Functional Forkshop: Part 1

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July 24, 2019

About us

Valik

Server guild manager in Kyiv. Formerly forced people to use functional programming style in the Domains (Premium) team. Now works on Tagless Infra to provide you with the best tools for your daily needs. Which are all functional, of course.

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Boris

Developer at Payments by Wix team. Jumps between two extremes - Emacs Lisp and Haskell. Wants to force people around to use both languages, but can't explain why.

About the Forkshop

- Basic forkshop is split into several parts:
 - 1. Type classes, Semigroups and Monoids.
 - 2. Functors and Applicative Functors.
 - 3. Monads.
 - 4. Readers.
 - 5. Comonads.
- Theory and practice. Make sure that you are ready to write the code.
- Target audience is Scala developers learning FP.
- Forkshop is duplicated in Haskell.

Whys

- Functional programming roams (a bit).
 - More projects are using functional programming techniques and idioms (at different scale).
- Some people are still confused by all these functional talks (OptionT, type lambdas etc).
- Having a common language and understanding of some fundamental stuff is important.

Agenda

- Type classes
- Semigroups
- Monoids
- 3 interesting[™] tasks

Type classes

- Problem:
 - Application design
 - Data and logic separation
- Plan:
 - Write a simple application
 - Evolve it
 - Check different approaches
 - Introduce type classes

Application definition

- We are writing a game.
- With multiple different creatures.
- Everyone introduces themselves.
- Introduction consists of animations and text showing in a bubble.

Meet the hero

```
case class Hero(name: String, job: String, level: Int) {
  def introduce(): String = s"Hi! My name is $name. I am $level level $job."
}

object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)

  someRealShitSounds()
  drawBubble(player.introduce())
  someRealShitAnimations()
}

// Hi! My name is Valik. I am 20 level Black Mage.
```

Every hero needs a monster

```
case class Orc(name: String, level: Int) {
  def introduce(): String =
    s"Lok-tar ogar! Me be $name. Me be strong. Level $level strong!"
}
case class Ooze(level: Int) {
  def introduce(): String = 1.to(level).map(_=>"brlup").mkString("-")
}
```

Game

```
object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)
  val orc = Orc("Garrosh", 105)
  val coze = \log_{10}(2)
  // Introduce player
  someRealShitSounds()
  drawBubble(player.introduce())
  someRealShitAnimations()
  // Introduce orc
  someRealShitSounds()
  drawBubble(orc.introduce())
  someRealShitAnimations()
  // Introduce ooze
  someRealShitSounds()
  drawBubble(ooze.introduce())
  someRealShitAnimations()
// Hi! My name is Valik. I am 20 level Black Mage.
// Lok-tar ogar! Me be Garrosh. Me be strong. Level 105 strong!
// brlup-brlup
```

Game

```
object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)
  val orc = Orc("Garrosh", 105)
  val coze = \log_{10}(2)
  // Introduce player
  someRealShitSounds()
  drawBubble(player.introduce())
  someRealShitAnimations()
  // Introduce orc
  someRealShitSounds()
  drawBubble(orc.introduce())
  someRealShitAnimations()
  // Introduce ooze
  someRealShitSounds()
  drawBubble(ooze.introduce())
  someRealShitAnimations()
// Hi! My name is Valik. I am 20 level Black Mage.
// Lok-tar ogar! Me be Garrosh. Me be strong. Level 105 strong!
// brlup-brlup
```

Issues with this code:

- 1. Repetition
- 2. Noise
- 3. Refactoring (all these introduce are not related to each other).

```
object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)
  val orc = Orc("Garrosh", 105)
  val ooze = Ooze(2)
  // Introduce player
  someRealShitSounds()
  drawBubble(player.introduce())
  someRealShitAnimations()
  // Introduce orc
  someRealShitSounds()
  drawBubble(orc.introduce())
  someRealShitAnimations()
  // Introduce onze
  someRealShitSounds()
  drawBubble(ooze.introduce())
  someRealShitAnimations()
```

```
object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)
  val orc = Orc("Garrosh", 105)
  val coze = Noze(2)
  // Introduce player
  someRealShitSounds()
  drawBubble(player.introduce())
  someRealShitAnimations()
  // Introduce orc
  someRealShitSounds()
  drawBubble(orc.introduce())
  someRealShitAnimations()
  // Introduce onze
  someRealShitSounds()
  drawBubble(ooze.introduce())
  someRealShitAnimations()
```

```
def introduce(phrase: String): Unit = {
  someRealShitSounds()
  drawBubble(phrase)
  someRealShitAnimations()
```

```
object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)
  val orc = Orc("Garrosh", 105)
  val coze = Noze(2)
  // Introduce player
  someRealShitSounds()
  drawBubble(player.introduce())
  someRealShitAnimations()
  // Introduce orc
  someRealShitSounds()
  drawBubble(orc.introduce())
  someRealShitAnimations()
  // Introduce onze
  someRealShitSounds()
  drawBubble(ooze.introduce())
  someRealShitAnimations()
```

```
def introduce(phrase: String): Unit = {
  someRealShitSounds()
  drawBubble(phrase)
  someRealShitAnimations()
object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)
  val orc = Orc("Garrosh", 105)
  val ooze = 0oze(2)
  introduce(player.introduce())
  introduce(orc.introduce())
  introduce(ooze.introduce())
```

```
object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)
  val orc = Orc("Garrosh", 105)
  val coze = Noze(2)
  // Introduce player
  someRealShitSounds()
  drawBubble(player.introduce())
  someRealShitAnimations()
  // Introduce orc
  someRealShitSounds()
  drawBubble(orc.introduce())
  someRealShitAnimations()
  // Introduce once
  someRealShitSounds()
  drawBubble(ooze.introduce())
  someRealShitAnimations()
```

```
def introduce(phrase: String): Unit = {
  someRealShitSounds()
  drawBubble(phrase)
  someRealShitAnimations()
object Game extends App {
  val player = Hero("Valik", "Black Mage", 20)
  val orc = Orc("Garrosh", 105)
  val ooze = 0oze(2)
  introduce(player.introduce())
  introduce(orc.introduce())
  introduce(ooze.introduce())
Cool, but can we introduce(player)?
```

Introducing abstractions

```
case class Hero(...) {
  def introduce(): String = s"..."
}
case class Orc(...) {
  def introduce(): String = s"..."
}
case class Ooze(...) {
  def introduce(): String = s"..."
}
```

Introducing abstractions

```
case class Hero(...) {
  def introduce(): String = s"..."
}
case class Orc(...) {
  def introduce(): String = s"..."
}
case class Ooze(...) {
  def introduce(): String = s"..."
}
```

```
trait Introducible {
  def introduce(): String
}

case class Hero(...) extends Introducible {
  override def introduce(): String = s"..."
}

case class Orc(...) extends Introducible {
  override def introduce(): String = s"..."
}

case class Ooze(...) extends Introducible {
  override def introduce(): String = s"..."
```

Game with trait

```
def introduce(phrase: String): Unit = {
   someRealShitSounds()
   drawBubble(phrase)
   someRealShitAnimations()
}

object Game extends App {
   /* ... */
   introduce(player.introduce())
   introduce(orc.introduce())
}
```

Game with trait

```
def introduce(phrase: String): Unit = {
   someRealShitSounds()
   drawBubble(phrase)
   someRealShitAnimations()
}

object Game extends App {
   /* ... */
   introduce(player.introduce())
   introduce(orc.introduce())
   introduce(ooze.introduce())
}
```

```
def introduce(creature: Introducible): Unit = {
   someRealShitSounds()
   drawBubble(creature.introduce())
   someRealShitAnimations()
}

object Game extends App {
   /* ... */
   introduce(player)
   introduce(orc)
   introduce(ooze)
```

Game with trait

- No more introduce(_.introduce()).
- We are adaptive. Less code needs to be changed if we need something new in the introduce function (e.g. sound name) just add new 'method' to the trait.
- Refactoring becomes easier.

```
def introduce(phrase: String): Unit = {
   someRealShitSounds()
   drawBubble(phrase)
   someRealShitAnimations()
}

object Game extends App {
   /* ... */
   introduce(player.introduce())
   introduce(orc.introduce())
   introduce(ooze.introduce())
}
```

```
def introduce(creature: Introducible): Unit = {
   someRealShitSounds()
   drawBubble(creature.introduce())
   someRealShitAnimations()
}

object Game extends App {
   /* ... */
   introduce(player)
   introduce(orc)
   introduce(ooze)
}
```

Here comes the cockatrice

Shawarma to the rescue



```
import io.proprietary.monsters.cockatrice._
/* ... */
case class CockatriceWrapper(cockatrice: Cockatrice) extends Introducible {
  override def introduce(): String = {
    import cockatrice._
    s"Haha. I am a ${element.shortName} cockatrice of level ${level}."
object Game extends App {
  /* ... */
  val cockatrice = Cockatrice(level = 666, element = Element.Fire)
  val cockatriceW = CockatriceWrapper(cockatrice)
  introduce(cockatriceW)
 /* ... */
// Haha. I am a fire cockatrice of level 666.
```

Calm down and reevaluate our goal

 Abstraction - caring about what you can do and not what you are. E.g. separation of data and behaviour.

Calm down and reevaluate our goal

- Abstraction caring about what you can do and not what you are. E.g. separation of data and behaviour.
- Composition having a way to express something that can do several things at once.

Calm down and reevaluate our goal

- Abstraction caring about what you can do and not what you are. E.g. separation of data and behaviour.
- Composition having a way to express something that can do several things at once.
- Extensibility extending all kind of types:
 - types we own
 - types we don't own
 - even built-in types

trait + wrapper: abstraction

Abstraction holds. Proof is the introduce function itself.

```
def introduce(creature: Introducible): Unit = {
   someRealShitSounds()
   drawBubble(creature.introduce())
   someRealShitAnimations()
}
```

trait + wrapper: composition

Composition holds thanks to with keyword.

trait + wrapper: composition

Composition holds thanks to with keyword.

```
trait CanAttack {
   def attack(): Unit
}

def patheticAttack[A <: Introducible with CanAttack](creature: A): Unit</pre>
```

trait + wrapper: composition

Composition holds thanks to with keyword.

```
trait CanAttack {
  def attack(): Unit
}
def patheticAttack[A <: Introducible with CanAttack](creature: A): Unit</pre>
```

with keyword is not commutative

Introducible with CanAttack != CanAttack with Introducible.

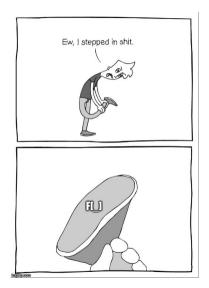
trait + wrapper: extensibility

Extensibility holds, but with several caveats:

- 1. No consistency we wrap only types we don't own.
- 2. Wrappers don't compose very well. You might even wrap your wrappers.
- 3. Bad usability you can't interchangeably use wrapper and the underlying value.

You know where it's going to, right?

You know where it's going to, right?



Dividing data and behaviour

```
trait Introducible {
  def introduce(): String
}

def introduce(creatute: Introducible): Unit = {
  /* ... */
  drawBubble(creatute.introduce())
  /* ... */
}
```

Dividing data and behaviour

```
trait Introducible {
  def introduce(): String
}

def introduce(creatute: Introducible): Unit = {
  /* ... */
  drawBubble(creatute.introduce())
  /* ... */
}
```

Usage

```
// Define new trait
trait Introducible[A] {
  def introduce(a: A): String
}
```

Usage

```
// Define new trait
trait Introducible[A] {
  def introduce(a: A): String
}

// Remove behaviour from data
case class Hero(name: String, job: String, level: Int)
```

Usage

```
// Define new trait
trait Introducible [A] {
  def introduce(a: A): String
// Remove behaviour from data
case class Hero(name: String, job: String, level: Int)
// Implement behaviour as a value in companion object
object Hero {
  val introducibleHero: Introducible[Hero] = new Introducible[Hero] {
    override def introduce(a: Hero): String =
      s"..."
```

Usage

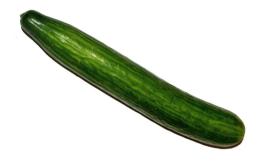
```
// Define new trait
trait Introducible [A] {
  def introduce(a: A): String
// Remove behaviour from data
case class Hero(name: String, job: String, level: Int)
// Implement behaviour as a value in companion object
object Hero {
  val introducibleHero: Introducible[Hero] = new Introducible[Hero] {
    override def introduce(a: Hero): String =
      s"..."
// Pass data and behaviour separately
object Game extends App {
  /* ... */
  introduce(
    creature = hero.
   impl = Hero.introducibleHero
```

External types? Pff...

External types? Pff. . .

```
import io.proprietary.monsters.cockatrice._
// Implement behaviour as a value in companion object
object CockatriceInstances {
  val introducibleCockatrice: Introducible[Cockatrice] = new Introducible[Cockatrice] {
    override def introduce(a: Cockatrice): String =
      s"..."
// Pass data and behaviour separately
object Game extends App {
  /* ... */
  introduce(
    creature = cockatrice.
   impl = CockatriceInstances.introducibleCockatrice
```

But passing implementation around is. . .



Cucumbersome

So implicits:(

```
object Hero {
  val introducibleHero:
      Introducible[Hero] = ???
object CockatriceInstances {
  val introducibleCockatrice:
      Introducible[Cockatrice] = ???
def introduce[A] (creature: A.
                 impl: Introducible[A]): Unit = {
  /* ... */
  drawBubble(impl.introduce(creature))
  /* ... */
object Game extends App {
  /* ... */
  introduce(hero, introducibleHero)
  introduce(cockatrice, introducibleCockatrice)
```

So implicits:(

```
object Hero €
  val introducibleHero:
      Introducible[Hero] = ???
object CockatriceInstances {
  val introducibleCockatrice:
      Introducible[Cockatrice] = ???
def introduce[A] (creature: A.
                 impl: Introducible[A]): Unit = {
  /* ... */
  drawBubble(impl.introduce(creature))
  /* ... */
object Game extends App {
  /* ... */
  introduce(hero, introducibleHero)
  introduce(cockatrice, introducibleCockatrice)
```

```
object Hero €
  implicit val introducibleHero:
      Introducible[Hero] = ???
object CockatriceInstances {
  implicit val introducibleCockatrice:
      Introducible[Cockatrice] = ???
def introduce[A](creature: A)
             (implicit impl: Introducible[A]): Unit = {
  /* ... */
  drawBubble(impl.introduce(creature))
  /* ... */
object Game extends App {
  /* ... */
  introduce(hero)
  introduce(cockatrice)
```

Summoning the summoner

Summoning the summoner

```
trait Introducible[A] {
                                                           trait Introducible [A] {
  def introduce(a: A): String
                                                             def introduce(a: A): String
                                                           object Introducible {
                                                             def apply[A: Introducible]: Introducible[A] =
                                                               implicitly[Introducible[A]]
def introduce[A](creature: A)
                                                           def introduce[A: Introducible](creature: A): Unit = {
             (implicit impl: Introducible[A]): Unit = {
  /* ... */
                                                             /* ... */
  drawBubble(impl.introduce(creature))
                                                             drawBubble(Introducible[A].introduce(creature))
  /* ... */
                                                             /* ... */
```

What have we done?

Type class is just a construct that supports ad hoc polymorphism. E.g. allows one to define polymorphic functions that can be applied to arguments of different types and behave differently based the type of the arguments.

In other words, type classes are solution for supporting function overloading.

What have we done?

Type class is just a construct that supports ad hoc polymorphism. E.g. allows one to define polymorphic functions that can be applied to arguments of different types and behave differently based the type of the arguments.

In other words, type classes are solution for supporting function overloading.

In Scala this can be achieved in several ways:

- Class inheritance or traits.
- Type classes (traits + implicits).

Type classes: abstraction

Abstraction holds. Proof is the introduce function itself.

Type classes: abstraction

Abstraction holds. Proof is the introduce function itself.

```
def introduce(creature: Introducible): Unit = {
   /* ... */
   drawBubble(creature.introduce())
   /* ... */
```

```
def introduce[A: Introducible](creature: A): Unit = {
   /* ... */
   drawBubble(Introducible[A].introduce(creature))
   /* ... */
}
```

Type classes: abstraction

Abstraction holds. Proof is the introduce function itself.

```
def introduce(creature: Introducible): Unit = {
   /* ... */
   drawBubble(creature.introduce())
   /* ... */
}

def introduce[A: Introducible](creature: A): Unit = {
   /* ... */
   drawBubble(Introducible[A].introduce(creature))
   /* ... */
}
```

We gain literal data and behaviour separation.

Composition holds. We just pass two different behaviours.

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```
def patheticAttack[A <: Introducible with CanAttack](creature: A): Unit</pre>
```

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But with type classes we don't care about the order.

Type classes: extensibility

Extensibility holds with some gains:

- 1. Consistency we treat our own type the same way we treat external types.
- 2. Usability no wrappers, no interchangeability problem.

Type classes: final thoughts

- 1. Simple idea giving us good properties.
- 2. Found a good use for controversial implicits feature.
- 3. Literal separation of data and values.
- 4. Good for overloading.
- 5. As with any abstraction, not so good for performance.

Warning

In the next two parts we are going to talk about:

- 1. Abstract mathematical objects.
- 2. Laws and properties.

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Only after that:

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- 2. Tasks.

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- 1. Practical meaning.
- 2. Tasks.

Please keep calm and remember that our focus is practical importance :)

Semigroup

Semigroup is a set S with binary closed operation $\cdot: S \times S \to S$ that satisfies associativity property:

$$\forall a, b, c \in S : (a \cdot b) \cdot c = a \cdot (b \cdot c)$$

Operation is closed when $\forall a, b \in S : a \cdot b \in S$.

But it's not that scary

```
package object typeclass {

//
// Laws:
// 1. \forall a, b, c \in A : (a \cdot b) \cdot c = a \cdot (b \cdot c)
//
trait Semigroup[A] {
    def combine(x: A, y: A): A
}

object Semigroup {
    def apply[A: Semigroup]: Semigroup[A] =
        implicitly[Semigroup[A]]
}
```

But it's not that scary

```
package object typeclass {

//
// Laws:
// 1. \forall a, b, c \in A : (a \cdot b) \cdot c = a \cdot (b \cdot c)
//
trait Semigroup[A] {
    def combine(x: A, y: A): A
}

object Semigroup {
    def apply[A: Semigroup]: Semigroup[A] =
        implicitly[Semigroup[A]]
}
```

In simple words, semigroup is a set with means of combining elements of that set.

But it's not that scary

```
package object typeclass {

//
// Laws:
// 1. ∀a,b,c ∈ A: (a·b)·c = a·(b·c)
//
trait Semigroup[A] {
  def combine(x: A, y: A): A
}

object Semigroup {
  def apply[A: Semigroup]: Semigroup[A] =
   implicitly[Semigroup[A]]
}
```

In simple words, semigroup is a set with means of combining elements of that set.



Important!

Semigroup is a pair of the set and the operation.

You can't say that string is a semigroup, you must provide an operation.

And in many cases there is more than one operation for a set to form a semigroup.

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- So type classes should have some associated laws.
- Laws describe properties of these operations and connection between operations in one type class.

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- Operations in the type classes are very generic.
 def combine(x: A, y: A): A
- So type classes should have some associated laws.
- Laws describe properties of these operations and connection between operations in one type class.
- Contract of the interface gives us confidence when we write generic code.

- In programming world it's just a contract.
- Operations in the type classes are very generic.
 def combine(x: A, y: A): A
- So type classes should have some associated laws.
- Laws describe properties of these operations and connection between operations in one type class.
- Contract of the interface gives us confidence when we write generic code.
- And as you will see, we really care about these laws.

Instance example

```
package object implicits {
  implicit val stringSemigroup: Semigroup[String] = new Semigroup[String] {
    override def combine(x: String, y: String): String = x + y
  }
}
```

Checking laws - pen and paper in comments

```
package object implicits {
  implicit val stringSemigroup: Semigroup[String] = new Semigroup[String] {
    override def combine(x: String, y: String): String = x + y
}
}

/*
combine(a, combine(b, c))
= combine(a, b + c)
= a + (b + c)
= (associativity of +)
= (a + b) + c = combine(a + b, c)
= combine(combine(a, b), c)
*/
```



Question on the interview: property based testing

```
object SemigroupSpecification extends Properties("Semigroup") with SemigroupSpecificationSupport {
 include(semigroup[String](stringSemigroup))
trait SemigroupSpecificationSupport {
 def semigroup[A](sg: Semigroup[A])(implicit ar: Arbitrary[A], tag: ClassTag[A]): Properties =
   new Properties(s"Semigroup[${tag.toString}]") {
     // \forall a, b, c \in A : (a \cdot b) \cdot c = a \cdot (b \cdot c)
     property("associativity") = forAll { (a: A, b: A, c: A) =>
       sg.combine(sg.combine(a, b), c) =? sg.combine(a, sg.combine(b, c))
/*
+ Semigroup. Semigroup[java.lang. String]. associativity: OK. passed 100 tests
*/
```

More than one valid instance

```
package object implicits {
  implicit val stringSemigroup: Semigroup[String] = new Semigroup[String] {
    override def combine(x: String, y: String): String = x
  }
}
```

More examples

- Numbers with +, *, min, max
- Booleans with conjunction, disjunction, implication etc.
- Square nonnegative matrices with multiplication.
- Lists, Strings, Maps etc. with concatenation/union
- We will see even more examples during practical part.

Contra-examples

- $\{\mathbb{N}, /\}$ is not a Semigroup, because / is not associative.
- The same goes for $\{\mathbb{N}, a^b\}$.
- $\{\mathbb{N}, -\}$ is not a Semigroup, because is not a closed operation, e.g. $\exists a, b \in \mathbb{N} : a b \notin \mathbb{N}$, for example $10 15 = -5 \notin \mathbb{N}$.

Lets hack

- 1. Clone git@github.com:d12frosted/wax.git
- 2. Import it as sbt project.

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- 2. Import it as sbt project.
- 1. Task 1
 - 1.1 Implement missing Semigroup instances in wax.typeclass.semigroup.cats.implicits
 - 1.2 Run wax.typeclass.semigroup.laws.cats.SemigroupSpec

Lets hack

- Clone git@github.com:d12frosted/wax.git
- 2. Import it as sbt project.

1. Task 1

- 1.1 Implement missing Semigroup instances in wax.typeclass.semigroup.cats.implicits
- 1.2 Run wax.typeclass.semigroup.laws.cats.SemigroupSpec

1. Task 2

- 1.1 Create Semigroup typeclass manually in wax.typeclass.semigroup.manual.typeclass
- 1.2 Implement missing Semigroup instances in wax.typeclass.semigroup.manual.implicits
- 1.3 Run wax.typeclass.semigroup.laws.manual.SemigroupSpec

Monoid

A monoid is a set S with binary closed operation $\cdot: S \times S \to S$ that satisfies associativity property:

$$\forall a, b, c \in S : (a \cdot b) \cdot c = a \cdot (b \cdot c)$$

and identity element e that satisfies

$$\forall a \in S : e \cdot a = a \cdot e = a$$

Operation is closed when $\forall a, b \in S : a \cdot b \in S$.

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In other words, monoid is just a semigroup with identity element.

Again, it's not that scary

```
package object typeclass {

//
// Laws:
// 1.  \forall a, b, c \in S: (a \cdot b) \cdot c = a \cdot (b \cdot c)
// 2.  \forall a \in S: e \cdot a = a \cdot e = a

//
trait Monoid[A] extends Semigroup[A] {
    def empty: A
}

object Monoid {
    def apply[A: Monoid]: Monoid[A] = implicitly[Monoid[A]]
}
```

Examples

- $\{\mathbb{N}_0, +\}$, where 0 is the identity element.
- $\{\mathbb{N}, *\}$, where 1 is the identity element.
- Boolean with XOR, XNOR, OR, AND.
- String with concatenation (empty string is identity element).

Examples

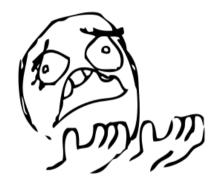
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But not every Semigroup forms a Monoid (we are not talking about free monoids here):

BigNumber practically doesn't have identity element for min.

The most important question

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Why did we learn this?

The Fibonacci numbers

The Fibonacci numbers

On the interview we ask people to write a function that returns the nth Fibonacci number.

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On the interview we ask people to write a function that returns the nth Fibonacci number.

$$F_0 = 0$$

 $F_1 = 1$
 $F_n = F_{n-1} + F_{n-2}, \forall n > 1$

Solution

What we expect

```
def fib(n: Int): Int = {
  def fibTail(n: Int, a: Int, b: Int): Int = n match {
    case 0 => a
    case _ => fibTail(n - 1, b, a + b)
}
fibTail(n, 0, 1)
}
```

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Ideal solution

$$F_{n} = \frac{\phi^{n} - (-\phi)^{-n}}{\sqrt{5}}$$
$$= \frac{\phi^{n} - (-\phi)^{-n}}{2\phi - 1}$$

$$\phi = \frac{1+\sqrt{5}}{2}$$

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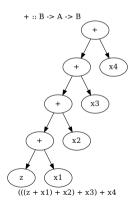
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As they say, truth is somewhere in the logarithm.

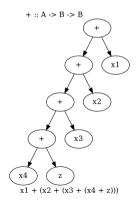
- def fold1[A, B](xs: Seq[A])(z: B)(op: B => A => B): B
 - Folds the structure from left to right

- def foldl[A, B](xs: Seq[A])(z: B)(op: B => A => B): B
 - Folds the structure from left to right



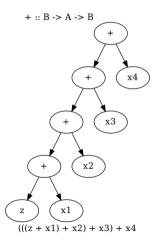
- def foldl[A, B](xs: Seq[A])(z: B)(op: B \Rightarrow A \Rightarrow B): B
- def foldr[A, B](xs: Seq[A])(z: B)(op: A \Rightarrow B \Rightarrow B): B
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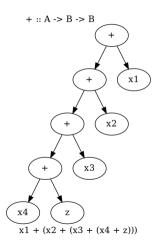


- def foldl[A, B](xs: Seq[A])(z: B)(op: B => A => B): B
- def foldr[A, B](xs: Seq[A])(z: B)(op: A => B => B): B
- Since combining function is asymmetrical in its types:
 - It's impossible to place parentheses in the arbitrary fashion or even just change the direction of the fold
 - It's impossible to implement a total fold without default value of type B

foldl



foldr



• Combining function is symmetrical (combine : A -> A -> A).

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- So we can define a special fold
 - def foldMonoid[A: Monoid](xs: Seq[A]): A
- Associativity law says that we can put parentheses in an arbitrary fashion.
- Identity law says that we can place identity element anywhere.

Power in terms of Monoid

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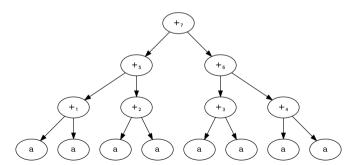
$$a + (a + (a + \ldots + a) \ldots) = a^n$$

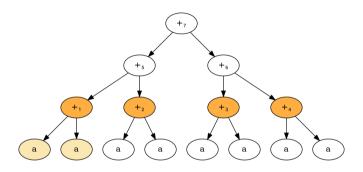
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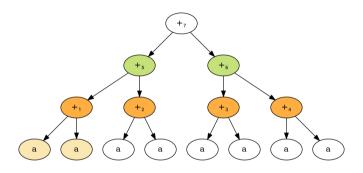
$$a+(a+(a+\ldots+a)\ldots)=a^n$$

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Evaluating a + a always yields the same result. So there is no point in repeating this calculation 4 times.



The same thing with the upper level. In this particular example, we can avoid 4 operations out of 7. In general, this optimisation leads to the result in $\log n$ operations.

All this means that we can define a function exp:

```
def exp[A: Monoid](a: A, n: Int): A = {
    ???
}
```

Fibonacci number can be defined in a different way.

$$\begin{pmatrix} F_{n+1} & F_n \\ F_n & F_{n-1} \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 0 \end{pmatrix}^n$$

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$$\begin{pmatrix} F_4 & F_3 \\ F_3 & F_2 \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 0 \end{pmatrix}^3 = \begin{pmatrix} 2 & 1 \\ 1 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 1 \\ 1 & 0 \end{pmatrix} = \begin{pmatrix} 3 & 2 \\ 2 & 1 \end{pmatrix}$$

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- The Fibonacci number can be calculated using square nonnegative matrix multiplication.
- Square nonnegative matrices form Monoid with multiplication.
- So we can put parentheses in a way we like it.

Coding time

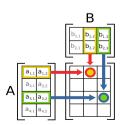
- Open wax.exercise.fibonacci.Main object.
 - Main runs two implementations and profiles them.
 - Fib contains implementation of tailrec and matrix approaches.
 - ExpUtils implements generic exp function.
- Task is to implement monoid for Matrix2x2 in the Fib object.
- Run MatrixSpec to test your instance.
- Run FibSpec to test implementation of Fib.
- Run Main to see performance differences by yourself.

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$$\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \cdot \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} =$$

$$\begin{pmatrix} a_{11} \cdot b_{11} + a_{12} \cdot b_{21} & a_{11} \cdot b_{12} + a_{12} \cdot b_{22} \\ a_{21} \cdot b_{11} + a_{22} \cdot b_{21} & a_{21} \cdot b_{12} + a_{22} \cdot b_{22} \end{pmatrix}$$



Profiling results

N	Matrix	Tailrec
10	60	0
100	0	0
1000	1	1
10000	5	6
100000	46	168
1000000	888	15211
10000000	11266	-

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Monoids are everywhere around us. We deal with them every day, without even noticing it. Did you expect us to solve Fibonacci using Monoid?

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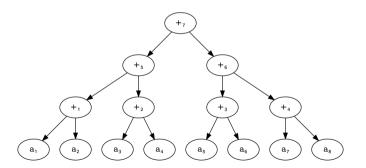
You might forget how matrix multiplication works, but now you remember, right?

Folds with Monoids

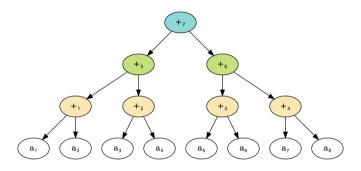
- We already know that Monoids give us an ability to place parentheses in any fashion.
- We already saw that when it comes to folding the list of the same elements we gain performance.
- But what if the elements are not equal? Do we gain anything?

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Folds with Monoids



Every expression on each level does not depend on other expressions from the same level, which means that we can evaluate them in parallel.

MapReduce

- Sometimes we have a collection of elements that don't form Monoid.
- But we can transform (going ahead, map) them into something that is a Monoid
 - Again, going ahead, this also can be done in parallel.
- There is a strange accent, where people pronounce 'fold' as 'reduce'.
- This is how we get the mapReduce.

Getting the top used words from set of books

- Open wax.exercise.mapreduce module.
- Task is to
 - Implement monoid for MapReduce.Result[A].
 - Implement the job function. Let's find the most used word among all the books that is also longer than 4 symbols.
- Books are located in the resources directory.
- Use allBooks to load all available books or authorBooks to load all books of specific author.
 - authorBooks("boris") you can use this author with small amount of text to test your job.
- Compare benchmark results.

Things to note

- Functional programming is not about Monads and IO.
 - Funny enough, first versions of Haskell were naked and no one dared to tell the committee that IO is missing.
- Functions matter.

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- Functional programming is not about Monads and IO.
 - Funny enough, first versions of Haskell were naked and no one dared to tell the committee
 that IO is missing.
- Functions matter.
- Can a function be monoid?

Let's start with some wrappers (pun intended)

- Suppose that we have some case class Wrapper[A] (value: A)
- Can it be a monoid?
- Well, generally speaking, not! Because we know nothing about the type A.
- But what if A is a monoid?

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- Suppose that we have some case class Wrapper[A] (value: A)
- Can it be a monoid?
- Well, generally speaking, not! Because we know nothing about the type A.
- But what if A is a monoid?

```
case class Wrapper[A](value: A)

object Wrapper {
  implicit def wrapperMonoid[A: Monoid]: Monoid[Wrapper[A]] = new Monoid[Wrapper[A]] {
    override def empty: Wrapper[A] = Wrapper(Monoid[A].empty)

    override def combine(x: Wrapper[A], y: Wrapper[A]): Wrapper[A] =
        Wrapper(Monoid[A].combine(x.value, y.value))
    }
}
```

Wrappers of monoids are monoids

- So IO can also be a monoid def ioMonoid[A: Monoid]: Monoid[IO[A]] = ???
- Which means that we can combine IO actions (in some new sense).
- Functions are wrappers (in some sense), so they also can be monoids
 def functionMonoid[A, B: Monoid]: Monoid[Function[A, B]] = ???
- Which means that we can combine functions (in some new sense).

Logger

Logger is basically a function from String to IO[Unit].
 type Logger = String => IO[Unit]

```
    Unit forms a monoid.
```

- So IO[Unit] forms a monoid.
- So String => IO[Unit] forms a monoid.
- So Logger forms a monoid.
- So we can combine loggers
 - combine(fileLogger, consoleLogger) logs both into file and to console

Logger

- Open wax.exercise.logging module
- Task is to implement monoid for IO[Logger]
- Have fun!

Recap (recup?)

- Semigroup is something with means of combining these somethings.
- Monoid is semigroup that also has neutral element that doesn't affect a combination.
- Associativity is a powerful property giving us an ability to solve some tasks.
 - a^n in $\log n$
 - mapReduce
- Monoids are everywhere. They act like a plague, once something forms a monoid, something else also begins to form a monoid.
- We want some rest after a long session of forkshop.

Questions?

 $\epsilon\rho\omega\tau\eta\sigma\eta$?

Thank you very much!

We hope you enjoyed this session.