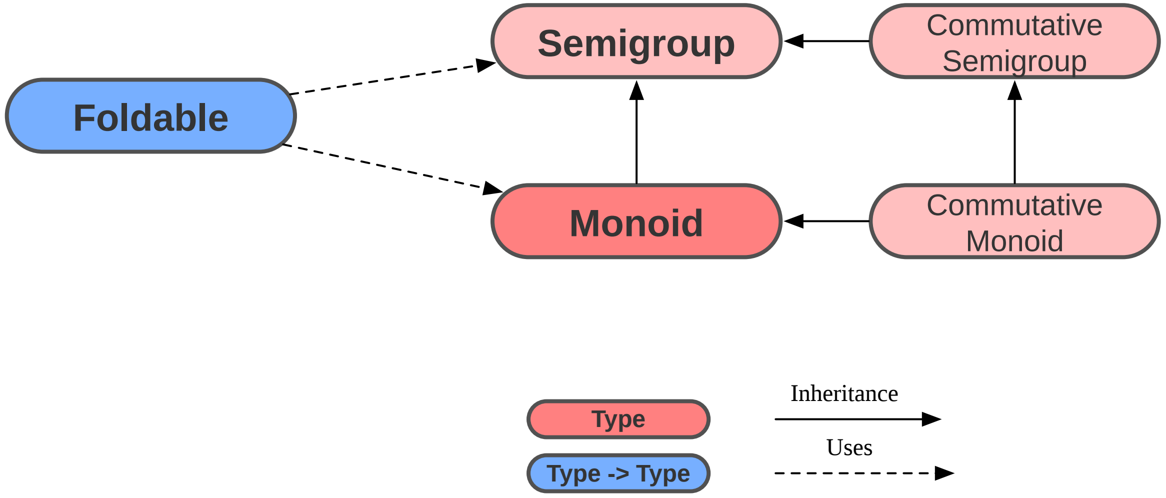
FOUNDATION

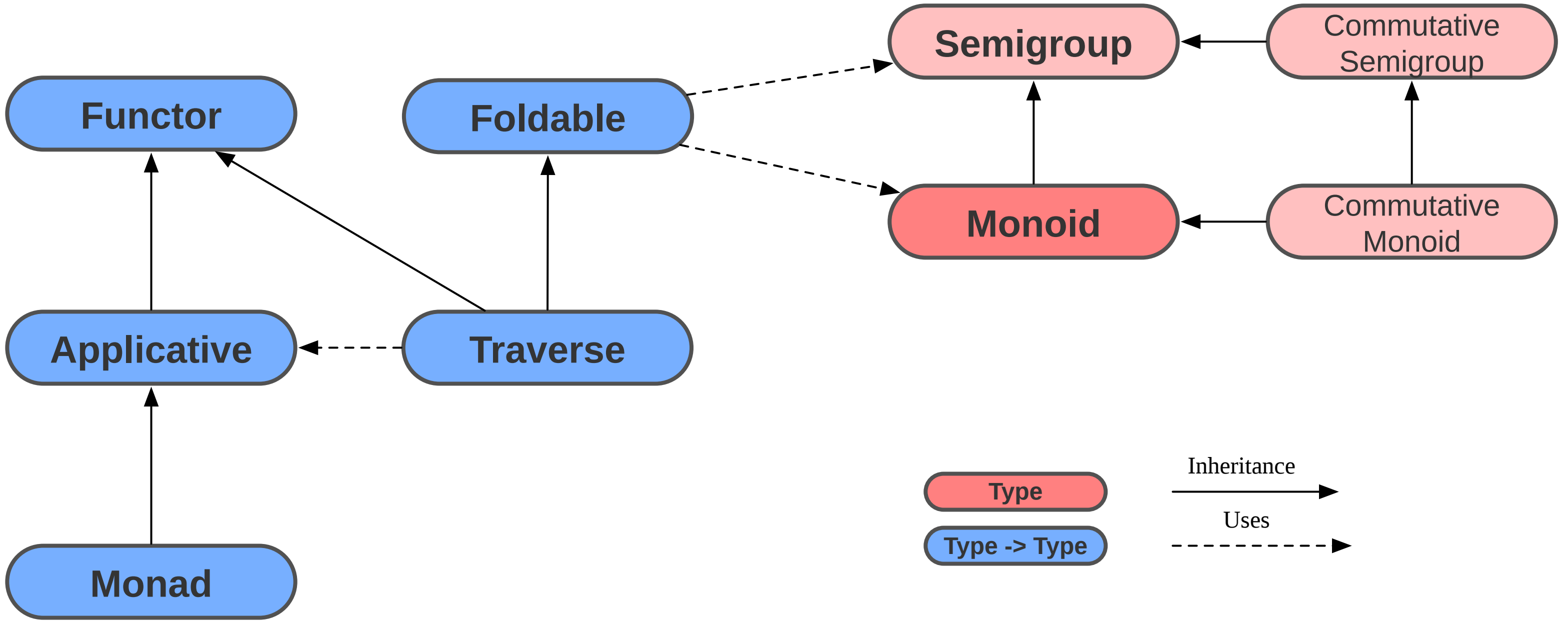
# Functors

# Previously



Semigroup
Commutative Semigroup
Foldable
Monoid
Commutative Monoid
Type
Type -> Type
Inheritance
Uses

# Plan


Functor
Foldable
Semigroup
Commutative Semigroup
Monoid
Commutative Monoid
Applicative
Traverse
Monad
Type
Type -> Type
Inheritance
Uses

# Why Functors? Where are they used?

# Where are Functors used?

Data structures: List, Vector, Map, Set, Graph

Error handling: Option, Either, Validated

Async: IO, Future

Parsing, Serialisation, Configuration, etc ...

# Plan

- Functor hierarchy
- 20+ generic functions
- Variance
- Typeclass coherence

# Functor

# Functor

```scala
trait Functor[F[_]] {
  def map[A, B](fa: F[A])(f: A => B): F[B]
}
```

# Functor

```scala
trait Functor[F[_]] {
  def map[A, B](fa: F[A])(f: A => B): F[B]
}
```

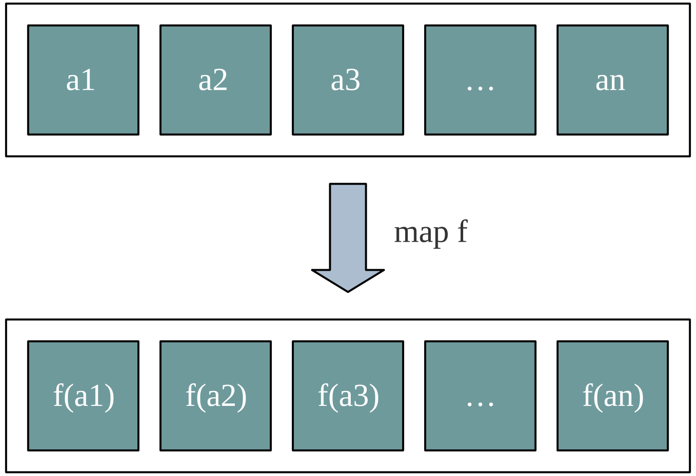
## Functor is a higher kinded typeclass

- It applies to **type constructor** with a **single** hole
- But **types** like `Int`, `String` **cannot** be a Functor

# Which F[_] is a Functor?

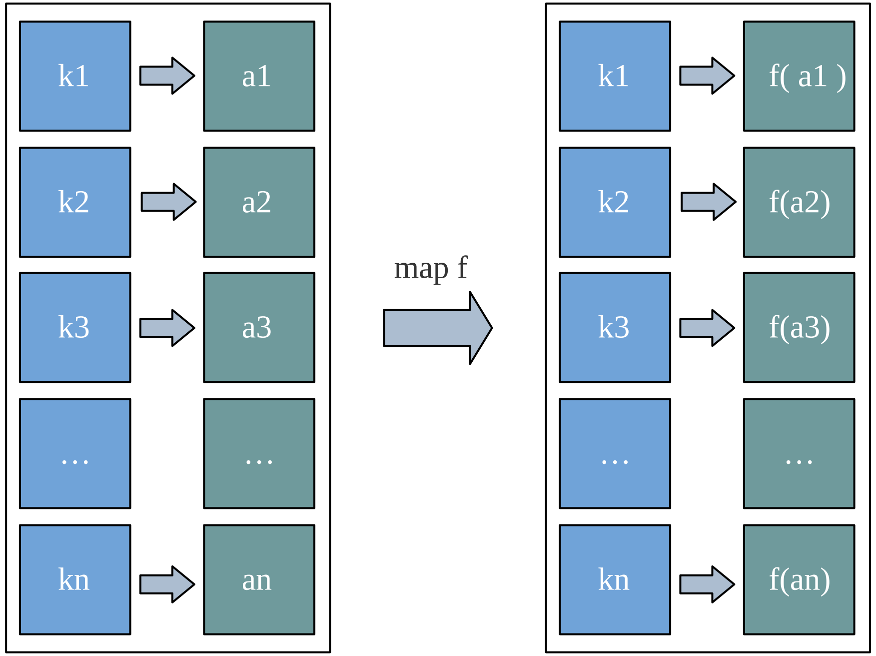
# F is a container

- List, Vector, Stream
- Option, Try



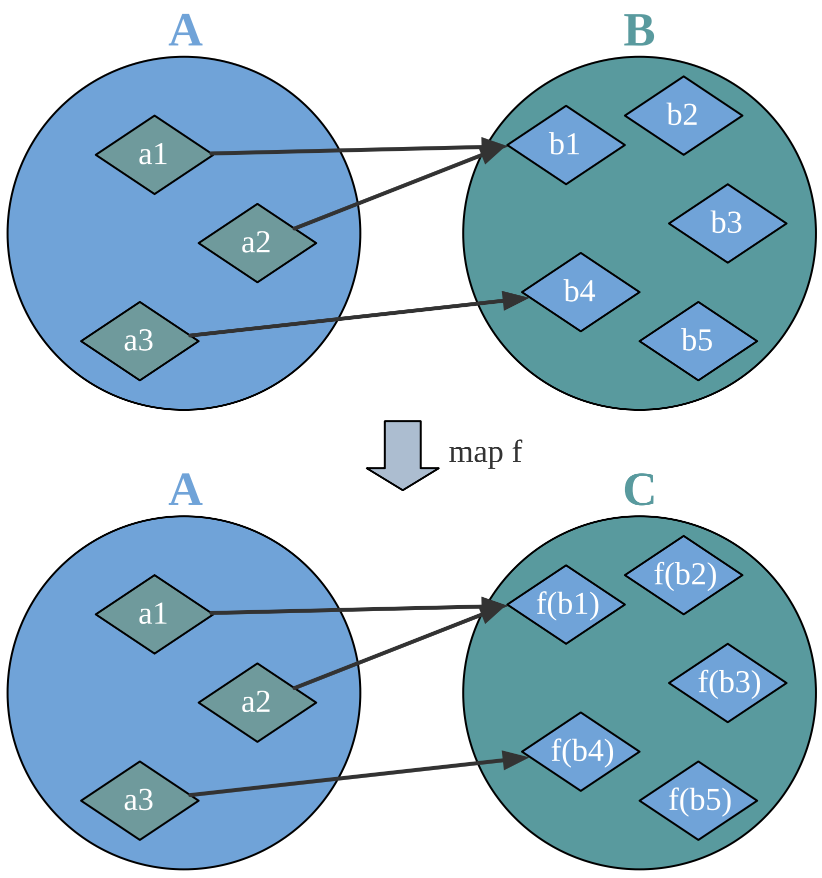
# F is a container

- List, Vector, Stream
- Option, Try
- Map[K, ?], Either[E, ?]

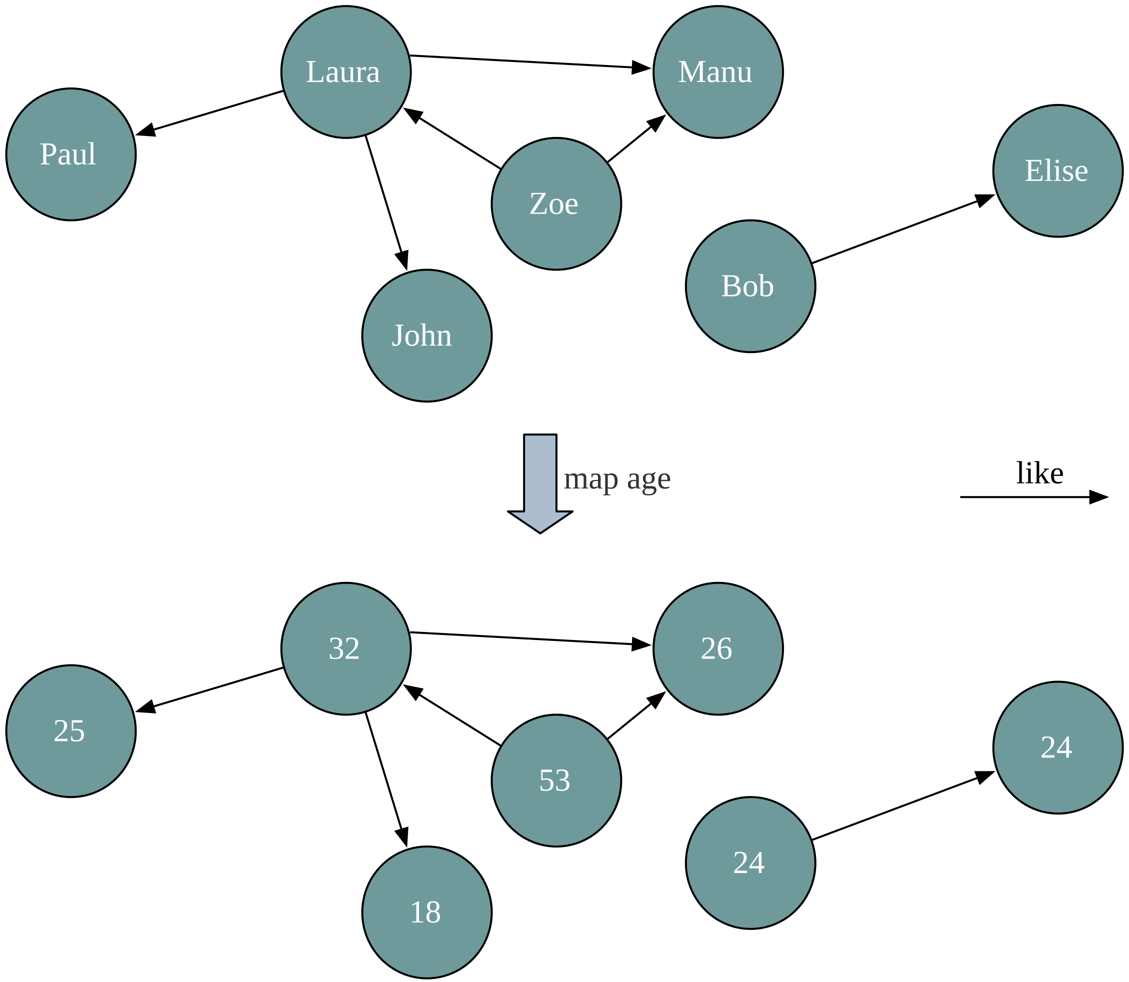


# F is a container

- List, Vector, Stream
- Option, Try
- Map[K, ?], Either[E, ?]
- A => ?



# A Functor does not alter the structure



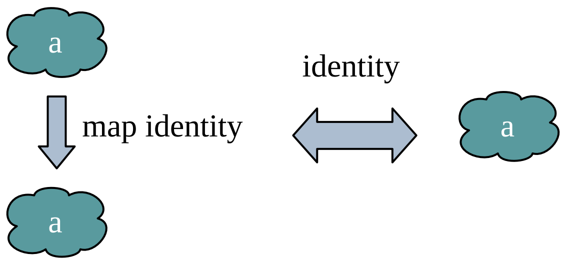
# F is an effect

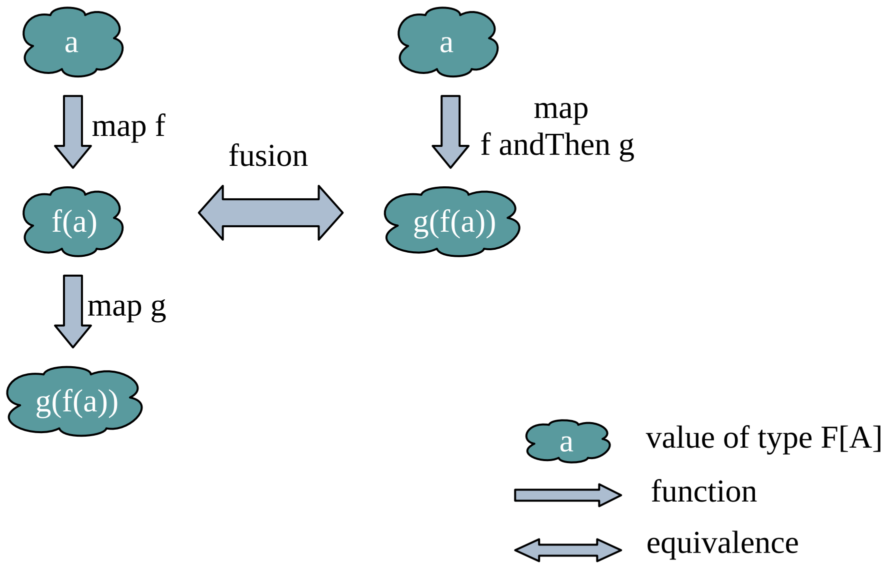
```scala
type Failure[A] = Option[A] or Either[String, A]

type Nondeterminism[A] = List[A] or Vector[A]

type SideEffect[A] = IO[A]

type MutableState[A] = State[Int, A]

type ImmutableState[A] = Reader[Int, A]

type Console[A] = ...

type Logger[A] = ...
```

A Functor is an abstraction to update an effectful value **without** altering its effect

# Functor Laws

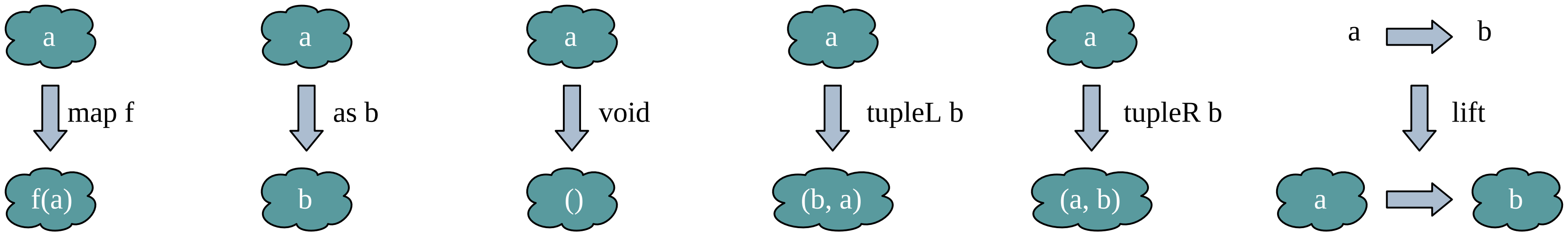
```
forAll(fa: F[A] => fa.map(identity) == fa)

forAll((fa: F[A], f: A => B, g: B => C) =>
  fa.map(f).map(g) == fa.map(f andThen g)
)
```



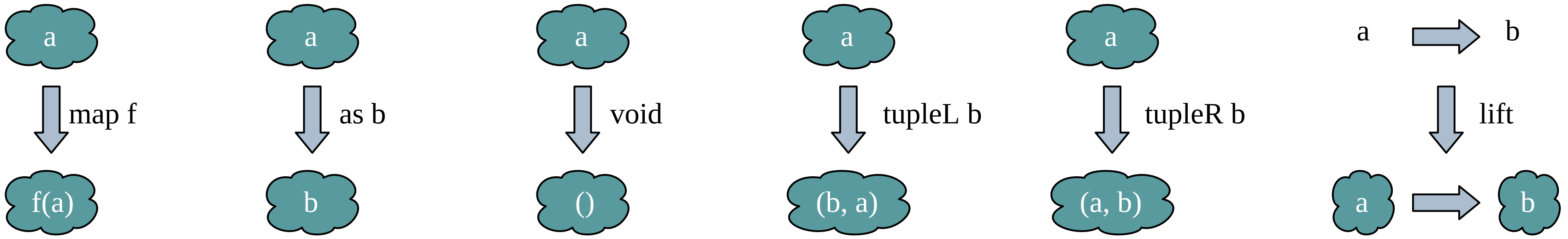



# Functor API

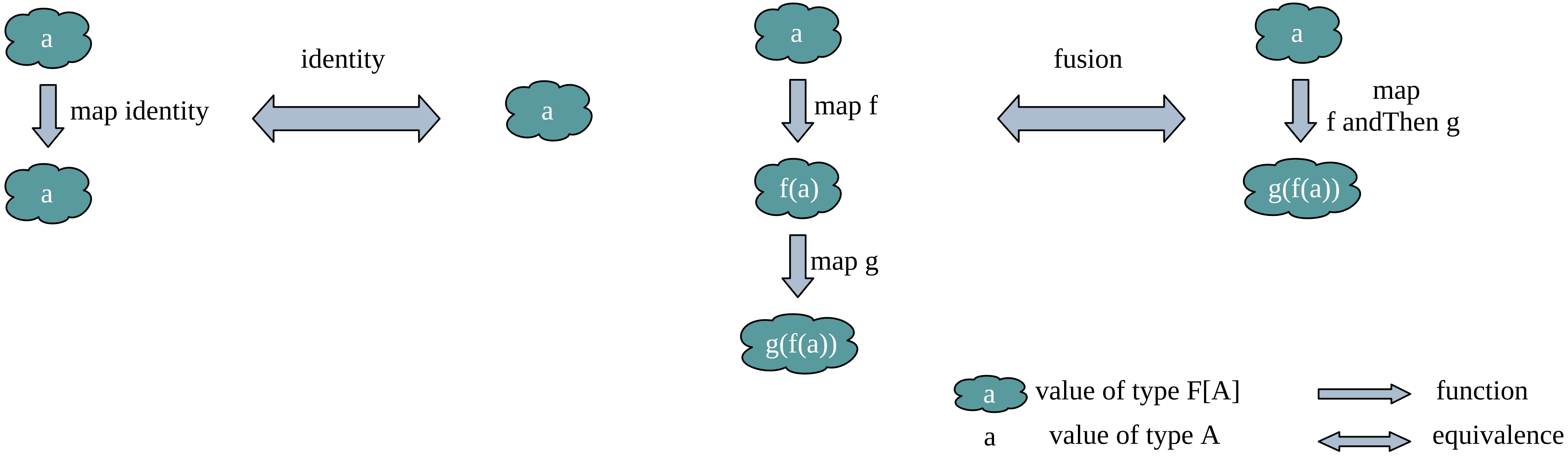
```scala
trait Functor[F[_]] {
  def map[A, B](fa: F[A])(f: A => B): F[B]

  def as[A, B](fa: F[A])(value: B): F[B]
  def void[A] (fa: F[A]): F[Unit]

  def tupleL[A, B](fa: F[A])(value: B): F[(B, A)]
  def tupleR[A, B](fa: F[A])(value: B): F[(A, B)]

  def lift[A, B](f: A => B): F[A] => F[B]
}
```



# API


a
map f
f(a)
a
as b
b
a
void
()
a
tupleL b
(b, a)
a
tupleR b
(a, b)
a
b
lift
a
b

# Laws


a
map identity
a
identity
a
a
map f
f(a)
map g
g(f(a))
fusion
a
map
f andThen g
g(f(a))
a
value of type F[A]
a
value of type A
function
equivalence

# Exercise 1

# Functor

## ADT

```scala
case class Foo[A](i: Int, a: A)

sealed trait Bar[A]
case class Bar1[A](i: Int    , a: A) extends Bar[A]
case class Bar2[A](b: Boolean, a: A) extends Bar[A]
case class Bar3[A](s: String       ) extends Bar[A]
```

## Function result

```scala
case class Producer[A](func: Int => A)
```

# Functor

## ADT

```scala
case class Foo[A](i: Int, a: A)

sealed trait Bar[A]
case class Bar1[A](i: Int    , a: A) extends Bar[A]
case class Bar2[A](b: Boolean, a: A) extends Bar[A]
case class Bar3[A](s: String       ) extends Bar[A]
```

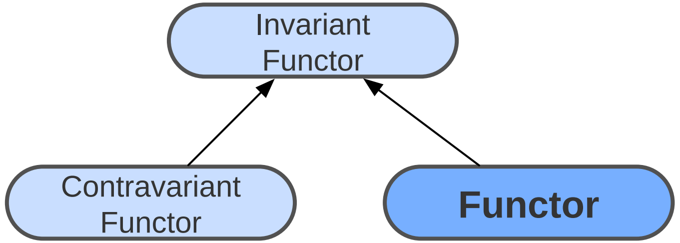
## Function input

```scala
case class Predicate[A](func: A => Boolean)
```

## Function result

```scala
case class Producer[A](func: Int => A)
```

# Functor variance




```scala
trait InvariantFunctor[F[_]]{
  def imap[A, B](fa: F[A])(f: A => B)(g: B => A): F[B]
}

trait ContravariantFunctor[F[_]] extends InvariantFunctor[F] {
  def contramap[A, B](fa: F[A])(f: B => A): F[B]
}

trait Functor[F[_]] extends InvariantFunctor[F] { // CovariantFunctor
  def map[A, B](fa: F[A])(f: A => B): F[B]
}
```

# Functor variance

```scala
trait JsonDecoder[A]{
  def decode(value: Json): A
}

trait JsonEncoder[A]{
  def encode(value: A): Json
}

trait JsonCodec[A] extends JsonDecoder[A] with JsonEncoder[A]
```

## What kind of Functor is JsonDecoder, JsonEncoder and JsonCodec?

# What kind of Functor is JsonDecoder?

```
trait JsonDecoder[A]{
  def decode(value: Json): A
}
```

# What kind of Functor is JsonDecoder?

```
trait JsonDecoder[A]{
  def decode(value: Json): A
}
```

is equivalent to

```
case class JsonDecoder[A](decode: Json => A)
```

hence

```
implicit val functor: Functor[JsonDecoder] = ???
```

# What kind of Functor is JsonEncoder?

```
trait JsonEncoder[A]{
  def encode(value: A): Json
}
```

# What kind of Functor is JsonEncoder?

```scala
trait JsonEncoder[A]{
  def encode(value: A): Json
}
```

is equivalent to

```scala
case class JsonEncoder[A](encode: A => Json)
```

hence

```scala
implicit val functor: ContravariantFunctor[JsonEncoder] = ???
```

# What kind of Functor is JsonCodec?

```
trait JsonCodec[A] extends JsonDecoder[A] with JsonEncoder[A]
```

# What kind of Functor is JsonCodec?

```
trait JsonCodec[A] extends JsonDecoder[A] with JsonEncoder[A]
```

## is equivalent to

```
case class JsonCodec[A](
  decode: Json => A,
  encode: A => Json
)
```

## hence

```
implicit val functor: InvariantFunctor[JsonCodec] = ???
```

# Variance

| Type | Example | A | B |
|---|---|---|---|
| Product | (A, B) | Covariant | Covariant |
| Sum | Either[A, B] | Covariant | Covariant |
| Function | A => B | Contravariant | Covariant |
| Endo Function | A => A | Invariant | N/A |

# Variance

| **Type** | **A** | **B** | **C** |
| --- | --- | --- | --- |
| (A => B) => C | Covariant | Contravariant | Covariant |

Thinking with types by Sandy Maguire

# Generalising Functor

```
Functor              = FunctorOf (->) (->)
ContravariantFunctor = FunctorOf (<-) (->)
InvariantFunctor     = FunctorOf Iso Iso
Bifunctor
Profunctor
...
```

See Functor-Of from Vladimir Ciobanu and @Iceland_jack

A Functor is an abstraction to update an effectful value without altering its effect

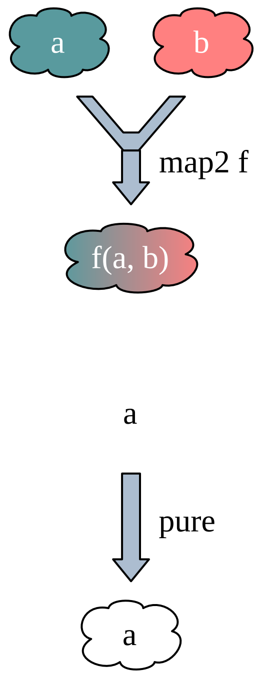
# What if we have more than 1 effect?

# How can we combine effects? e.g. F[A] and F[B]

# Applicative

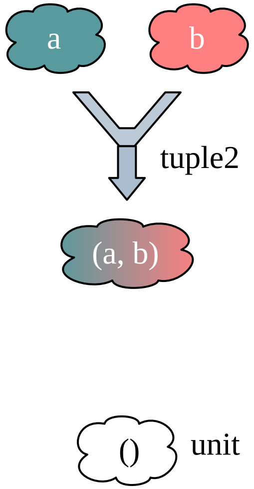
# Applicative

```
trait Applicative[F[_]] extends Functor[F] {

  def map2[A, B, C](fa: F[A], fb: F[B])(f: (A, B) => C): F[C]

  def pure[A](a: A): F[A]

}
```



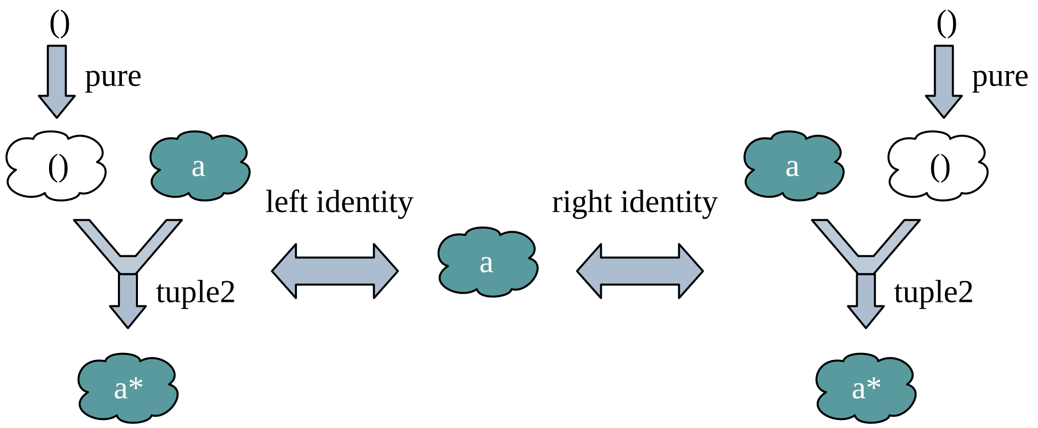
# Applicative alternative encoding

```scala
trait Applicative[F[_]] extends Functor[F] {

  def tuple2[A, B](fa: F[A], fb: F[B]): F[(A, B)]

  def unit: F[Unit]

}
```

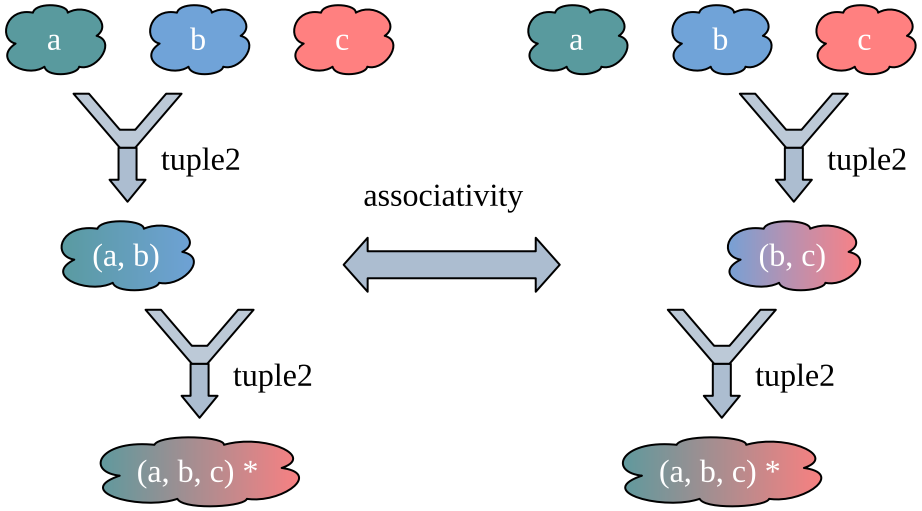


# Applicative laws

```
forAll(fa: F[A] => tuple2(pure(()), fa  )     == fa)    // equalities hold if we flatten tuples,
forAll(fa: F[A] => tuple2(fa       , pure(())) == fa)    // e.g. (a, ()) == a == ((), a)

forAll((fa: F[A], fb: F[A], fc: F[C]) =>
  tuple2(tuple2(fa, fb), fc) == tuple2(fa, tuple2(fb, fc)) // ((a, b), c) == (a, b, c) == (a, (b, c))
)
```




* need to flatten tuple

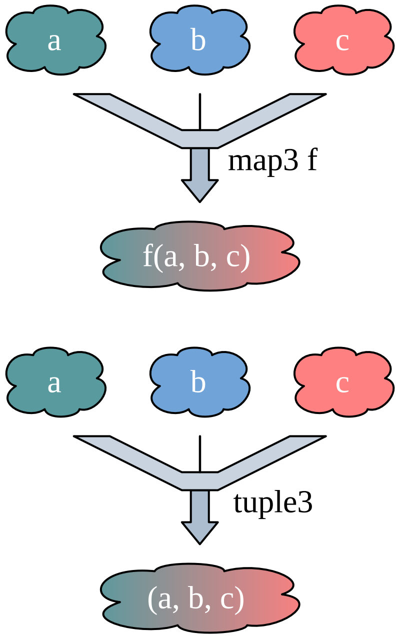


An Applicative combines 2 effects associatively

and lift pure values into NOOP effect

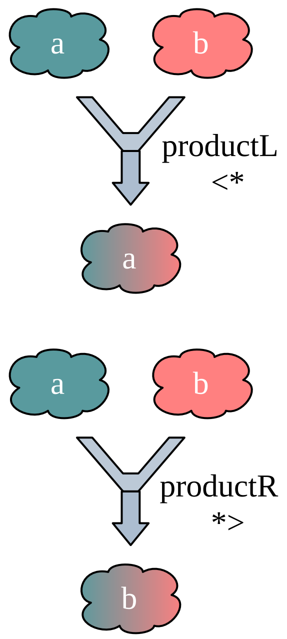
# Applicative API

```
trait Applicative[F[_]] extends Functor[F] {
  def pure[A](a: A): F[A]
  def map2[A, B, C](fa: F[A], fb: F[B])(f: (A, B) => C): F[C]


  def map3[A, B, C, D](fa: F[A], fb: F[B], fc: F[C])
                      (f: (A, B, C) => D): F[D]


  def tuple3[A, B, C](fa: F[A], fb: F[B], fc: F[C]): F[(A, B, C)]

}
```

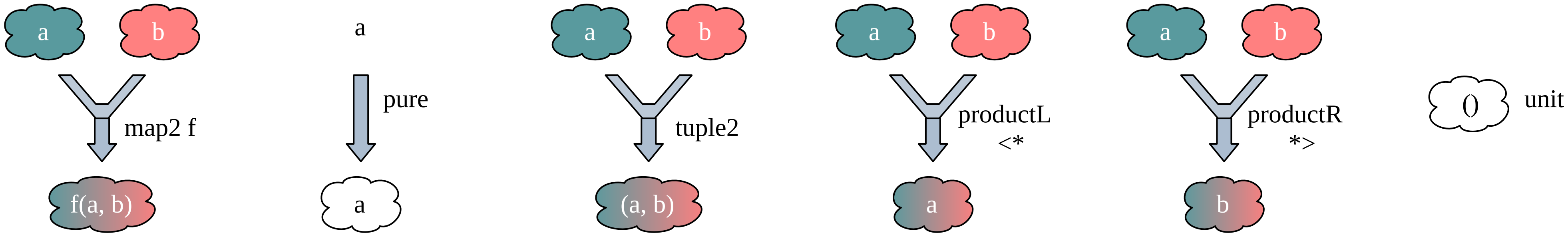


# Applicative API

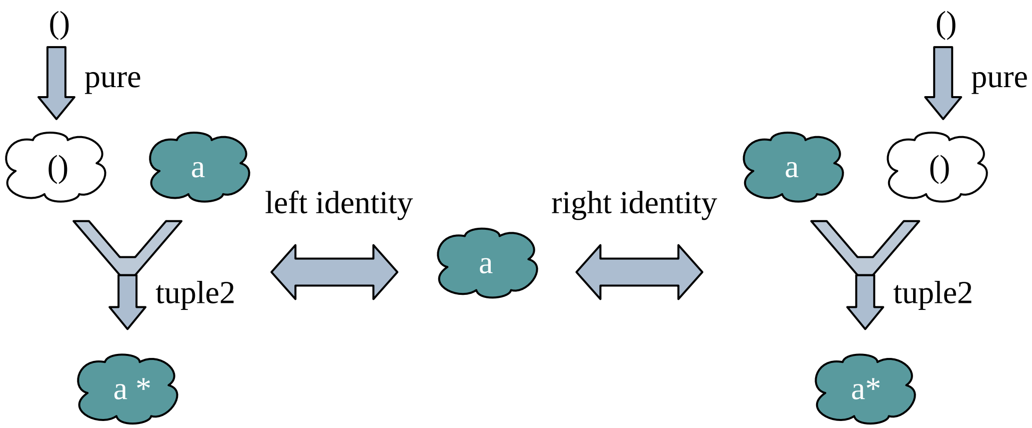
```
trait Applicative[F[_]] extends Functor[F] {
  def pure[A](a: A): F[A]
  def map2[A, B, C](fa: F[A], fb: F[B])(f: (A, B) => C): F[C]


  // alias to <*
  def productL[A, B](fa: F[A], fb: F[B]): F[A]


  // alias to *>
  def productR[A, B](fa: F[A], fb: F[B]): F[B]

}
```

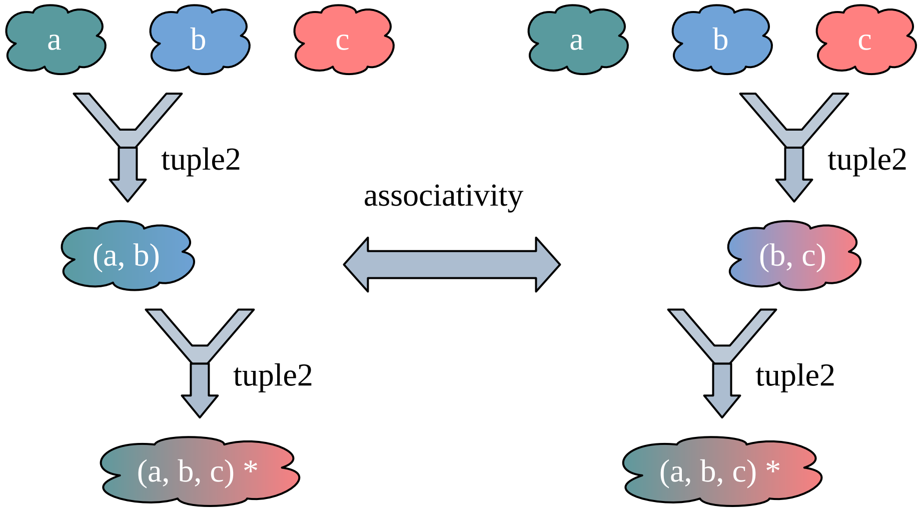


# API




# Laws




* need to flatten tuple

# Applicative combine effects: Failure

```scala
def right[A, E](a: A): Either[E, A] = Right(a)
def left [A, E](e: E): Either[E, A] = Left(e)
```

```
scala> (right(1), right("hello")).tuple2
res0: Either[Nothing,(Int, String)] = Right((1,hello))

scala> (right(1), left("an error")).tuple2
res1: Either[String,(Int, Nothing)] = Left(an error)

scala> (left("oops"), right(2)).tuple2
res2: Either[String,(Nothing, Int)] = Left(oops)
```

```
scala> (left("oops"), left("an error")).tuple2
res3: Either[String,(Nothing, Nothing)] = Left(oops)
```

# Applicative combine effects: Failure

```
scala> println((validNel(1), validNel("hello")).tuple2)
Valid((1,hello))

scala> println((validNel(1), invalidNel("an error")).tuple2)
Invalid(NonEmptyList(an error))

scala> println((invalidNel("oops"), validNel(2)).tuple2)
Invalid(NonEmptyList(oops))
```

```
scala> println((invalidNel("oops"), invalidNel("an error")).tuple2)
Invalid(NonEmptyList(oops, an error))
```

# Applicative combine effects: Nondeterminism

```
scala> (List(1,2,3), List("foo", "bar")).tuple2
res8: List[(Int, String)] = List((1,foo), (1,bar), (2,foo), (2,bar), (3,foo), (3,bar))

scala> (List(1,2,3), Nil).tuple2
res9: List[(Int, Nothing)] = List()
```

# Applicative combine effects: Dependency injection

```scala
case class State(userName: String, useLargeList: Boolean)

def greet(state: State): String = s"Welcome ${state.userName}"

def listSize(state: State): Int = if(state.useLargeList) 100 else 10

val combined: State => (String, Int) = (greet _, listSize _).tuple2
```

```
scala> combined(State("John Doe", true))
res10: (String, Int) = (Welcome John Doe,100)

scala> combined(State("Lena Doe", false))
res11: (String, Int) = (Welcome Lena Doe,10)
```

# Applicative combine effects: Side Effect

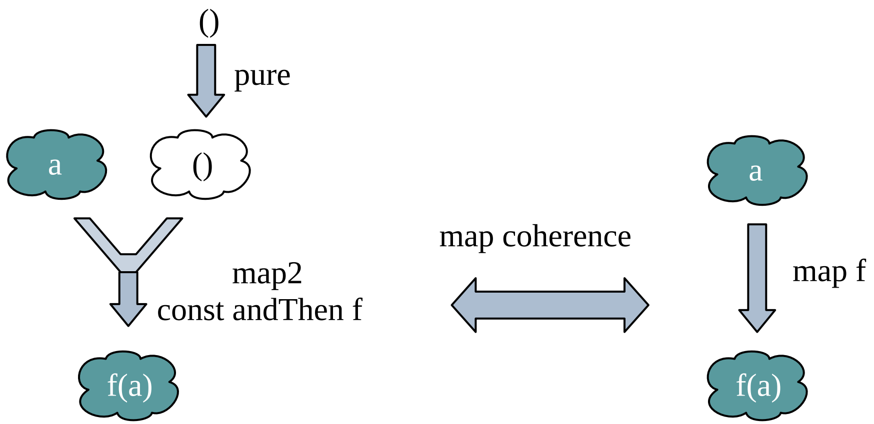
```scala
import cats.effect.IO

val combined = (IO(println("hello")), IO(println("I love FP!"))).tuple2
```

```
scala> combined.unsafeRunSync
hello
I love FP!
res12: (Unit, Unit) = ((),())
```

# Exercise 2

# Applicative is a Functor

```
trait Applicative[F[_]] extends Functor[F] {

  def pure[A](a: A): F[A]

  def map2[A, B, C](fa: F[A], fb: F[B])(f: (A, B) => C): F[C]

}
```




## Coherence Law

```
forAll((fa: F[A], f: A => B) =>
  (fa, pure(())).map2((a, _) => f(a)) == fa.map(f)
)
```

# Applicative is a Monoidal Functor

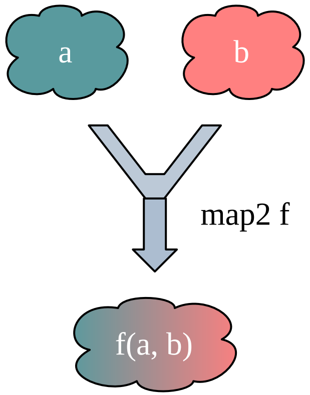
```
combine  :: A    => A    => A
tuple2   :: F[A] => F[B] => F[(A, B)]
```

```
empty ::      A
pure  :: A => F[A]
```

## Laws

```
forAll(a:  A    => combine(empty, a ) == a )
forAll(fa: F[A] => tuple2(unit  , fa) == fa) // equalities hold if we flatten tuples

forAll(a:  A    => combine(a, empty) == a )
forAll(fa: F[A] => tuple2(fa, unit ) == fa)

forAll(( a: A    ,  b: B    ,  c: C)    => combine(combine(a, b), c)  == combine(a, combine(b, c)))
forAll((fa: F[A], fb: F[A], fc: F[C]) => tuple2(tuple2(fa, fb), fc) == tuple2(fa, tuple2(fb, fc)))
```

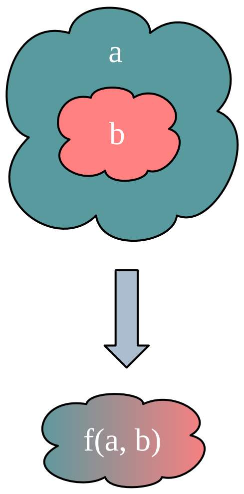
# Applicative combines effects



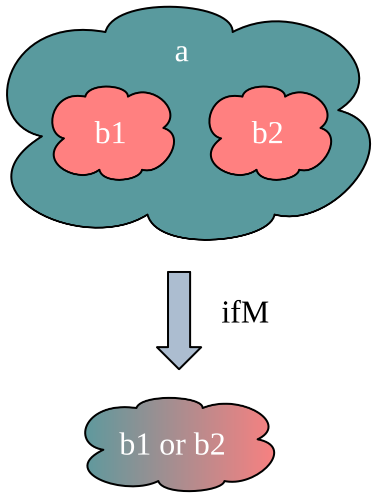
What if one effect depends on another one?

e.g. F[B] depends on A

# Nested effects

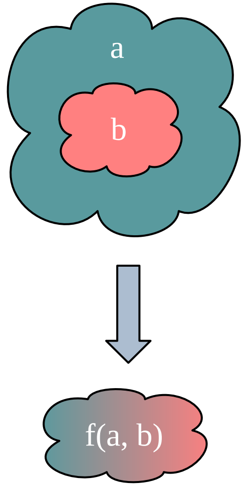


# Nested effects: ifM

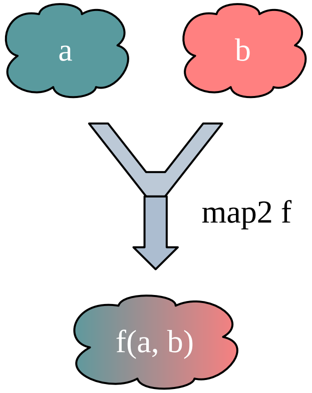


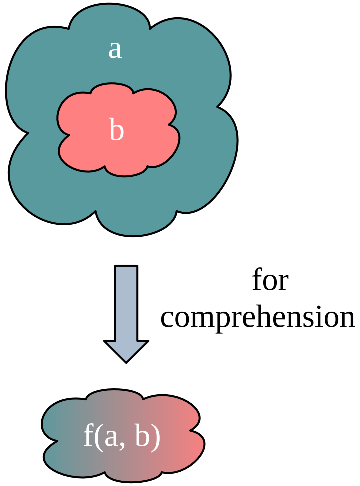
# Nested effects

```
for {
  a <- fa
  b <- fb(a)
} yield f(a, b)
```



# Independent vs dependent effects



# For comprehension

```
val res: F[D] =
  for {
    a: A <- fa: F[A]
    b: B <- fb: F[B]
    c: C <- fb: F[C]
  } yield f(a,b,c): D
```

# For comprehension

```
val res: F[D] =
  for {
    a: A <- fa: F[A]
    b: B <- fb: F[B]
    c: C <- fb: F[C]
  } yield f(a,b,c): D
```

## Using Monad

```
val res =
  fa.flatMap(a =>
    fb.flatMap(b =>
      fc.flatMap(c =>
        f(a,b,c).pure[F]
      )))
```

## Using FlatMap

```
val res =
  fa.flatMap(a =>
    fb.flatMap(b =>
      fc.map(c =>
        f(a,b,c)
      )))
```

# For comprehension is for a single Monad

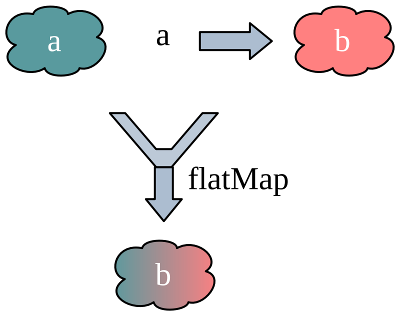
```
for {
  a: A <- fa: F[A]
  b: B <- fb: G[B] 
  c: C <- fb: H[C] 
} yield f(a,b,c)
```

```
scala> for {
     |   i <- List(1,2,3)
     |   e <- if(i == 1) Right("One") else Left("Expected 1")
     | } yield i
<console>:32: error: type mismatch;
 found   : scala.util.Either[String,Int]
 required: scala.collection.GenTraversableOnce[?]
         e <- if(i == 1) Right("One") else Left("Expected 1")
           ^
```

# Monad

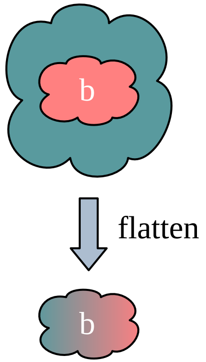
# Monad

```scala
trait Monad[F[_]] extends Applicative[F] {
  def flatMap[A, B](fa: F[A])(f: A => F[B]): F[B]
}
```



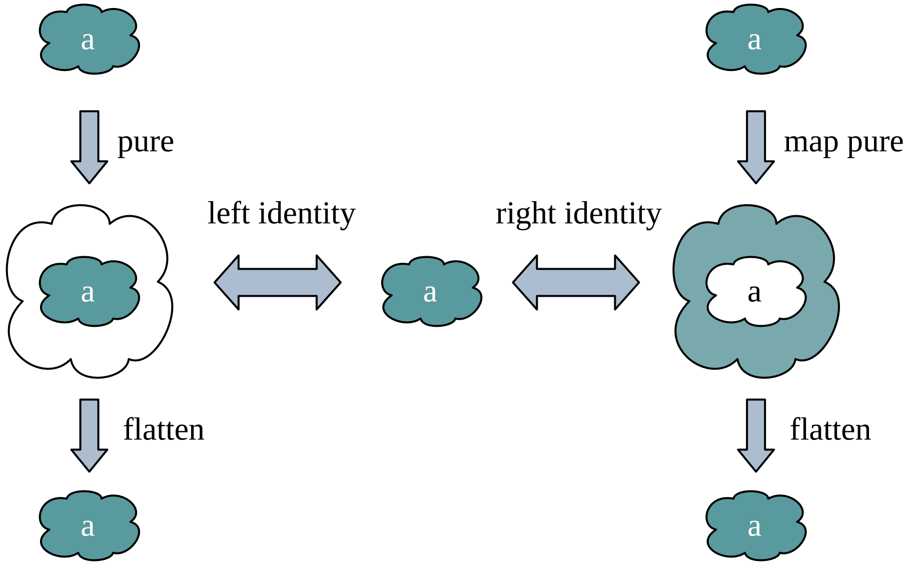
# Monad alternative encoding

```
trait Monad[F[_]] extends Applicative[F] {
  def flatten[A](ffa: F[F[A]]): F[A]
}
```



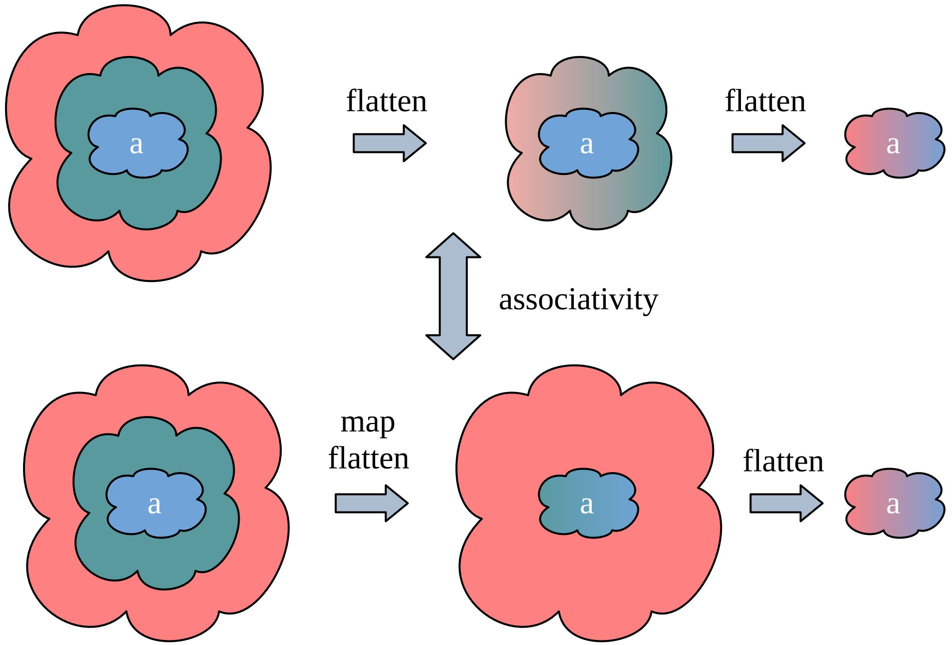
# Monad identity laws

```
forAll(fa: F[A] => fa.pure[F].flatten == fa)
forAll(fa: F[A] => fa.map(_.pure[F]).flatten == fa)
```



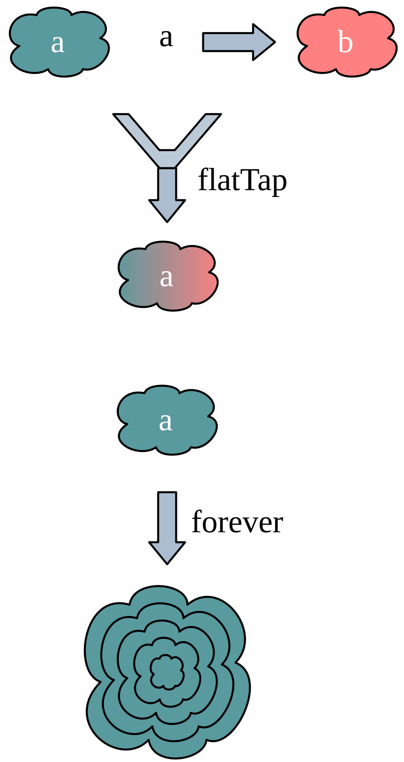
# Monad associativity law

```
forAll(fffa: F[F[F[A]]] =>
  fa.flatten.flatten == fa.map(_.flatten).flatten
)
```

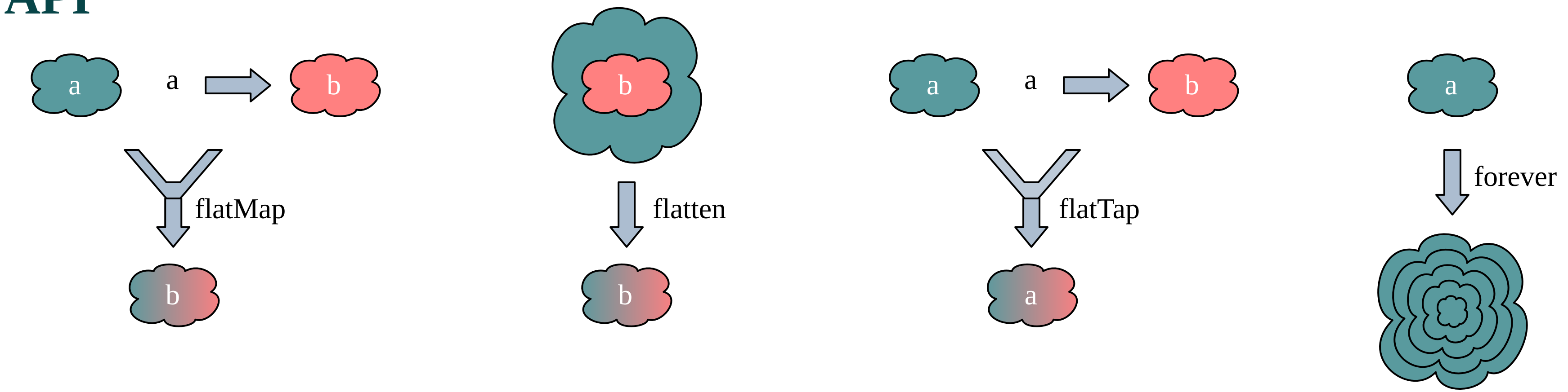


# Monad API

```scala
trait Monad[F[_]] extends Applicative[F] {
  def flatMap[A, B](fa: F[A])(f: A => F[B]): F[B]
  def flatten[A](ffa: F[F[A]]): F[A]


  def flatTap[A, B](fa: F[A])(f: A => F[B]): F[A]


  def forever[A](fa: F[A]): F[Nothing]
}
```

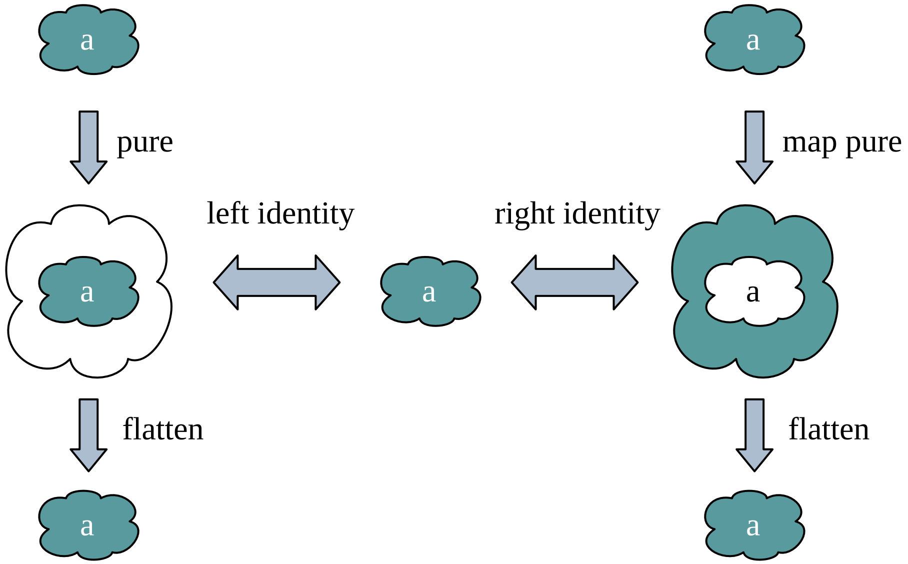


# API

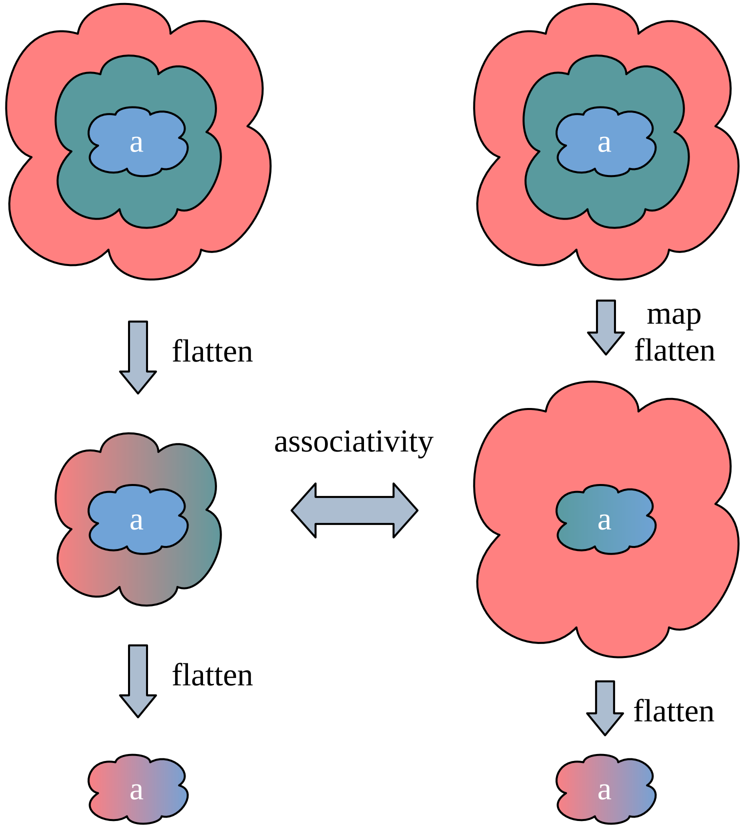


a
a
b
flatMap
b
b
flatten
b
a
a
b
flatTap
a
a
forever


# Laws



a
pure
a
left identity
a
right identity
a
a
map pure
flatten
a
flatten
a

a
a
flatten
map
flatten
a
associativity
a
flatten
a
flatten
a

# Exercise 3

# Monad is an Applicative

```scala
trait Monad[F[_]] extends Applicative[F] {

  def flatMap[A, B](fa: F[A])(f: A => F[B]): F[B]

}
```

## Coherence Law

```scala
forAll((fa: F[A], fb: F[B]) =>
  fa.flatMap(a => fb.map(b => (a, b))) == (fa, fb).tuple2
)
```

# Monad is an Applicative

```scala
trait Monad[F[_]] extends Applicative[F] {

  def flatMap[A, B](fa: F[A])(f: A => F[B]): F[B]

}
```

## Coherence Law

```scala
forAll{ (fa: F[A], fb: F[B]) =>

  val combinedFor = for {
     a <- fa
     b <- fb
  } yield (a, b)

  combinedFor == (fa, fb).tuple2
}
```

# Monad is for sequential composition of effects

```
val res =
  for {
    a <- fa
    b <- foo(a)
  } yield f(a,b)
```

# Monad is for sequential composition of effects

```
val res =
  for {
    a <- fa
    b <- foo(a)
  } yield f(a,b)
```

```
def sendStatement(userId: UserId): IO[Unit] =
  for {
    user    <- getUser(userId)
    account <- getAccount(user.accountId)
    _       <- sendStatement(user.email, account.statement)
  } yield ()
```

Monad is for sequential composition

&

Applicative must be coherent with Monad

# All Monadic effects must have a sequential Applicative

# Coherence implication

```scala
import exercises.errorhandling.{Country, User, Username}
import answers.functors.FunctorsAnswers.DefaultMonad

def validateUsername(x: String): ValidatedNel[String, Username] = {
  if(x.length > 5) valid(Username(x))
  else invalidNel(s"Username $x too short")
}

def validateCountry(x: String): ValidatedNel[String, Country] =
  x match {
    case "FRA" => valid(Country.France)
    case _     => invalidNel(s"Unsupported country $x")
  }

implicit def validatedMonad[E]: Monad[Validated[E, ?]] = new DefaultMonad[Validated[E, ?]] {
    def pure[A](a: A): Validated[E, A] = Valid(a)

    def flatMap[A, B](fa: Validated[E, A])(f: A => Validated[E, B]): Validated[E, B] =
      fa match {
        case Invalid(e) => Invalid(e)
        case Valid(a)   => f(a)
      }
  }
```

# Coherence implication

```scala
val combinedFor: ValidatedNel[String, User] = for {
  username <- validateUsername("foo")
  country  <- validateCountry("UK")
} yield User(username, country)
```

```
scala> println(combinedFor)
Invalid(NonEmptyList(Username foo too short))
```

# Coherence implication

```scala
val combinedFor: ValidatedNel[String, User] = for {
  username <- validateUsername("foo")
  country  <- validateCountry("UK")
} yield User(username, country)
```

```
scala> println(combinedFor)
Invalid(NonEmptyList(Username foo too short))
```

```scala
def map2[E: Semigroup, A, B, C](fa: Validated[E, A], fb: Validated[E, B])(f: (A, B) => C): Validated[E, C] =
  (fa, fb) match {
    case (Valid(a), Valid(b))         => Valid(f(a, b))
    case (Invalid(e), Valid(_))       => Invalid(e)
    case (Valid(_), Invalid(e))       => Invalid(e)
    case (Invalid(e1), Invalid(e2)) => Invalid(e1 |+| e2)
  }
val combinedMap2 = map2(validateUsername("foo"), validateCountry("UK"))(User(_, _))
```

```
scala> println(combinedMap2)
Invalid(NonEmptyList(Username foo too short, Unsupported country UK))
```

# Validated cannot be a Monad

# IO Applicative cannot combine in parallel (but IO.Par can)

# Composition

if F and G are a Functor then F[G[_]] is a Functor

if F and G are an Applicative then F[G[_]] is an Applicative

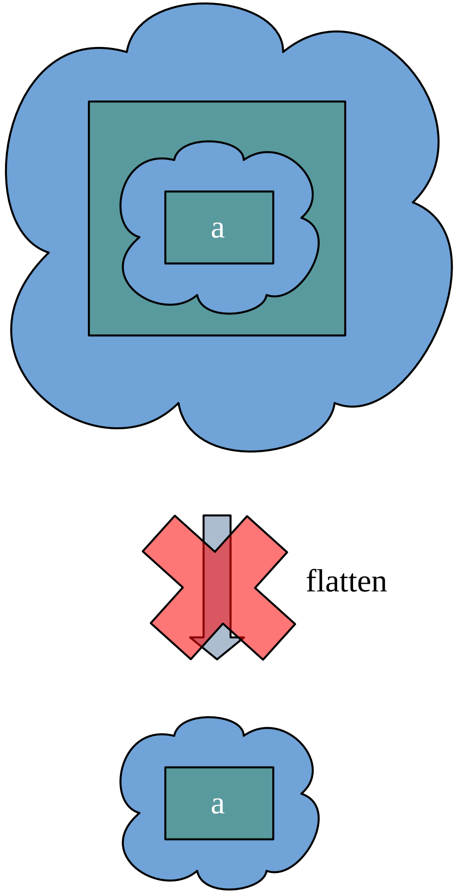
# Composition

if F and G are a Functor then F[G[_]] is a Functor

if F and G are an Applicative then F[G[_]] is an Applicative

but if F and G are a Monad then F[G[_]] is not necessarily a Monad

# Monad do not compose



If you can combine effects then …

# Imperative code is Monadic

```
def getOrderTotal(userId: Int, orderId: Int): Double = {
  log.trace(s"User $userId get order total for order $orderId"): Unit
  val hasAccess = canUserCanAccessOrder(userId, orderId): Boolean
  if(! hasAccess)
    throw new Exception(s"User $userId does not have access to order $orderId")
  else {
    val order = getOrder(orderId): Order
    order.total: Double
  }
}
```

# Imperative code is Monadic

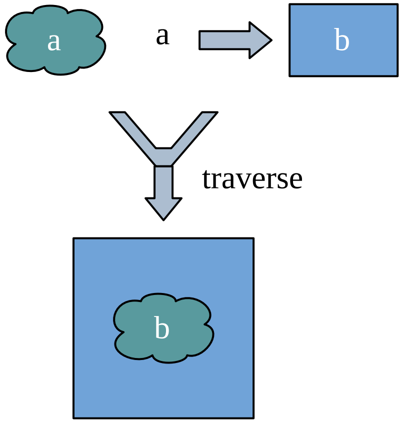
```scala
def getOrderTotal(userId: Int, orderId: Int): Double = {
  log.trace(s"User $userId get order total for order $orderId"): Unit
  val hasAccess = canUserCanAccessOrder(userId, orderId): Boolean
  if(! hasAccess)
    throw new Exception(s"User $userId does not have access to order $orderId")
  else {
    val order = getOrder(orderId): Order
    order.total: Double
  }
}
```

```scala
type MyEffect[+A] = ... // Log + DB + Error with Exception

def getOrderTotal(userId: Int, orderId: Int): MyEffect[Double] =
  for {
    _         <- log.trace(s"User $userId get order total for order $orderId"): MyEffect[Unit]
    hasAccess <- canUserCanAccessOrder(userId, orderId): MyEffect[Boolean]
    _         <- if(hasAccess) unit: MyEffect[Unit]
                 else fail(new Exception(s"User $userId does not have access to order $orderId")): MyEffect[Nothing]
    order     <- getOrder(orderId): MyEffect[Order]
  } yield order.total: Double
```

# Traverse

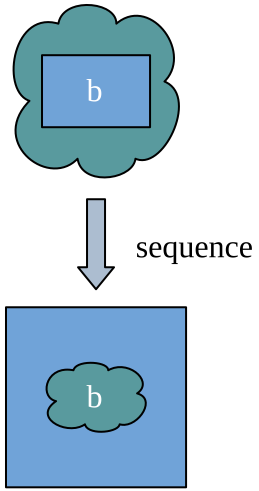
# Traverse

```scala
trait Traverse[F[_]] extends Functor[F] with Foldable[F] {

  def traverse[G[_]: Applicative, A, B](fa: F[A])(f: A => G[B]): G[F[B]]

}
```



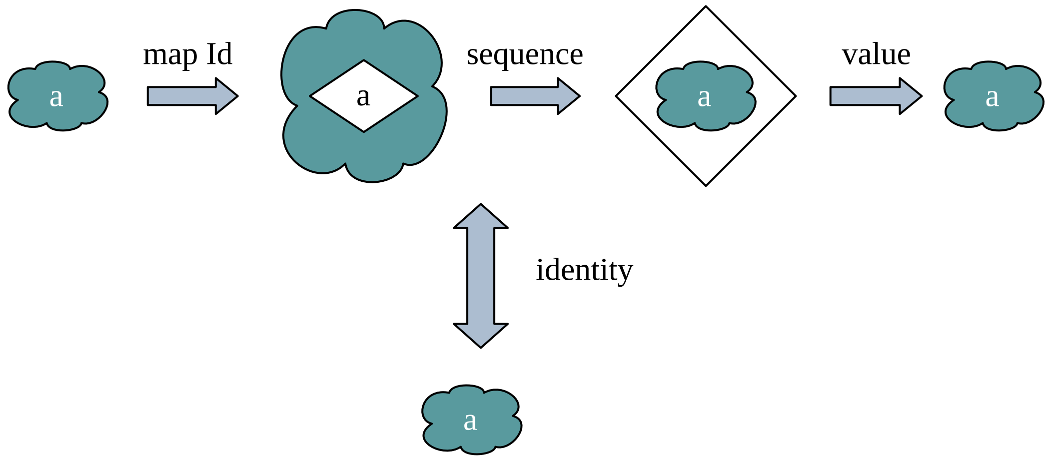
# Traverse alternative encoding

```scala
trait Traverse[F[_]] extends Functor[F] with Foldable[F] {

  def sequence[G[_]: Applicative, A](fga: F[G[A]]): G[F[A]]

}
```



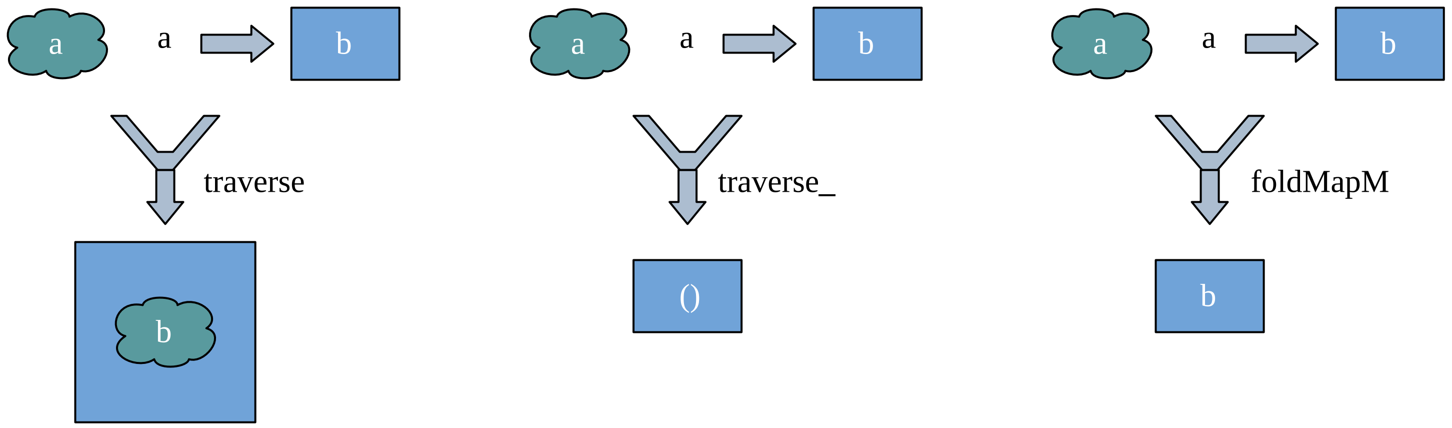
# Traverse Law

```
forAll(fa: F[A] => fa.map(Id(_)).sequence.value == fa)
```

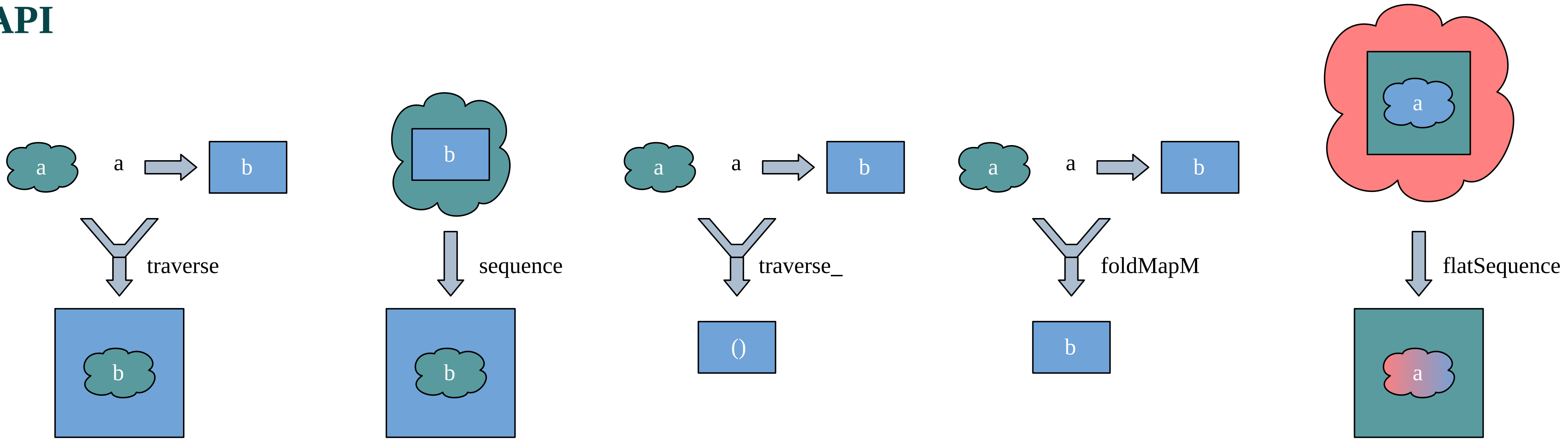


# Traverse API

```scala
trait Traverse[F[_]] extends Functor[F] with Foldable[F] {

  def traverse[G[_]: Applicative, A, B](fa: F[A])(f: A => G[B]): G[F[B]]

  def traverse_[G[_]: Applicative, A, B](fa: F[A])(f: A => G[B]): G[Unit]

  def foldMapM[G[_]: Applicative, A, B: Monoid](fa: F[A])(f: A => G[B]): G[B]

}
```

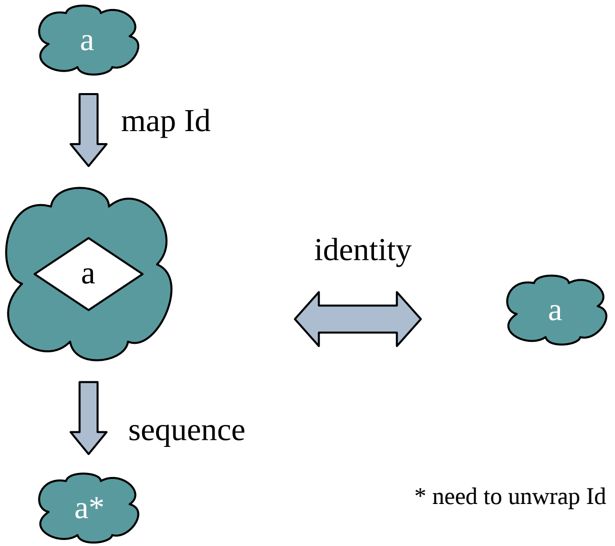


# API

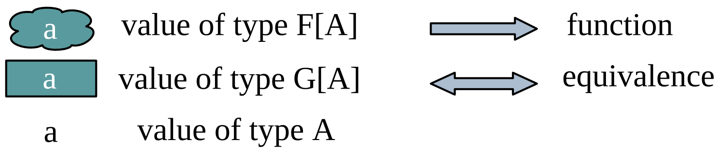


a
a
b
traverse
b
b
sequence
b
a
a
b
traverse_
()
a
a
b
foldMapM
b
a
flatSequence
a


# Laws



a
map Id
a
identity
a
sequence
a*
* need to unwrap Id

a
value of type F[A]
function
a
value of type G[A]
equivalence
a
value of type A

# Exercise 4

# Traverse is a Functor

```
trait Traverse[F[_]] extends Functor[F] with Foldable[F] {

  def traverse[G[_]: Applicative, A, B](fa: F[A])(f: A => G[B]): G[F[B]]

}
```

## Coherence Law

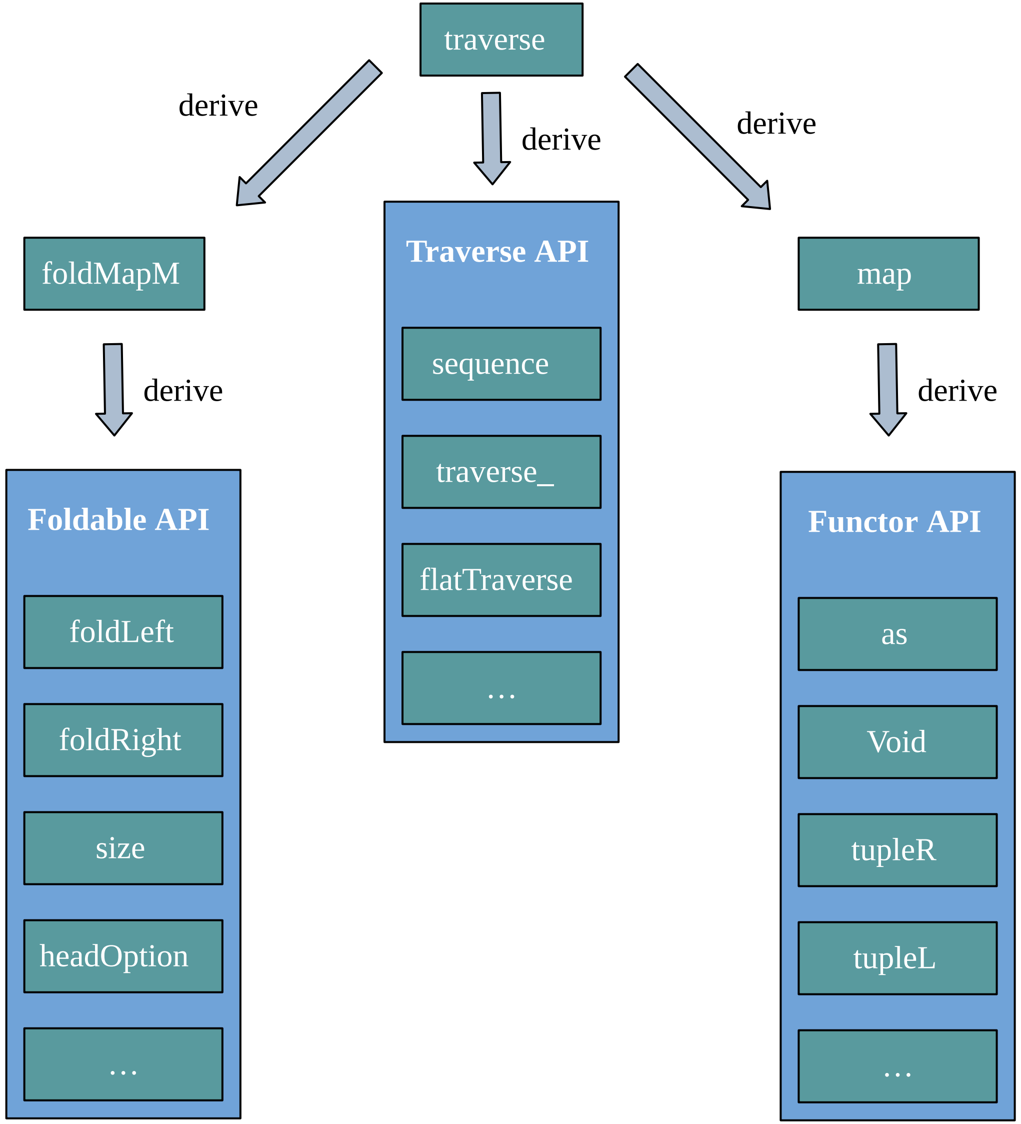
```
forAll((fa: F[A], f: A => B) => fa.traverse(a => Id(f(a))).value == fa.map(f))
```

# Traverse is a Foldable

```
trait Traverse[F[_]] extends Functor[F] with Foldable[F] {

  def traverse[G[_]: Applicative, A, B](fa: F[A])(f: A => G[B]): G[F[B]]

}
```

## Coherence Law

```
forAll((fa: F[A], f: A => B) => fa.traverse(a => Const(f(a))).getConst == fa.foldMap(f))
```


traverse
derive
derive
derive
foldMapM
Traverse API
map
sequence
derive
derive
traverse_
Foldable API
Functor API
flatTraverse
…
foldLeft
as
foldRight
Void
size
tupleR
headOption
tupleL
…
…

# Default implementation

```
traverse > foldMap > size
```

```
def sizeDefault[F[_]: Traverse, A](fa: F[A]): Int =
  fa.traverse(_ => Const(1)).getConst
```

```
sizeDefault = (Const(1) |+| Const(1) |+| ... |+| Const(1)).getConst  // O(n)
```

# Default implementation

```
traverse > foldMap > size
```

```
def sizeDefault[F[_]: Traverse, A](fa: F[A]): Int =
  fa.traverse(_ => Const(1)).getConst
```

```
sizeDefault = (Const(1) |+| Const(1) |+| ... |+| Const(1)).getConst  // O(n)
```

```
val vectorTraverse: Traverse[Vector] = new Traverse[Vector] {
  def traverse[G[_]: Applicative, A, B](fa: Vector[A])(f: A => G[B]): G[Vector[B]] = ???
  overload def size[A](fa: Vector[A]): Int = fa.size // O(1)
}
```

# Default implementation

```
traverse > foldMap > size
```

```scala
def sizeDefault[F[_]: Traverse, A](fa: F[A]): Int =
  fa.traverse(_ => Const(1)).getConst
```

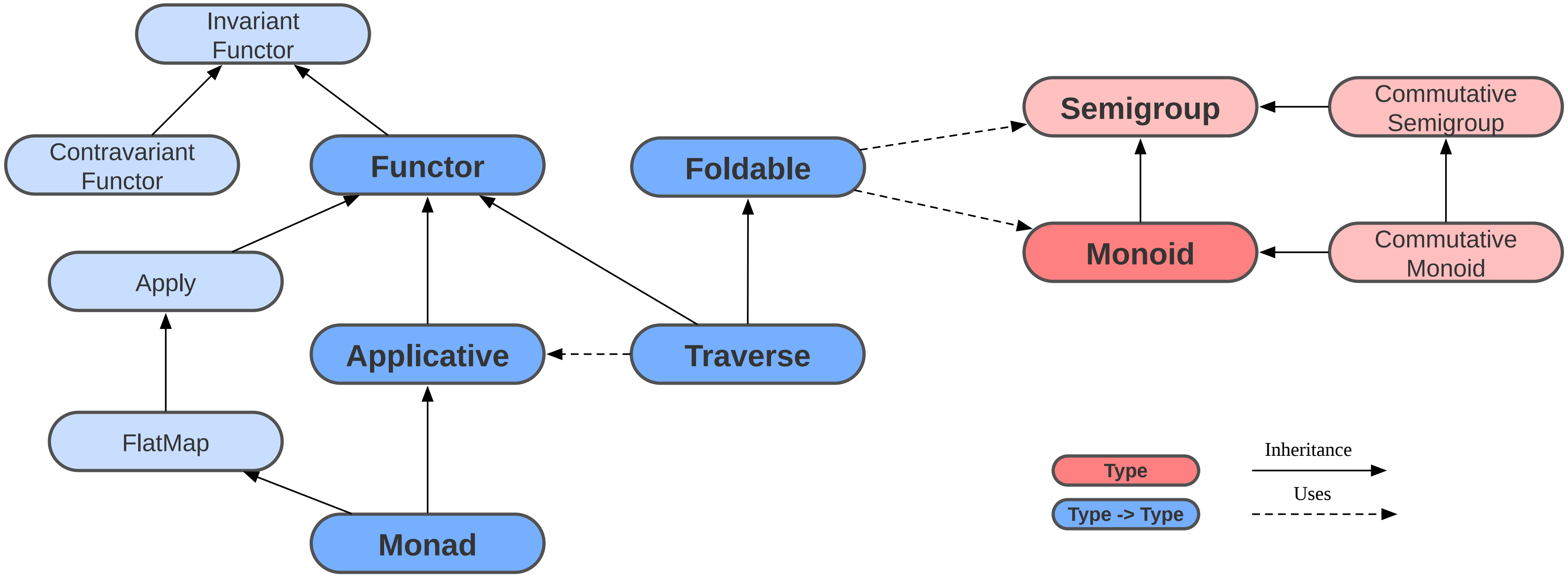
```scala
sizeDefault = (Const(1) |+| Const(1) |+| ... |+| Const(1)).getConst  // O(n)
```

```scala
val vectorTraverse: Traverse[Vector] = new Traverse[Vector] {
  def traverse[G[_]: Applicative, A, B](fa: Vector[A])(f: A => G[B]): G[Vector[B]] = ???
  overload def size[A](fa: Vector[A]): Int = fa.size // O(1)
}
```

## Coherence law

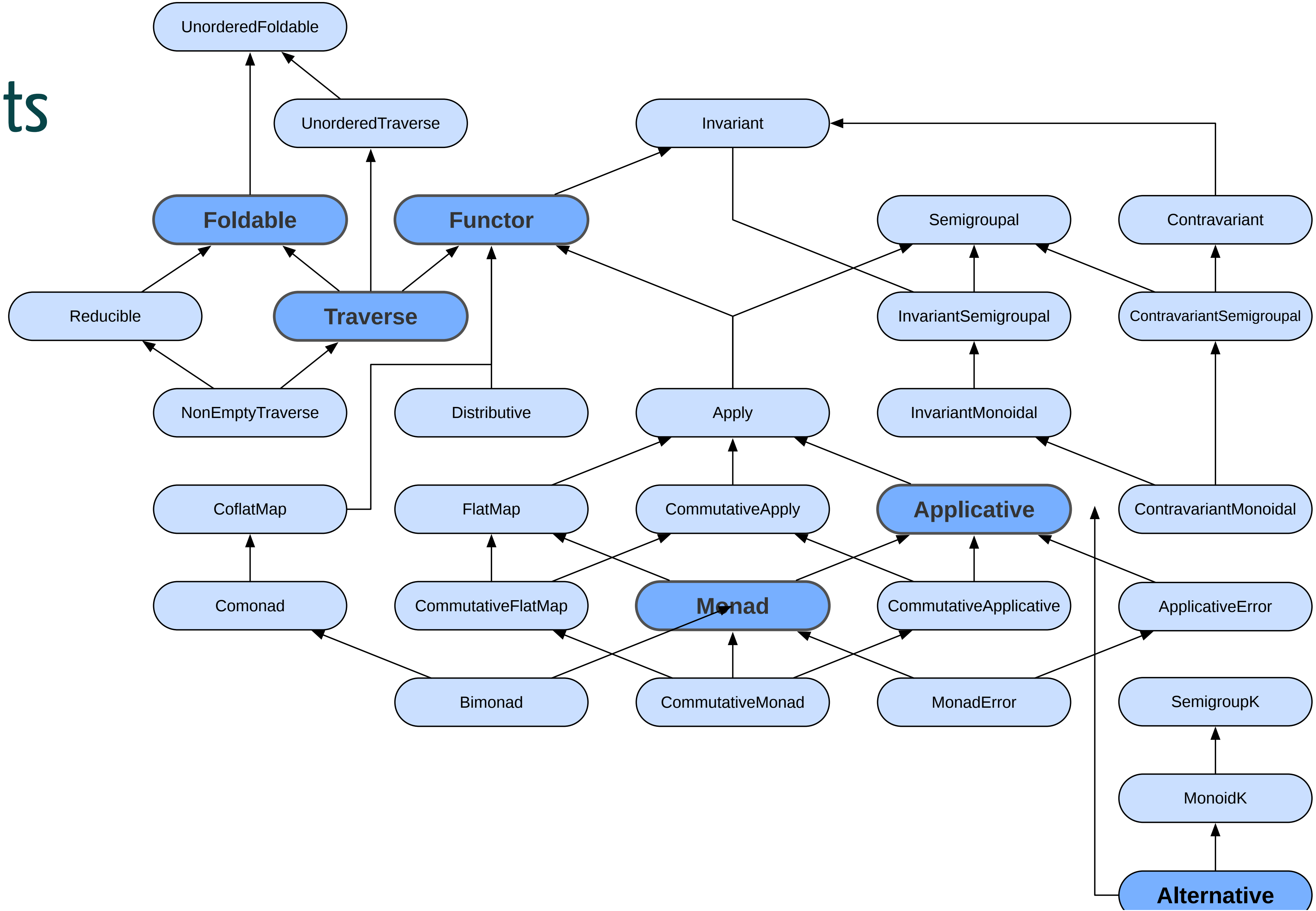
```scala
forAll(fa: F[A] => fa.size == sizeDefault(fa))
```

# Review


Invariant Functor
Contravariant Functor
Functor
Foldable
Semigroup
Commutative Semigroup
Monoid
Commutative Monoid
Apply
Applicative
Traverse
FlatMap
Monad
Type
Type -> Type
Inheritance
Uses

# Granularity

# Cats


UnorderedFoldable
UnorderedTraverse
Invariant
Foldable
Functor
Semigroupal
Contravariant
Reducible
Traverse
InvariantSemigroupal
ContravariantSemigroupal
NonEmptyTraverse
Distributive
Apply
InvariantMonoidal
CoflatMap
FlatMap
CommutativeApply
Applicative
ContravariantMonoidal
Comonad
CommutativeFlatMap
Monad
CommutativeApplicative
ApplicativeError
Bimonad
CommutativeMonad
MonadError
SemigroupK
MonoidK
Alternative

# Granularity

- There is not a single "correct" granularity

# Granularity

- There is not a single "correct" granularity
- Applicative was discovered in 2008
- Selective Applicative Functor in 2018!

# Recommendations

## Define strongest typeclasses for data types

```
val instances: Monad[Option] with Traverse[Option] = ?
```

- Better defined behaviour
- More tests for free
- More powerful API

## Use weakest typeclasses for functions

```
def program[F[_]: Console: Applicative]: F[String] = ?
```

- Principle of least power
- More reasoning
- Less tests to write

# Resources and further study

- Cats infographic: typeclass diagrams for cats
- Thinking with types: variance
- Constraints Liberate, Liberties Constrain from Runar Bjarnason
- Applicative paper Applicative Programming with Effects
- Selective Applicative Functor paper Selective Applicative Functors

# The End