator.OfInt = st.javaIterator
while(it.hasNext)
  println(it.next())
```

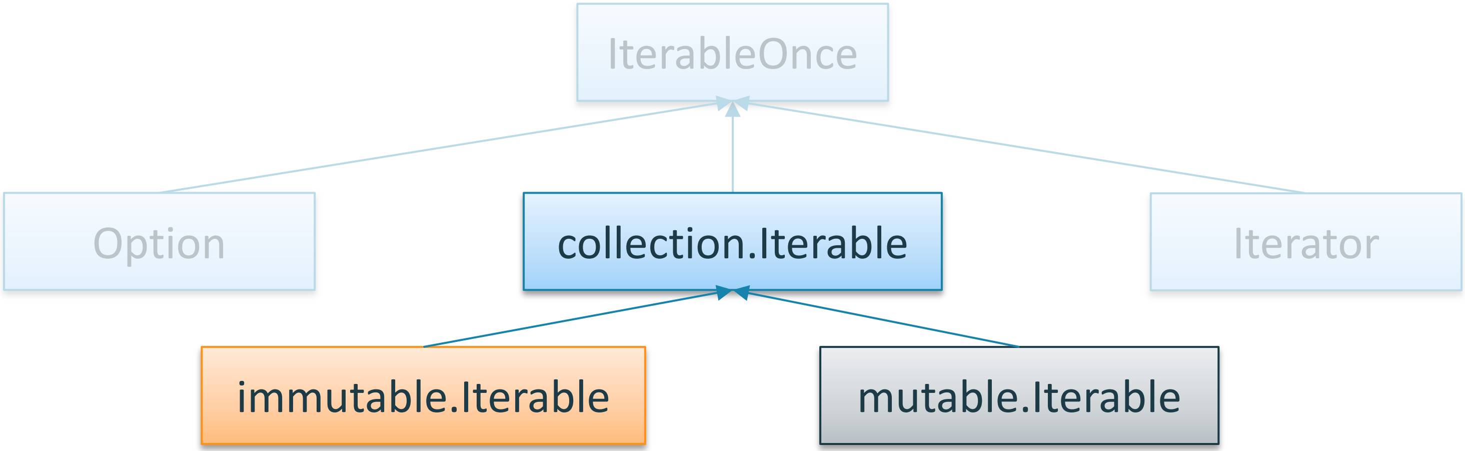
Implementing a Real Collection

Simplified immutable.ArraySeq

- Sequence of elements with arbitrary type
- Immutable
- Array-like performance characteristics

```
class MySeq[+A](data: Array[Any]) extends ??? {
  ...
}
```

Abstract Collection Types



IterableOnce

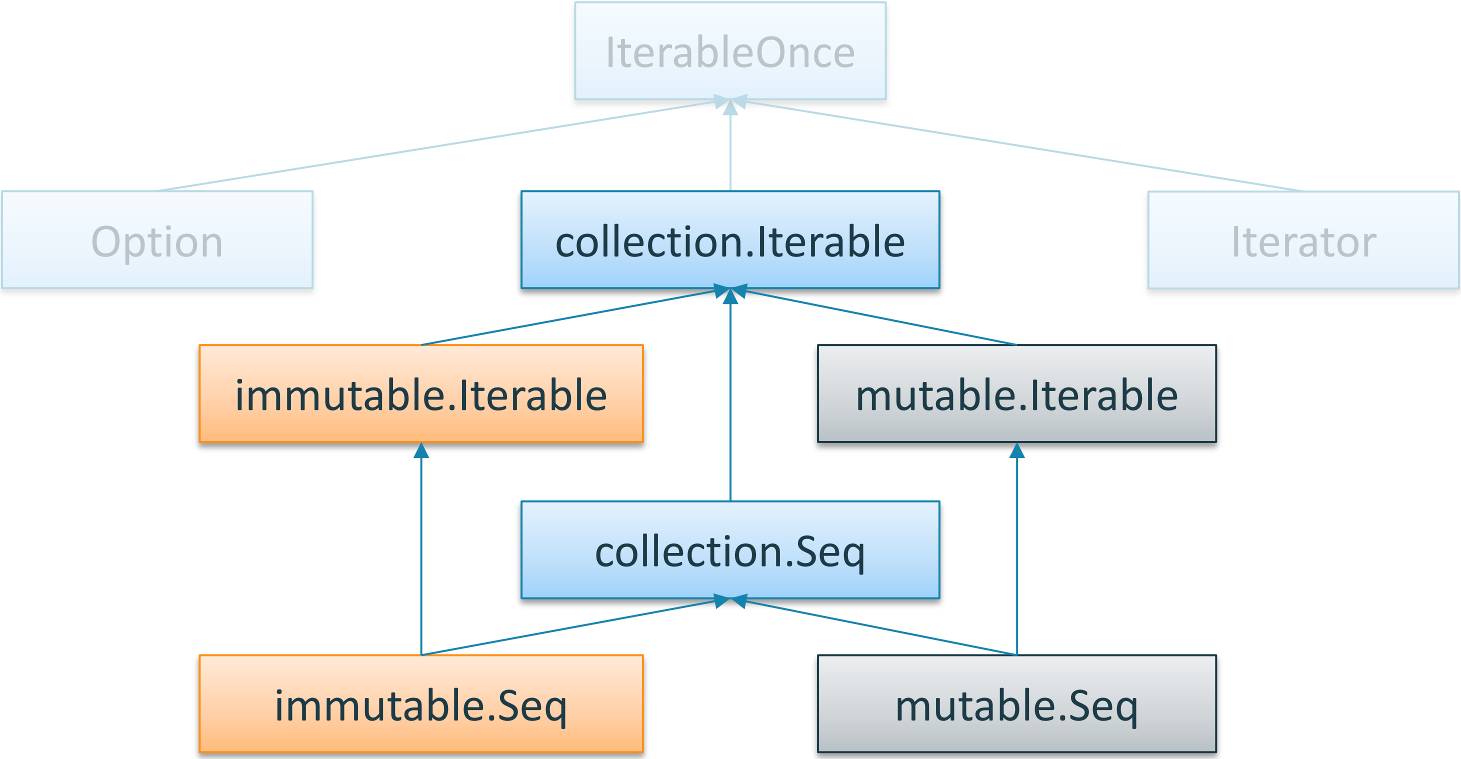
Option

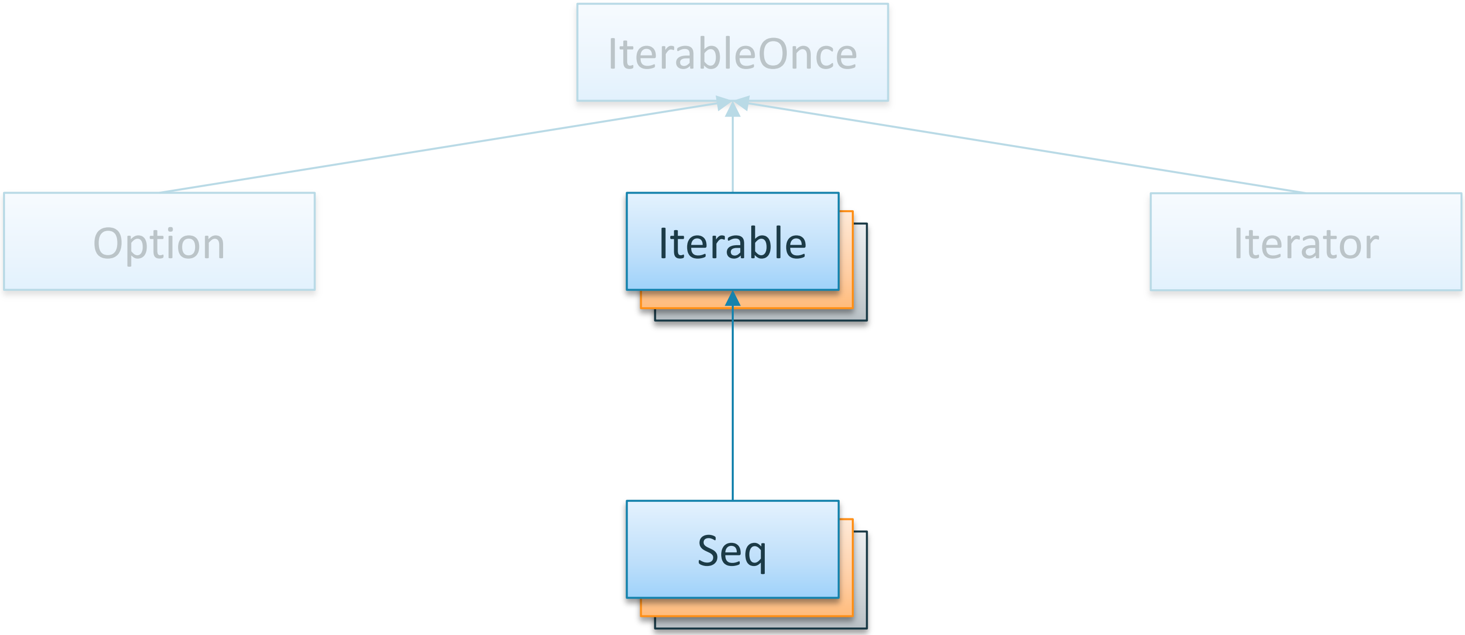
collection.Iterable

Iterator

immutable.Iterable

mutable.Iterable


IterableOnce
Option
collection.Iterable
Iterator
immutable.Iterable
mutable.Iterable
collection.Seq
immutable.Seq
mutable.Seq


IterableOnce
Option
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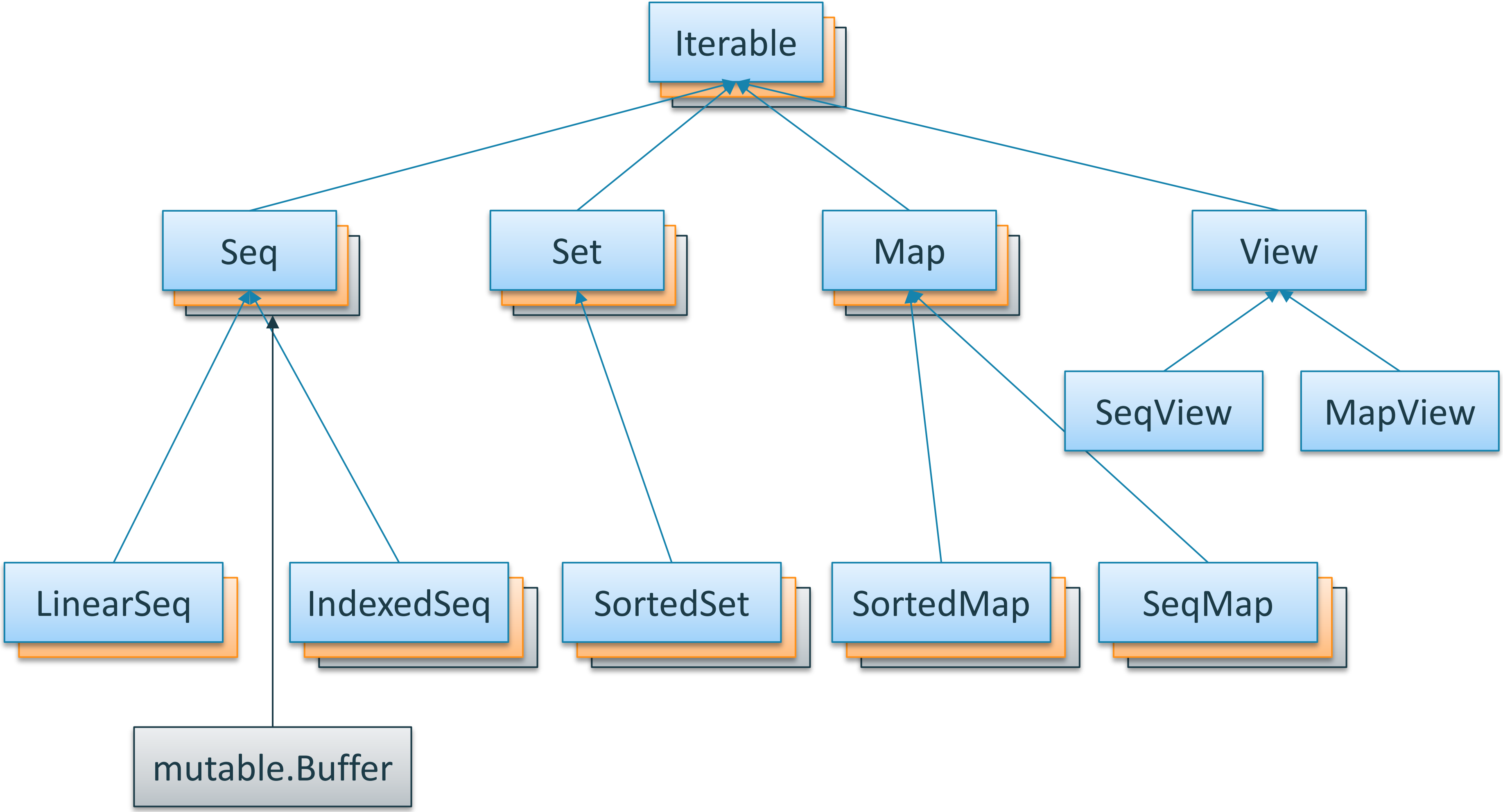Iterable
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SortedSet
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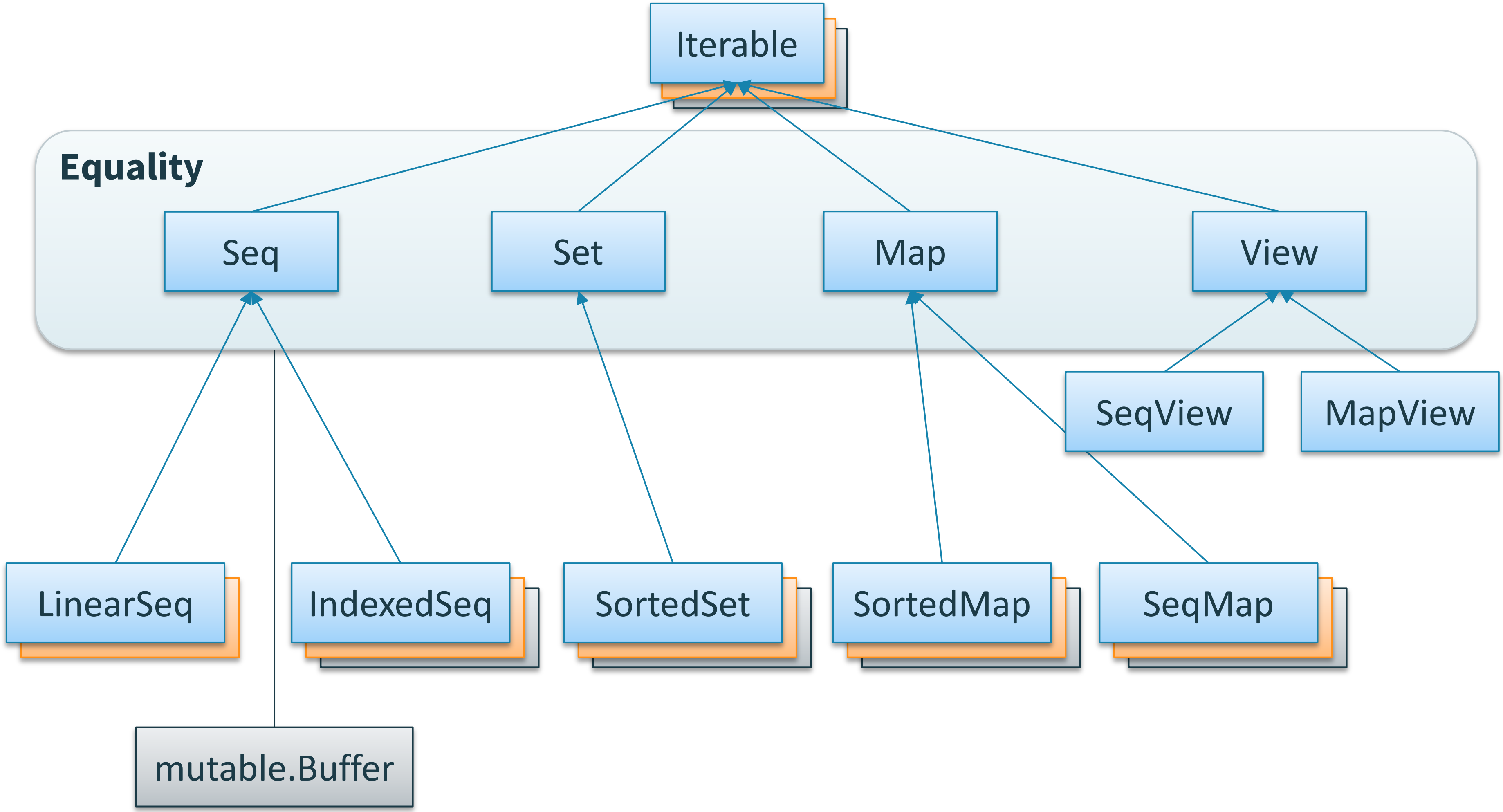
mutable.Buffer


Iterable
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MapView
LinearSeq
IndexedSeq
SortedSet
SortedMap
SeqMap
mutable.Buffer

Implementing an immutable IndexedSeq

Simple IndexedSeq

```scala
class MySeq[+A](data: Array[Any]) extends IndexedSeq[A] {
  def length: Int = data.length
  def apply(i: Int): A = data(i).asInstanceOf[A]
  override def className = "MySeq"
}

scala> val s = new MySeq[String](Array("a", "b", "c"))
s: com.example.MySeq[String] = MySeq(a, b, c)

scala> s.foreach(println)
a
b
c

scala> println(s.indexWhere(_ > "b"))
2
```

Companion Object as Factory

```scala
object MySeq extends SeqFactory[MySeq] {

  private[this] val _empty = new MySeq(Array.empty)
  def empty[A]: MySeq[A] = _empty

  def newBuilder[A]: mutable.Builder[A, MySeq[A]] =
    Array.newBuilder[Any].mapResult(new MySeq(_))

  def from[A](source: IterableOnce[A]): MySeq[A] =
    new MySeq(Array.from(source))
}
```

Using the Factory

```
scala> MySeq.tabulate(5)(_ * 10)
res0: com.example.MySeq[Int] = MySeq(0, 10, 20, 30, 40)

scala> List("a", "b", "c").to(MySeq)
res1: com.example.MySeq[String] = MySeq(a, b, c)
```

Using the Factory

```
scala> MySeq.tabulate(5)(_ * 10)
res0: com.example.MySeq[Int] = MySeq(0, 10, 20, 30, 40)

scala> List("a", "b", "c").to(MySeq)
res1: com.example.MySeq[String] = MySeq(a, b, c)


scala> res0.filter(_ > 25)
res2: IndexedSeq[Int] = Vector(30, 40)

scala> res0.map(_.toString)
res3: IndexedSeq[String] = Vector(0, 10, 20, 30, 40)
```

Ops Traits

```
class MySeq[+A](data: Array[Any])
  extends IndexedSeq[A] {

  ...
}
```

extends IndexedSeqOps[A, IndexedSeq, IndexedSeq[A]]

```
  def map[B](f: A => B): CC[B] = ...
  def filter(pred: A => Boolean): C = ...
```

Ops Traits

```
class MySeq[+A](data: Array[Any])
  extends IndexedSeq[A] {

  ...
}
```

trait IndexedSeqOps[+A, +CC[_], +C]

extends IndexedSeqOps[A, IndexedSeq, IndexedSeq[A]]

```
  def map[B](f: A => B): CC[B] = ...
  def filter(pred: A => Boolean): C = ...
```

Simple IndexedSeq

```
class MySeq[+A](data: Array[Any])
  extends IndexedSeq[A]
  with IndexedSeqOps[A, MySeq, MySeq[A]]
  with IterableFactoryDefaults[A, MySeq] {

  override def iterableFactory: SeqFactory[MySeq] = MySeq
  ...
}
```

IndexedSeq Optimizations

```
class MySeq[+A] private (data: Array[Any])
  extends AbstractSeq[A]
  with IndexedSeq[A]
  with IndexedSeqOps[A, MySeq, MySeq[A]]
  with StrictOptimizedSeqOps[A, MySeq, MySeq[A]]
  with IterableFactoryDefaults[A, MySeq]
  with DefaultSerializable {

  override def iterableFactory: SeqFactory[MySeq] = MySeq
  def length: Int = data.length
  def apply(i: Int): A = data(i).asInstanceOf[A]
  override def className = "MySeq"
}
```

Overriding Methods

```
class MySeq[+A] private (data: Array[Any]) ... {
  ...

  override def map[B](f: A => B): MySeq[B] = {
    val len = length
    val a = new Array[Any](len)
    var i = 0
    while(i < len) {
      a(i) = f(data(i).asInstanceOf[A])
      i += 1
    }
    new MySeq[B](a)
  }
}
```

Collection Kinds

Kinds in Type Theory

- Kinds classify types (like types classify values)
- *Proper types* are of kind `*` ("type")
  - All *values* have a *proper type*
  - For example: `Int`, `String`, `List[Int]`
- Unary type constructors are of kind `* → *`
  - For example: `List`, `Set`
- Binary type constructors are of kind `* → * → *`
  - For example: `Map`, `Function1`

Extending Kinds for Scala[*]

- Proper types have lower and upper bounds: `*(T, U)`
  - Abbreviate `*(Nothing, T)` to `*(T)`
  - Abbreviate `*(Any)` to `*`
- Variance tracked by kind arrows

```
trait Map[K, +V]
```

- The kind of immutable.`Map` is $* \to * \overset{+}{\to} *$
- The kind of mutable.`AnyRefMap` is $*(\texttt{AnyRef}) \to * \to *$

```
trait AnyRefMap[K <: AnyRef, V]
```

[*] http://adriaanm.github.io/files/higher.pdf

Collection Kinds

- Need to track context bounds
  - Similar to type bounds
- But not *kinds* in the type theory sense anymore
  - A type with a missing context bound implicit cannot be instantiated
  - But it is still a valid type

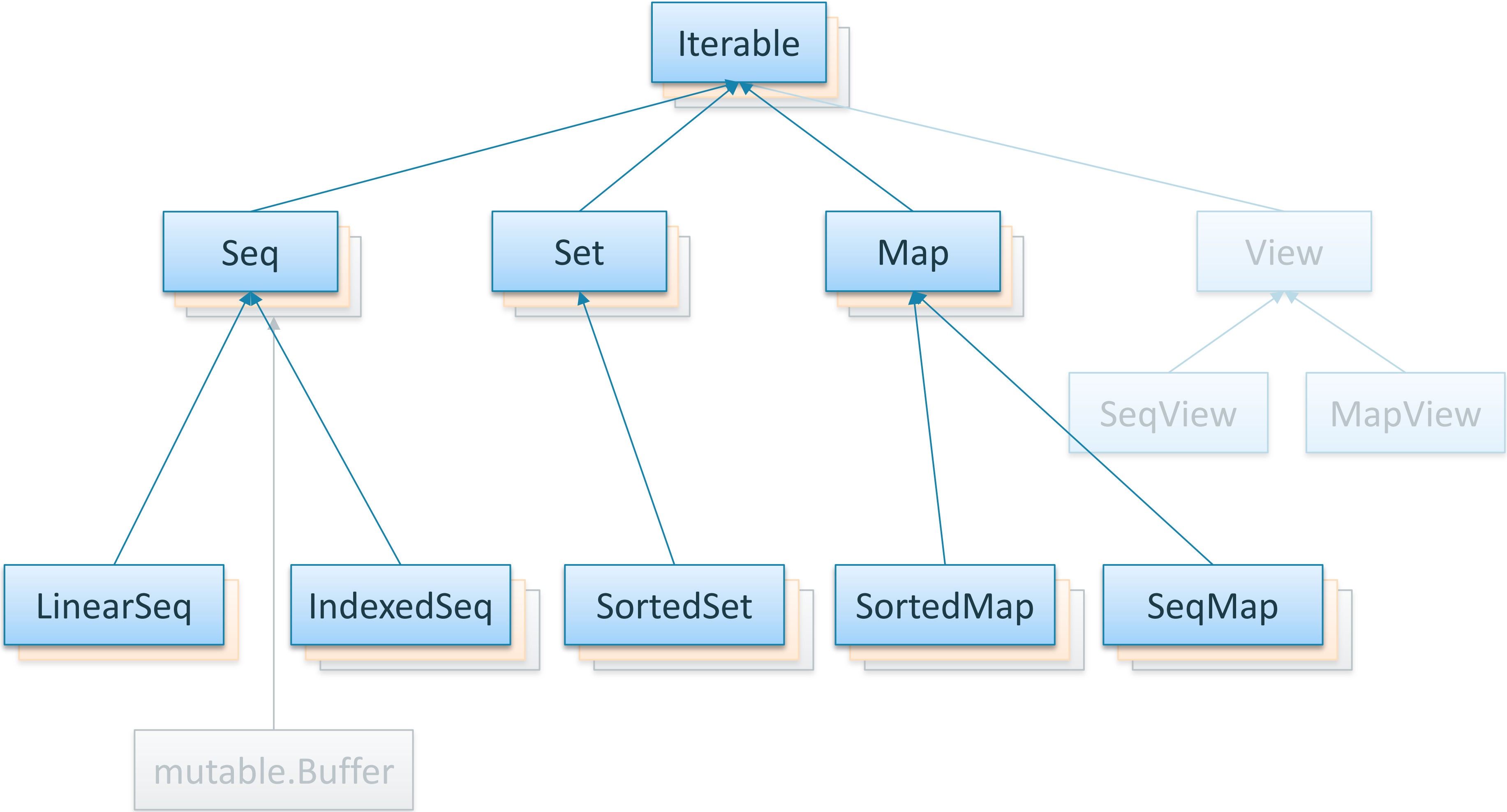
- Collection kinds capture what you need to instantiate types *and values*

Standard Collection Kinds

	Collection Kind[*]	Collection	Factory
Iterable	* → *	✓	✓
Map	* → * → *	✓	✓
Evidence Iterable	(Ev @ (* → *)) → (* : Ev) → *		✓
Sorted Iterable	(* : Ordering) → *	✓	✓
Sorted Map	(* : Ordering) → * → *	✓	✓
Specific Iterable	*		✓

- Non-standard kinds can be implemented

[*] Improvised notation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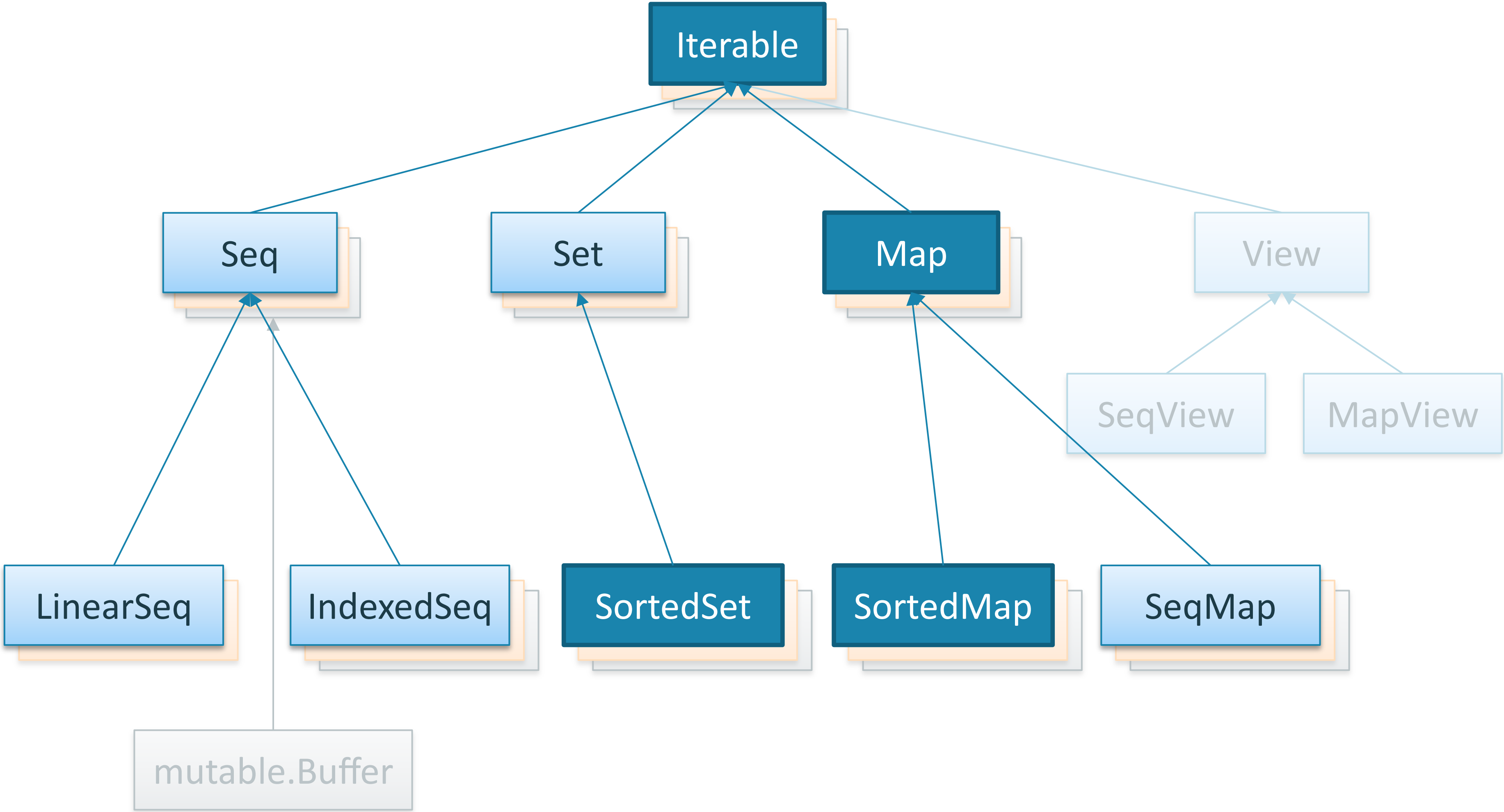
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Collection Kinds

```
trait   IterableOps [+A,      +CC[_],         +C     ]

trait   MapOps      [ K, +V,  +CC[_, _] <: …, +C     ]
extends IterableOps [(K,  V),  Iterable,       C     ]

trait   SortedSetOps[ A,      +CC[_] <: …,    +C <: …]
extends SetOps      [ A,       Set,            C     ]

trait   SortedMapOps[ K, +V,  +CC[_, _] <: …, +C <: …]
extends MapOps      [ K,  V,   Map,            C     ]
```

- Different `CC` type for each kind
- Collections must support all kinds of their parent types

Implementing a Map

Factory

```
object MyMap extends MapFactory[MyMap] {

  private[this] val _empty = new MyMap(new JHashMap[Any, Any])
  def empty[K, V]: MyMap[K,V] = _empty.asInstanceOf[MyMap[K, V]]

  def from[K, V](it: IterableOnce[(K, V)]): MyMap[K,V] =
    newBuilder[K, V].addAll(it).result()

  def newBuilder[K, V]: mutable.Builder[(K, V), MyMap[K,V]] =
    new mutable.Builder[(K, V), MyMap[K, V]] {
      private[this] val m = new JHashMap[K, V]
      def clear() = m.clear()
      def result() = new MyMap[K, V](m)
      def addOne(elem: (K, V)) = { m.put(elem._1, elem._2); this }
    }
}
```

Outline

```
class MyMap[K, +V] private (m: JHashMap[K, _ <: V])
  extends AbstractMap[K, V]
  with StrictOptimizedMapOps[K, V, MyMap, MyMap[K, V]]
  with MapFactoryDefaults[K, V, MyMap, immutable.Iterable] {

  override def mapFactory = MyMap
  //override def iterableFactory = immutable.Iterable

  ...
}
```

Implementation

```
class MyMap[K, +V] private (m: JHashMap[K, _ <: V]) ... {
  ...
  def iterator: Iterator[(K, V)] =
    m.entrySet().iterator().asScala.map(e => (e.getKey, e.getValue))
  def get(key: K): Option[V] = Option(m.get(key)).orElse {
    if(m.containsKey(key)) Some(null.asInstanceOf[V]) else None
  }
  def removed(key: K): MyMap[K,V] = if(!contains(key)) this else {
    val m2 = m.clone().asInstanceOf[JHashMap[K, V]]
    m2.remove(key)
    new MyMap(m2)
  }
  def updated[V1 >: V](key: K, value: V1): MyMap[K,V1] = {
    val m2 = m.clone().asInstanceOf[JHashMap[K, V1]]
    m2.put(key, value)
    new MyMap(m2)
  }
}
```

Overriding

```
class MyMap[K, +V] private (m: JHashMap[K, _ <: V]) ... {
  ...

  override def map[K2, V2](f: ((K, V)) => (K2, V2)):
    MyMap[K2, V2] = ...

  override def map[B](f: ((K, V)) => B):
    immutable.Iterable[B] = super.map(f)
}
```

- Methods that return a `CC` are overloaded
- Typical cases: `map`, `flatMap`, `collect`, `concat`

Non-Standard Collection Kinds

In the Standard Library

- AnyRefMap
- IntMap
- LongMap
- BitSet
- CollisionProofHashMap

immutable.BitSet

```scala
sealed abstract class BitSet
  extends AbstractSet[Int]
  with SortedSet[Int]
  with StrictOptimizedSortedSetOps[Int, SortedSet, BitSet]
  with collection.BitSet
  with collection.BitSetOps[BitSet]
  with Serializable {

  override protected def fromSpecific(coll: IterableOnce[Int]): BitSet =
    bitSetFactory.fromSpecific(coll)
  override protected def newSpecificBuilder: Builder[Int, BitSet] =
    bitSetFactory.newBuilder
  override def empty: BitSet = bitSetFactory.empty

  def bitSetFactory = BitSet
  ...
}
```

No …FactoryDefaults

mutable.CollisionProofHashMap

```
final class CollisionProofHashMap[K, V](...)(implicit ordering: Ordering[K])
  extends AbstractMap[K, V]
  with MapOps[K, V, Map, CollisionProofHashMap[K, V]]
  with StrictOptimizedIterableOps[(K, V), Iterable,
                                  CollisionProofHashMap[K, V]]
  with StrictOptimizedMapOps[K, V, Map, CollisionProofHashMap[K, V]] {

  private[this] final def sortedMapFactory:
    SortedMapFactory[CollisionProofHashMap] = CollisionProofHashMap  ...
}
```

- Reuse SortedMapFactory
- But not SortedMap

immutable.IntMap

```
sealed abstract class IntMap[+T]
  extends AbstractMap[Int, T]
  with StrictOptimizedMapOps[Int, T, Map, IntMap[T]]
  with Serializable {

  protected def intMapFrom[V2](coll: IterableOnce[(Int, V2)]):
    IntMap[V2] = ...

  def map[V2](f: ((Int, T)) => (Int, V2)): IntMap[V2] =
    intMapFrom(new View.Map(toIterable, f))  ...
}
```

- Typical overloads: `map`, `flatMap`, `collect`, `concat`
- Good baseline implementation: wrap a `View` with the appropriate `from` method

IntMap Factory

```
object IntMap {
  def empty[T] : IntMap[T] = ...
  def singleton[T](key: Int, value: T): IntMap[T] = ...
  def apply[T](elems: (Int, T)*): IntMap[T] = ...
  def from[V](coll: IterableOnce[(Int, V)]): IntMap[V] = ...
  def newBuilder[V]: Builder[(Int, V), IntMap[V]] = ...

  ...
}
```

- No standard factory type
- Methods up to the collection implementor

BuildFrom & Factory

- `Factory` enables static type-driven collection building
- `BuildFrom` enables dynamic type-driven collection building
  - based on an existing object of the same type
- Implementations are generally the same for *concrete* collection types

	Implicit Conversion of Companion Object	Implicit Instance for Type

`Factory`	**`List(1 -> "a")`**
	`.to(IntMap)`
		`implicitly[`
		`Factory[Int, List[Int]]`
		`]`

`BuildFrom`	`Future.sequence(xs)`
	`(List)`
		`val xs: Iterable[Future[Int]]`
		`Future.sequence(xs)`

IntMap Factory

```
object IntMap { ...
  implicit def toFactory[V](dummy: IntMap.type): Factory[(Int, V), IntMap[V]] =
    ToFactory.asInstanceOf[Factory[(Int, V), IntMap[V]]]

  private[this] object ToFactory
    extends Factory[(Int, AnyRef), IntMap[AnyRef]] with Serializable {
    def fromSpecific(it: IterableOnce[(Int, AnyRef)]): IntMap[AnyRef] =
      IntMap.from[AnyRef](it)
    def newBuilder: Builder[(Int, AnyRef), IntMap[AnyRef]] =
      IntMap.newBuilder[AnyRef]
  }

  implicit def iterableFactory[V]: Factory[(Int, V), IntMap[V]] =
    toFactory(this)
}
```

- Implicit Factory and implicit conversion to Factory

IntMap Factory

```
object IntMap { ...
  implicit def toBuildFrom[V](factory: IntMap.type):
    BuildFrom[Any, (Int, V), IntMap[V]] =
    ToBuildFrom.asInstanceOf[BuildFrom[Any, (Int, V), IntMap[V]]]

  private[this] object ToBuildFrom
    extends BuildFrom[Any, (Int, AnyRef), IntMap[AnyRef]] {
    def fromSpecific(from: Any)(it: IterableOnce[(Int, AnyRef)]) =
      IntMap.from(it)
    def newBuilder(from: Any) = IntMap.newBuilder[AnyRef]
  }

  implicit def buildFromIntMap[V]:
    BuildFrom[IntMap[_], (Int, V), IntMap[V]] = toBuildFrom(this)
}
```

- The same for BuildFrom

Summary

Summary

- Integration of non-collection types via `IterableOnce`
- Unboxed and parallel iteration with `Stepper`
- Use of collection factories
- No special treatment of Iterable-kinded collections anymore
    - Abstractions for some standard kinds is provided
    - Non-standard kinds can be added
- Factory and `BuildFrom` replace `CanBuildFrom`

Links

- The Architecture of Scala 2.13's Collections
  https://docs.scala-lang.org/overviews/core/architecture-of-scala-213-collections.html
  - and other collection docs on docs.scala-lang.org
- Demo project and slides:
  https://github.com/szeiger/implementing-scala-collections
- 🐦 @StefanZeiger