COMPUTATIONAL INTELLIGENCE LIBRARY

SSCI 2015 Tutorial

http://github.com/cirg-up/cilib

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Please interrupt at any time if you have questions

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Things we fight, daily

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Things that add complexity:

- Parallelism, Threading and concurrency
- Managing application state
- Complex object interactions
- Different kinds of OO semantics (X and Y have similar but different OO implementations)
- Pseudo-randomness on computers
- Discrepancies between algorithm descriptions (within and out of published works) and the actual implementations.


99 little bugs in the code.
99 little bugs in the code.
Take one down, patch it around.
127 little bugs in the code...

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What do we want?

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We want:

- A way to talk about algorithms and their implementations, without necessarily troubling ourselves with the complexities that make implementation difficult

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- A way to talk about algorithms and their implementations, without necessarily troubling ourselves with the complexities that make implementation difficult
- We want a declarative process to describe things, worrying about how to "do" them at a later stage

CIlib: Making sense of complexity

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Several things, however, are very important to get right:

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Furthermore, we want to make implementation as simple as possible by removing the boring parts that usually take up far too much time and are tricky to get right.

Several things, however, are very important to get right:

- Correctness
  Principled design to promote intuitive usage
- Experimental reproducability
  Not being able to reproduce experimental results is utterly useless
- Type safety
  The ability to exploit types to prevent errors by making the construction of error states impossible

CIlib: Design changes

Library first: No assumptions are made about how the code in this project is used

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Reliance on pre-existing libraries to simplify implementations:

- Scalaz: FP abstractions (lets see what happens with this and Cats)
- Spire: Numeric abstractions
- Monocle: Lens library

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Huge benefits:

- User has choice of persistence for results: memory, files, database or cloud storage
- Portions of library can simply be ignored if not needed
- Greater focus on algorithms
- Focused tests
- Opt-in parallelism


Scala

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About Scala

We decided on Scala for a very simple reason: familiarity with the JVM.
It's not **that** different from Java (on the runtime that is)

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Scala features:

- Object-orientated / Functional hybrid language
- Static typing
- Supports local type inference
- Extensible (e.g: syntax)
- Allows for symbolic method names, including UTF-8

```
def □ (x: String) =
  "This is probably not a good idea, but it's completely valid, " + x
```

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Quick intro to Scala syntax

There are some difference in the syntax between Java and Scala, but these are in truth, minimal.

All types are defined after variable names

```
def foo(first: String, last: String): Person =
  ...
```

Everything is an expression, which yields a value. In blocks, the last expression is the value of the entire block

```
val x: Int = {
  println("I'm a statement that returns Unit")
  List(1,2,3)
  4
}
```

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Syntax: Class definitions

Java

```
public class Person {
  private final String first;
  private final String last;

  public Person(
    String name, String last) {
    this.first = first;
    this.last  = last;
  }

  public String getFirst() {
    return this.first;
  }

  public String getLast() {
    return this.last;
  }
}
```

Scala

```
case class Person(
   first: String, last: String)
```

There is always a primary constructor in Scala. This constructor **is** the class definition

Auxiliary constructors are required to call the primary constructor.

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Syntax: General

- Everything is an object and has a top type of `Any`, with a bottom type of `Nothing`
- The end of line terminator:
  - `;` is not needed as the *normal* EOL character is `\n`
  - Multiple expressions on the same line, however, use `;` to separate individual expressions
- Linearization is used for multiple inheritance

```
class Dog extends Animal
              with Loyalty
              with Woofing
              with Mammal
```

- Variance annotations:
  - `List[+A]` - `+A` indicates *covariance* (i.e: subtypes)
  - `Array[A]` - `A` indicates the type is *invariant*
  - `class Contravariant[-A]` - `-A` indicates *contravariance* (i.e: supertypes)

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Syntax: General (2)

- The normal OO style access modifiers (`private`, `protected`, `public`) exist, plus a few extra
- The default access modifier is `public`
- Immutable values are defined using `val`. E.g: `val x = 3`
- Mutable variables are defined using `var`
- Methods are defined using `def foo()`
- There are several uses for _:
  - Imports: `import scala.collection._`
  - Hiding imports: `import scala.Predef.{ any2stringadd => _, _ }`
  - Placeholder syntax: `x => (_: Int) + x + 3`
  - Ignoring a value: `val (x, _) = tuple`
  - Catch-all in pattern match

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Syntax: General (3)

- Scala has `traits`, which are like Java interfaces but can contain concrete method implementations

```
trait Adder {
  def add(x: Int, y: Int) = x + y
}
```

```
trait T[A] {
  def foo(a: A): String
}
```

Trait like interfaces now exist in Java 8, but it's not quite enough

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Syntax: General (4)

- Multiple parameter groups are completely valid: `def foo(a: Int)(b: Int)(c: Int): Double`
- *Implicit parameters* are also allowed. These are parameters that the user need not provide, the compiler will insert the "nearest" scoped implicit value. Must be the **last** parameter group:
  `def bar(x: String)(implicit X: Monoid[String]) = ...`

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Syntax: General (5)

An important tool we need is parametricity

Type parameters can be added to `class`, `def` and type aliases: `type C[A] = List[A]`

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Generic programming means we can write less code to do more

Scala also allows us to abstract over *type constructors*, which is also know as **higher-kinded polymorphism**

```
def fooHigher[F[_],A](fa: F[A]) =
  ...
```

The above function works for types like `List`, `Set`, `Vector`, but not for `Map[A,B]`

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Syntax: Pattern matching

Functional languages allow for "pattern matching", whereby a data structure can be deconstructed, without the need for reflection and in a way that the compiler can type-check for you.

Pattern matching uses the `match` syntax:

```
scala> List(1,2,3) match {
     | case x :: xs => 4
     | }
<console>:8: warning: match may not be exhaustive.
It would fail on the following input: Nil
              List(1,2,3) match {
                  ^
res0: Int = 4
```

Just note that the first matching case in the list of patterns will be used. We'll look at pattern matching in depth when we discuss Algebraic Data Types (ADTs)

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REPL: Read Evaluate Print Loop

Scala, like most functional languages, has a REPL within which experimentation can happen without needing to create an entire compiling program. It aids thinking dramatically!

```
λ Garys-MacBook-Pro gif → scala -Dscala.color
Welcome to Scala version 2.11.6 (Java HotSpot(TM) 64-Bit Server VM, Java 1.8.0_40).
Type in expressions to have them evaluated.
Type :help for more information.

scala> List(1,2,3).map(_ + 4)
res0: List[Int] = List(5, 6, 7)

scala> List(1,2,3) ++ List(3,4,5)
res1: List[Int] = List(1, 2, 3, 3, 4, 5)

scala> def foo[A](x: A): A = x
foo: [A](x: A)A

scala> foo(2)
res2: Int = 2

scala> foo("2")
res3: String = 2

scala> L
```

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Functions

The ultimate tool

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Functions: First class values

Functions are first class values in Scala, meaning that they can be passed around as you would pass around an `Int`

```
val f: Int => String = (x: Int) => x.toString
```

Functions can be returned as a result and / or can be passed in as input

```
def foo(x: Int => String): Int => List[Int] =
  ...
```

Functions that take and return functions are called Higher Order Functions (HOF)

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Functions: Partial application

Functions of many parameters may have some of these parameters bound to values, resulting in a new function that requires the remaining parameters only

This is known as *partial function application*

```
// Using methods, this is the way
def add(x: Int)(y: Int) = x + y  // Multiple parameter groups
def add5 = add(5)(_)

// Using functions
val add = (x: Int) => (y: Int) => x + y
val add5 = add(5)
```

It should be obvious that there is a similarity between the forms. Note that the latter is more flexible

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Functions: Curried and uncurried

Currying (named after Haskell Curry) is the process where a function of many arguments is transformed into a sequence of functions, taking a single argument each

Uncurrying is the "dual" process of currying, whereby a curried function is transformed into a function taking a tuple of arguments

```
val curried: Int => Int => Int => Double =
  x => y => z => (x + y + z) / 0.5

val uncurried: (Int, Int, Int) => Double =
  (x, y, z) => (x + y + z) / 0.5
```

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val uncurried: (Int, Int, Int) => Double =
  (x, y, z) => (x + y + z) / 0.5
```

Functions in Scala are right associative, so the curried function `Int => Int => Double` is isomorphic (exactly the same) as `Int => (Int => Double)`, where the latter has parenthesis applied to make the binding explicit

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Algebraic Data Types (ADTs)

You already know a number of types, such as: `Int`, `Double`, `List[Int]`

Composite types are created in two forms, namely **Product** or **Sum** types

Product types multiply types together, producing types that are the combination of the sub types.
Examples are: normal classes, tuples and records

Sum types are also called disjoint types or discriminated unions. Example: `Either[String,Int]`

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ADTs are known as "algebraic" types because they form a **closed** algebra which cannot be altered

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ADTs: Definition

Languages such as Haskell support the creation of ADTs directly in the language.

Scala does support them, but the encoding is done using `case` classes / objects and `sealed`

```
sealed trait Option[A]
case class Some[A](a: A) extends Option[A]
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Because of how Scala encodes ADTs, using subtyping, direct instantiating of `Some` and `None` are possible because Scala regards them as unique types themselves. These instances are of the types `Some.type` and `None.type` but they really should be of the type: `Option[A]`

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When using ADT structures, like `Option` you always talk about things being `Option` and not a `Some` / `None`. `Some(...)` and `None` are called "data constructors" as they create data, but the type is `Option`

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ADTs: Why use them?

ADTs allow us to have a fixed set of operations

They cannot be extended further and encode something specific into the type system

ADTs are what is missing in many languages, which then introduce more language features to try address this missing feature. ADTs are simple values and ***not*** language level semantics

Examples of language "things" added due to missing ADTs:

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Examples of language "things" added due to missing ADTs:

- Missing values -> the billion dollar mistake: `null`
- Descriptive errors -> exceptions
- Comparison semantics -> Using `Int` to compare values. `2^32` possible values instead of the needed `3`

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ADTs: Custom algebras

ADTs also play extremely nicely with pattern matching. Exhaustiveness checking from the pattern matcher will also apply to ADTs

The closed nature means that in-variants can be encoded into the type system, giving you greater guarantees

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- `RNG` - type of PRNG, limited to CMWC

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- `RNG` - type of PRNG, limited to CMWC
- `Generator` - random generators based on RNG, produce `Int`, `Double` or `Boolean`

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Typeclasses

Staying classy

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Typeclasses: Open-world interfaces

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Typeclasses: Open-world interfaces

- Typeclasses allow for adhoc polymorphism
- Serve to create a categorization of types
- Extend the functionality of a given type
- Does **not** involve inheritance, yay!
- Makes the compiler work for you and acts like a kind of proof-assistant

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Typeclasses: Definition

Typeclasses are a kind of **pattern** in Scala, whereas they are first-class in languages like Haskell

Typeclasses in Scala are defined using a parameterized `trait`:

```
trait Show[A] {
  def show(a: A): String
}
```

It's important to recognize that the type in question, `A`, is passed to the function directly and is not obtained from somewhere "magical"

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Typeclasses: Usage

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- Each instance of the typeclass is an instance of the typeclass trait, with a given value for the type parameter "hole"
- Each instance is defined as an implicit value

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- Compiler will lookup typeclass instances based on the needed type, looking at the current scoping

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- Each instance is defined as an implicit value
- Compiler will lookup typeclass instances based on the needed type, looking at the current scoping
- Missing typeclass instance for a given type: failure in compilation

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Typeclasses: Usage

- Typeclasses are made useful by having "instances" defined for the class
- Each instance of the typeclass is an instance of the typeclass trait, with a given value for the type parameter "hole"
- Each instance is defined as an implicit value
- Compiler will lookup typeclass instances based on the needed type, looking at the current scoping
- Missing typeclass instance for a given type: failure in compilation

```
implicit val intShow = new Show[Int] {
  def show(a: Int) = a.toString
}
```

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Typeclasses: Usage (2)

Functions that work with a given typeclass, expressly define it as an implicit parameter or context bound, resulting in a function that is "constrained"

```
def show[A](a: A)(implicit shower: Show[A]) = shower.show(a)
```

Context bounds are the same as an implicit parameter, except that the typeclass is not bound to a name and the constraint is provided in the type parameter:

```
def show[A: Show](a: A) = implicitly[Show[A]].show(a)
```

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Of course, there is no limit to the number of constraints a function may have. Each typeclass constraint adds a level of "strictness" to the function

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```

Of course, there is no limit to the number of constraints a function may have. Each typeclass constraint adds a level of "strictness" to the function

Syntax may also be used to achieve the same result. Scalaz adds such syntax for a set of types

```
3.shows // Syntax that uses Show[Int]
```

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Typeclasses: So what is the point?

- So we have declared functionality for a type, without actually changing the implementation of the type
  - The type `A` knows **nothing** about `Show`

- This is known as the *open world assumption*
- **Very important:** this is not subtyping
  - Subtyping requires an implementation of a method for each extending class
  - Typeclasses (aka adhoc polymorphism) allow the omission of implementations, which is fantastic if a certain type *shouldn't* have an instance defined because the functionality either doesn't make sense or if it is incorrect to have an instance defined (violation of laws)

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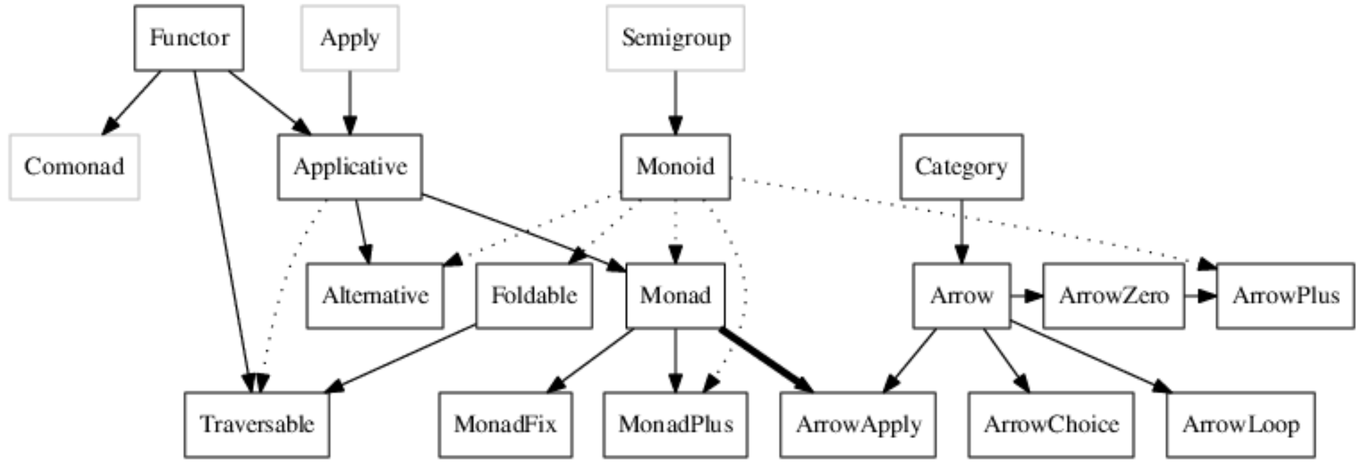
The Typeclassopedia

As taken from research done in Haskell:



- These structures allow better structure to functional programs
- Typeclasses are not magical, but do provide a common nomenclature
- Defined in the `scalaz` library

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Typeclasses: Semigroup

Imagine having a set of objects, of type `A`, and a function that can combine two values of `A` into a new value of type `A`.

This binary, two element, operator must always adhere to the associative law in order to behave in a consistent manner

```
a · (b · c) = (a · b) · c
```

where · is the binary operator and is also called `append`

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Typeclasses: Semigroup

Imagine having a set of objects, of type `A`, and a function that can combine two values of `A` into a new value of type `A`.

This binary, two element, operator must always adhere to the associative law in order to behave in a consistent manner

```
a · (b · c) = (a · b) · c
```

where · is the binary operator and is also called `append`

You can imagine the number of possible instances that the semigroup structure may have

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Typeclasses: Semigroup (2)

The representation in code:

```
trait Semigroup[A] {
  def append(x: A, y: A): A
}
```

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Typeclasses: Semigroup (2)

The representation in code:

```
trait Semigroup[A] {
  def append(x: A, y: A): A
}
```

Sample implementation

```
implicit val stringSemigroup = new Semigroup[String] {
  def append(x: String, y: String) = x + y
}
```

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Typeclasses: Monoid

Monoid is a structure that builds on Semigroup by adding an identity element to the abstraction. This operation is also called `zero` or `identity`. This mean that the following laws need to be adhered to

```
a · (b · c) = (a · b) · c
     a · id = id · a
```

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Typeclasses: Monoid (2)

In code:

```
trait Monoid[A] extends Semigroup[A] {
  def zero: A
}
```

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Typeclasses: Monoid (2)

In code:

```
trait Monoid[A] extends Semigroup[A] {
  def zero: A
}
```

Sample implementation

```
implicit val intMonoid = new Monoid[Int] {
  def zero: Int = 0
  def append(x: Int, y: Int) = x + y
}
```

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Typeclasses: Monoid (3)

There are **many** monoids. Far more than what seem obvious at first

Very important to remember that monoids beget monoids! Given a `Monoid[Int]` and a `Monoid[List]`, `Monoid[List[Int]]` can be constructed

Monoid examples

- `Int` Addition: `(0,+)`
- `Int` Multiplication: `(1,*)`
- `String` concatenation: `("",+)`
- Function composition: `(identity, compose)`
- List concatenation: `(Nil, ++)`
- etc

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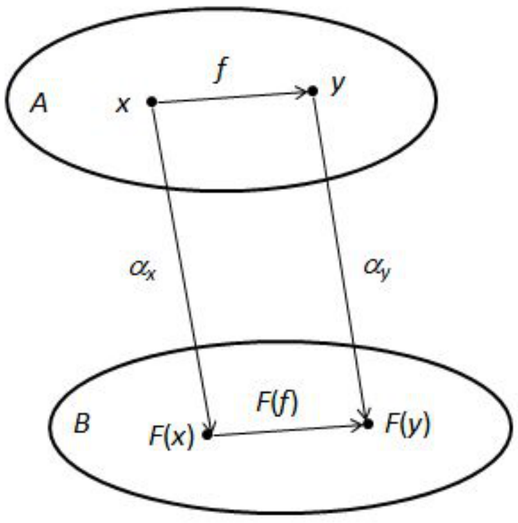
Typeclasses: Functor

`Functor` represents a structure that allows you to transform (map) a value in the structure into a value of another type (but still in the same structure), given a transformation function.

The structure is often called a "computational context", which is an abstract notion, but there is nothing else that really fits here.



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Typeclasses: Functor (2)

Functors are structures that define a single function `map`

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

An instance for the `Option` ADT

```
implicit val optionFunctor = new Functor[Option] {
  def map[A,B](fa: Option[A])(f: A => B): Option[B] =
    fa match {
      case Some(a) => Some(f(a))
      case None    => None
    }
}
```

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Typeclasses: Functor (3)

`Functor` instances, like normal functions, can be composed to create new `Functor` instances.

In essence, a `Functor` "lifts" a regular function into the context of the `Functor`

Functors operate on kinds of the shape `* -> *`, where a type parameter is needed to create the type, like

- `Lists`
- `Trees`
- `Maps`

Functor laws:

- `map(fa)(id) === fa`
- `map(fa)(f compose g) === map(map(fa)(g))(f)`

These laws prevent ridiculous definitions of `map`, and make it possible to predict how functions behave.

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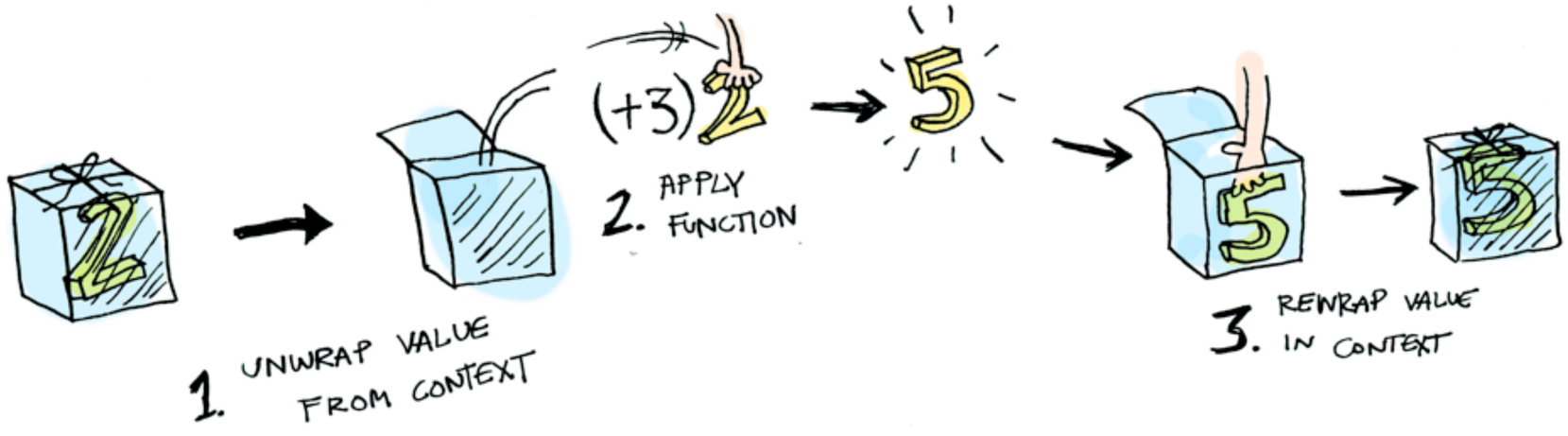
Typeclasses: Functor (3)



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Aside: Parametricity

```
def fun[A](a: A): A = ...
```

What is `fun`?

```
val x : List[Int] = ...
def foo[F[_] : Functor](fs : F[Int]): F[Int] = ...
```

What is `foo(x).length`?

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Typeclasses: Applicative functor

You can do a lot with `map`, but sometime you need more power

Consider

```
def parseInt(s: String): Option[Int] = ...
```

Now if you want to add two `Int`s together:

```
parseInt("5").map((x: Int) => (y: Int) => x + y)
```

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Consider

```
def parseInt(s: String): Option[Int] = ...
```

Now if you want to add two `Int`s together:

```
parseInt("5").map((x: Int) => (y: Int) => x + y)
```

So we get `Option[Int => Int]`, but what now?

We need a *more* powerful `map`-like operation, one that allows us to kind of "map in the context"

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Typeclasses: Applicative functor (2)

It can be achieved by adding more power to `Functor`:

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Typeclasses: Applicative functor (2)

It can be achieved by adding more power to `Functor`:

```
trait Applicative[F[_]] extends Functor[F] {
  def <*>[A, B](fa: F[A])(f: F[A => B]): F[B] // This is also called "apply" or "ap"
}
```

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Typeclasses: Applicative functor (2)

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```
trait Applicative[F[_]] extends Functor[F] {
  def <*>[A, B](fa: F[A])(f: F[A => B]): F[B] // This is also called "apply" or "ap"
}
```

Again, laws must be adhered to (Haskell-ish pseudo-code for space reasons):

- Identity: `pure identity <*> u === u`
- Composition: `pure (.) <*> u <*> v <*> w == u <*> (v <*> w)`
- Homomorphism: `pure f <*> pure x == pure (f x)`
- Interchange: `u <*> pure x == pure (\f -> f x) <*> u`

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Typeclasses: Applicative functor (3)

So this allows for the composition we wanted:

```
(parseInt("5")).<*>(parseInt("Nope").map(x => (y: Int) => x + y))
```

But that's obviously horrible...

Sadly, the syntax of scala is actually working against us. As an example, the same example in Haskell would be

```
(+) <$> parseInt("3") <*> parseInt("Nope")
```

Applicative functors are a generalization of `map`, allowing us to work with functions with multiple inputs

As a result, additional syntax is introduced to *smooth* out the usage in scala, which Scalaz provides known as the `ApplicativeBuilder` which allows us to use the code in a nicer manner

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```
(parseInt("5") |@| parseInt("Nope")) { _ + _ } // Option[Int]
```

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Typeclasses: Applicative functor (4)

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Typeclasses: Applicative functor (5)

So now operations in some context can be done with multi argument functions

What happens if you have a value that isn't in the context?

```
(parseInt("5") |@| 4) { _ + _ } // er.... this will not compile
```

Just like how we have `map`, that lifts a function into the context, we need a way to lift a *value* into the context

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Typeclasses: Applicative functor (6)

One small addition to the typeclass:

```
trait Applicative[F[_]] extends Functor[F] {
  def <*>[A, B](fa: F[A])(f: F[A => B]): F[B]
  def point[A](a : A): F[A]
}
```

With `point` defined, we can use the applicative as expected (using some syntax):

```
(parseInt("5") |@| 4.point[Option]) { _ + _ }
```

Additionally notice that the way `Applicative` receives its arguments means that all the arguments need to be available, and ready, before the composition function is applied. This actually can be exploited, allowing applicatives to do things in **parallel** before composition

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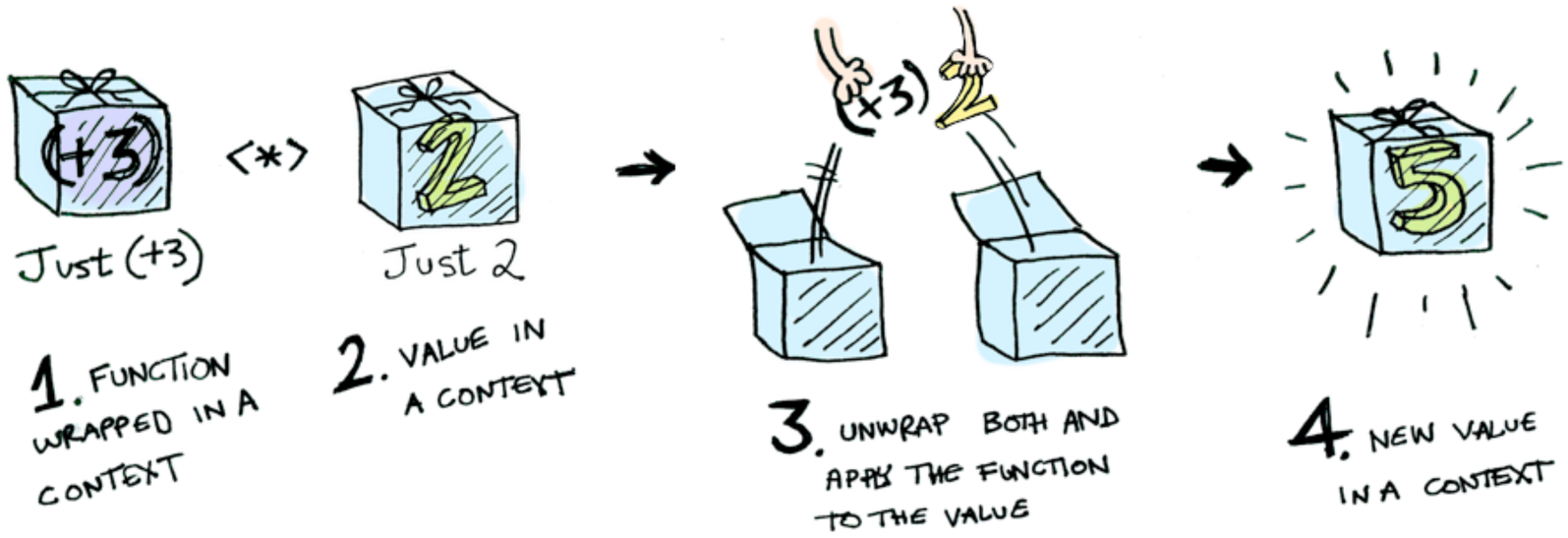
Typeclasses: Applicative functor (7)



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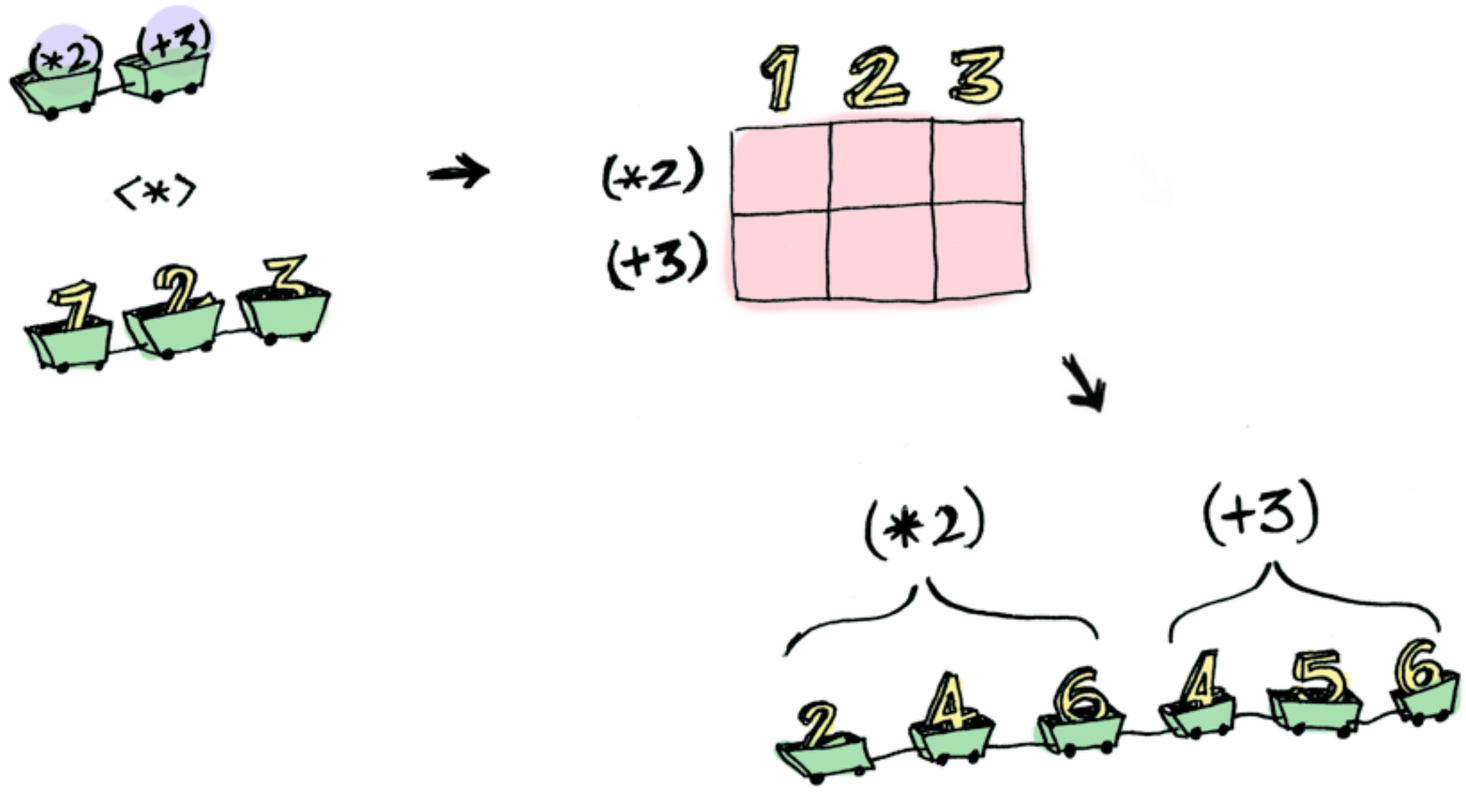
Typeclasses: Applicative functor (8)



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Typeclasses: Monad

Let's take a step back and see how something else might go wrong

Assume for a moment, that we needed to obtain a value from an associative `Map`, which then would need to be parsed into an integer value

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Typeclasses: Monad

Let's take a step back and see how something else might go wrong

Assume for a moment, that we needed to obtain a value from an associative `Map`, which then would need to be parsed into an integer value

Because getting the value from the `Map`, might fail (i.e: the value is not present), the return type is a `Option[String]`

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Because getting the value from the `Map`, might fail (i.e: the value is not present), the return type is a `Option[String]`

So we have:

```
val x: Option[String] = variables.get("x")
```

to which we apply our trusty hammer, `map`

```
x.map(parseInt) // Result is Option[Option[Int]]
```

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Typeclasses: Monad (2)

We need to be able to reach into a computational context, pull out the value and apply a function which results in a new computational context (which is the same as the original), then having the nested structure flattened

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Typeclasses: Monad (2)

We need to be able to reach into a computational context, pull out the value and apply a function which results in a new computational context (which is the same as the original), then having the nested structure flattened

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

This weird operator `>>=` is pronounced "bind" and there are a set of laws, naturally:

- Left identity: `return a >>= f ≡ f a`
- Right identity: `m >>= return ≡ m`
- Associativity: `(m >>= f) >>= g ≡ m >>= (\x -> f x >>= g)`

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Typeclasses: Monad (3)

Some people talk about a "shoving" values though the monad

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Typeclasses: Monad (4)

So, we can now do what we wanted, letting the monad correctly flatten the structure for us

```
variables.get("x") >>= parseInt // Option[Int]
```

This can be repeated, feeding the result of one action into a function that produces the next action:

```
monadicX >>= (x => monadicY >>= (y => monadicZ map (z => x+y+z)))
```

The pattern here is a a group of nested `bind`s followed by a single `map`, but its no fun to read

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This brings up an important concept: Monads allow for the *sequencing of effects*. This allows the lazy, purely functional language Haskell to do things in order

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Typeclasses: Monad (5)

If the syntax is formatted a little:

```
monadicX >>= ( x =>
monadicY >>= ( y =>
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   x + y + z
)))
```

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Typeclasses: Monad (5)

If the syntax is formatted a little:

```
monadicX >>= ( x =>
monadicY >>= ( y =>
monadicZ map ( z =>
   x + y + z
)))
```

That does look better, but because the pattern is used so often, the compiler provides some syntax sugar which the programmer can use, but the compiler de-sugars the syntax during compilation

```
for {
  x <- monadicX
  y <- monadicY
  z <- monadicZ
} yield x + y + z
```

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Typeclasses: Monad (6)

Monads provide an **embedded language**:

```
for {
  x <- monadicX
  y <- monadicY
} yield x + y
```

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Typeclasses: Monad (6)

Monads provide an **embedded language**:

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} yield x + y
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What does the above `for`-comprehension (scala parlance), or even better `monad`-comprehension do?

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for {
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} yield x + y
```

What does the above `for`-comprehension (scala parlance), or even better `monad`-comprehension do?

The answer is quite simple: it depends on what the monad is defined to do, while maintaining the laws

Monad	**Semantics**
`Option`	Anonymous exceptions / missing values
`Reader`	Read-only / immutable environment
`Validation`	Descriptive exceptions
`List`	Non-deterministic computation
`Future`	Valid computed asynchronously

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Typeclasses: Signatures

Have a look at the following, notice the difference in the structures

```
def map[A,B](fa: F[A])(f: A => B): F[B]    // Functor
def <*>[A,B](fa: F[A])(f: F[A => B]): F[B] // Applicative
def >>=[A,B](fa: F[A])(f: A => F[B]): F[B] // Monad
```

It should also be noted again that, as per the typeclassopedia diagram:

- All `Applicative` instances are also valid `Functor` instances, but not all `Functors` are `Applicative`
- All `Monad` instances are valid `Applicatives` (and by extension `Functors`), but not vice versa

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Typeclasses: Signatures (2)

Always use the relevant structure to achieve your desired goal. For example:

```
for {
  aa <- a
  bb <- b
} yield f(aa, bb)
```

does not need monad sequencing in order to call the function `f`. An applicative functor is better:

```
(a |@| b) { f(_, _) }
```

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Typeclasses: Monad transformers

In programming we need to deal with a variety of multiple kinds of effects:

- A program needs some configuration (`Reader`)
- A connection to an external system may fail (`Validation` or `Either`)
- Computation needs to be asynchronous (`Future`)
- Computation may produce zero or multiple results (`List`)
- We want to log some additional data during a computation (`Writer`)

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- A connection to an external system may fail (`Validation` or `Either`)
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- We want to log some additional data during a computation (`Writer`)

Unfortunately, combining these effects gets messy and the reason for this is that it is not possible to compose any two random monads - you simply cannot write the `>>=` operation in a completely generic way. Please feel free to try it :)

```
implicit val ComposedMonad[M: Monad, N: Monad] = new Monad[...] {
  def >>=[A, B](fa: M[N[A]])(f: A => M[N[B]]) : M[N[B]] = // ???
}
```

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Typeclasses: Monad transformers (2)

Let's see why stacking monads gets messy

```
type Env = Map[String, Int]
def lookup(s: String): Reader[Env, Option[Int]] =
  Reader(env => env.get(s) orElse parseInt(s))
```

Remember that you cannot "mix" monads! If you do, you completely invalidate the laws and as a result, it is impossible to ensure that the computation will be consistent.

Say we now add two numbers, using `Reader` to prevent repetition:

```
for {
 xOpt <- lookup("3")
 yOpt <- lookup("y")
} yield (for {
           x <- xOpt
           y <- yOpt
         } yield x + y)
```

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Typeclasses: Monad transformers (3)

This switch from monad to monad is often referred to as "stair-stepping" and results in very nested, verbose code. It's turtles all the way down.

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Typeclasses: Monad transformers (4)

Transformers are wrappers that exploit the knowledge of the inner monad instance of the given monad

```
case class OptionT[F[_], A](run: F[Option[A]]) {
  ...
}
```

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Typeclasses: Monad transformers (4)

Transformers are wrappers that exploit the knowledge of the inner monad instance of the given monad

```
case class OptionT[F[_], A](run: F[Option[A]]) {
  ...
}
```

```
OptionT(List(Some(1), None, Some(3), Some(4))).getOrElse(0) === List(1,0,3,4)
```

It's important to realize that the transformer is a monad itself, therefore you can nest transformers arbitrarily deep, but the order of the stacking is significant

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Typeclasses: Monad transformers (4)

It is the convention that the monad transformer instances mirror the inner monad's name, with a `T` suffix

- `OptionT`
- `ReaderT`, aka `Kleisli` (yes, from category theory: the Kleisli category)
- `WriterT`
- `EitherT`
- `ListT`

Now we can cleanup our previous stair-stepping example:

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- `OptionT`
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- `WriterT`
- `EitherT`
- `ListT`

Now we can cleanup our previous stair-stepping example:

```
for {
  x <- Kleisli(lookup("3"))
  y <- Kleisli(lookup("y"))
} yield x + y
```

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Typeclasses: Monad transformers (5)

Again, a monad transformer is defined by a typeclass:

```
trait MonadTrans[F[_[_], _]] {
  def liftM[G[_]: Monad, A](a: G[A]): F[G,A]
}
```

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Typeclasses: Monad transformers (5)

Again, a monad transformer is defined by a typeclass:

```
trait MonadTrans[F[_[_], _]] {
  def liftM[G[_]: Monad, A](a: G[A]): F[G,A]
}
```

`liftM` allows us to "lift" computations in the base monad into the transformer:

```
(for {
  x <- OptionT(List(Some(3), None))
  y <- List(1,2).liftM[OptionT]
} yield x + y).run // List(Some(4), None, Some(5), None)
```

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Lenses

Lenses are, in a very simplified sense, functional getters and setters that allow composition

They are part of a greater idea; that of `Optics` (which we won't get into today)

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Lenses are, in a very simplified sense, functional getters and setters that allow composition

They are part of a greater idea; that of `Optics` (which we won't get into today)

Assume a nested structure of case classes, to update a value deep inside, code ends up looking like:

```
val employee: Employee = ...

employee.copy(
  company = employee.company.copy(
    address = employee.company.address.copy(
      street = employee.company.address.street.copy(
        name = employee.company.address.street.name.capitalize // capitalize exists
      )
    )
  )
)
```

This need not be case classes, any nested structure is applicable

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Lenses (2)

Using lenses, we can define a composition to zoom down into a structure, handling the updates of all the immutable data by the lenses as we "zoom out"

```
val _name   : Lens[Street  , String]  = ...  // we'll see later how to build Lens
val _street : Lens[Address , Street]  = ...
val _address: Lens[Company , Address] = ...
val _company: Lens[Employee, Company] = ...

(_company composeLens _address
          composeLens _street
          composeLens _name).modify(_.capitalize)(employee)
```

There are a host of other abstractions that Lenses result in, but they are not in the scope for this talk - we do use lenses a lot in CIlib though

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Lenses (3)

Creating a lens is very simple. You need to provide the following for the types in question:

- `getter` function
- `setter` function

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```
case class Mem[A](b: Position[A], v: Position[A])

trait Memory[S,A] {
  def _memory: Lens[S, Position[A]]
}

object Memory {
  implicit def memMemory = new Memory[Mem[Double],Double] {
    def _memory = Lens[Mem[Double],Position[Double]](_.b)(b => a => a.copy(b = b))
  }
}
```

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CIlib 2.0

CIlib

We've spoken a lot about abstractions and the like before getting to this point. It was necessary as we build on these abstractions within CIlib

Now let's start going through the core concepts and abstractions we have:

- Entity
- Position
- RVar
- Dist
- Step
- Iteration

CIlib: Entity

Looking back on CIlib 1.0, there where many *entity* types:

- Individual
- Harmony
- Particle
  - StandardParticle
  - ChargedParticle
  - DynamicParticle
  - etc
- Bee
- etc

And various permutations and adaptations of the above

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CIlib: Entity (2)

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Every entity can be described / represented as a 2-tuple consisting of:

- State specific to the entity
- Position that the entity represents of some point in the search space

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Every entity can be described / represented as a 2-tuple consisting of:

- State specific to the entity
- Position that the entity represents of some point in the search space

```
case class Entity[S,A](state: S, pos: Position[A])
```

Furthermore, we needed to change our terminology: there is no need to talk about swarms, populations, colonies, etc. Instead we can just refer to a *collection* of entities

CIlib: Entity (3)

The interesting part of the `Entity` is actually the state represented by the `S` type parameter

`Entity` is a general data structure, so how do we represent that this `Entity` contains various "pieces of state"?

This is where some structure comes in, in the form of:

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- The state of an `Entity` is extracted using `Lens` instances
- `Lens` instances also are used to update `Entity` state

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- `Lens` instances also are used to update `Entity` state

The most important aspect is now that because the `Lens` instances constrain an `Entity`, they also then become the constraints that algorithms specify, thereby preventing the wrong "kind" of `Entity` being used in a given function.

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CIlib: Entity (4)

```
def updatePBest[S]( // S is the entity state type
  p: Particle[S,Double]
)(implicit M: Memory[S,Double]): Step[Double,Particle[S,Double]] = {
  val pbestL = M._memory
  Step.liftK(Fitness.compare(p.pos, (p.state applyLens pbestL).get).map(x =>
    Entity(p.state applyLens pbestL set x, p.pos)
  ))
}

def updateVelocity[S](
  p: Particle[S,Double],
  v: Position[Double]
)(implicit V: Velocity[S,Double]): Step[Double,Particle[S,Double]] =
  Step.pointR(RVar.point(Entity(p.state applyLens V._velocity set v, p.pos)))
```

CIlib: Position

`Position` is a data structure that is at the core of the library. `Position` is encoded as an ADT and represents two distinct cases:

- `Point` - A point within the problem search space
- `Solution` - A point within the search space that has been quantified to have both a `Fit` and a `List[Constraint[A,B]]` for constraint violations

`Position` is parameterized on the type of the individual dimension elements and are created by using `Bound` instances that define the search space

CIlib: Position (2)

Syntax has been added to allow for Vector based mathematics on `Position` instances, and any change to the position correctly translates it back to a `Point` instance

- `Position + Position`
- `Position - Position`
- `scalar_value *: Position`

Additionally, `Position` is also a valid `Monad`, so `Position` instances can be composed in all the usual ways

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CIlib: RVar

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`RVar` **tracks** the effect of randomness, and as a result allows for actions that use randomness to be declared and used without concerning ourselves with:

- How the randomness is applied
- Which PRNG to use

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- How the randomness is applied
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`RVar` is a declaration that the resulting type has randomness applied to it, and has the following guarantees:

- Using `RVar` is completely stack safe (i.e: no stack overflows)
- Providing the same seeded PRNG, you **will** get the same result

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CIlib: RVar (2)

Internals:

- `RVar` internally is itself a monad transformer stack
- The base monad is a `State` monad that concerns itself with managing the state of the PRNG
- Around the base monad is a `Trampoline`, which provides a way for the computation to suspend itself and then be resumed later
- `RVar` is the base monad for CIlib

`RVar` is constrained to only produce elements that are defined using the `Generator` typeclass, which are currently:

- `Double`
- `Int`
- `Boolean`

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CIlib: RVar (3)

`RVar` requires as a parameter, an instance of a `RNG`

There is only a single `RNG` provided by CIlib to users, the `CMWC` which is currently the suggested RNG for scientific computing. It has a period of 2^{131104} whereas the Mersenne Twister (which is also much more difficult to implement correctly) has a period of $2^{19937}-1$

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`RVar` makes use of the standard derived operations on the `Monad` typeclass for most of the provided functionality:

```
def ints(n: Int) =
  next[Int](Generator.IntGen) replicateM n
```

Additional functions made available by `RVar`, that return `RVar` instances include:

- `choose` - randomly select a value out of a `NonEmptyList` → `RVar[A]`
- `shuffle` - randomly shuffle the given `List` → `RVar[List[A]]`
- `sample` - randomly sample / choose `n` elements from the provided `List` → `RVar[List[A]]`

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CIlib: Dist

Building on `RVar` is `Dist`

`Dist` contains several algorithms that implement probability distributions using the primitives that `RVar` provides

The probability distributions currently supported:

- `uniformInt(from, to)` - Uniform integer from the provided range (inclusive)
- `uniform(from, to)` - Uniform number from the given range (upper bound excluded)
- `cauchy(□, □)`
- `gamma(k, □)`
- `exponential(l)`
- `lognormal(□, □)`
- `dirichlet(□*)`
- `gaussian(□, □)` - Gaussian numbers using Doornik's improved ziggurat method

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CIlib: Dist (2)

There are several "standard" distributions also available so that the parameters need not be provided each time:

- `stdUniform`
- `stdNormal`
- `stdCauchy`
- `stdExponential`
- `stdGamma`
- `stdLaplace`
- `stdLognormal`

The algorithms implemented for the probability distributions are, as far as possible, are based on published works and aim to try an minimize the usage of the RNG

For example: the JDK standard library implementation uses the "polar method" which samples two double values each time before testing if it will succeed the internal checks before being emitted. The ziggurat method used, in contrast, only samples a single double a time

CIlib: Step

The next abstraction is that of a `Step`. `Step` represents a single operation within an algorithm definition

The algorithms we are interested in are non-deterministic, and as a result the algorithms eventually ends up making use of randomness

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Randomness, encapsulated in `RVar`, is not the only concern that algorithms have. There are two other important pieces of information that govern the algorithm behavior:

- The optimization scheme: Minimization (`Min`) or maximization (`Max`)
- A mechanism to quantify the provided candidate solution: `Eval[A]`

CIlib: Step (2)

The `Eval[A]` instance, takes a `Position[A]` and yields a new `Position[A]`, except that the new `Position[A]` should contain a `Fit` and a list of all violated constraints

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Therefore, based on these requirements, `Step` instances need to provide both an `Opt` and an `Eval[A]` instance, which then finally yield `RVar[A]` values

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A: We define a `ReaderT` (aka `Kleisli`) monad transformer (because `RVar` is the base monad in CIlib), which provides a read-only environment of `(Opt, Eval[A])`

```
type Step[A,B] = Kleisli[RVar,(Opt,Eval[A]),B]
```

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```
type Step[A,B] = Kleisli[RVar,(Opt,Eval[A]),B]
```

The expanded form of the `Step`, as what the scala compiler will report in some scenarios, looks like this:

```
val stepAsFunc = (env: (Opt,Eval[A])) => RVar[A]
```

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CIlib: Step (3)

```
def gbest[S](
  w: Double,
  c1: Double,
  c2: Double,
  cognitive: Guide[S,Double],
  social: Guide[S,Double]
)(implicit M: Memory[S,Double], V: Velocity[S,Double], MO:
Module[Position[Double],Double]
): List[Particle[S,Double]] => Particle[S,Double] => Step[Double,Particle[S,Double]] =
  collection => x => for {
    cog     <- cognitive(collection, x)            // Step
    soc     <- social(collection, x)               // Step
    v       <- stdVelocity(x, soc, cog, w, c1, c2) // Step
    p       <- stdPosition(x, v)                   // Step
    p2      <- evalParticle(p)                     // Step
    p3      <- updateVelocity(p2, v)               // Step
    updated <- updatePBest(p3)                     // Step
  } yield updated
```

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CIlib: Step (4)

So, the entire `gbest` function, returns a new function of the shape

```
List[Particle[S,Double]] => Particle[S,Double] => Step[Double,Particle[S,Double]]
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which states that, given a `List[Particle[S,Double]]` (the collection of entities) and the current `Particle[S,Double]` (which is the `Entity`), you get back a **single** `Step[Double,Particle[S,Double]]`

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This `Step[Double,Particle[S,Double]]` may then be "executed" or "run" by providing the optimization environment `(Opt,Eval[Double])` and then finally a `RNG`

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The final result for this entire algorithm definition is a new version of the passed in `Particle[S,Double]`, based on the current collection and the old version of the particle

Applying this function repeatedly on all `Entity` instances in the collection results in the creations of a new collection

CIlib: Iteration

CIlib has based all its algorithm execution around the notion of an `Iteration`

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- Asynchronous (`async`) where the new `Entity` instances are determined off the currently building collection and the remainder of the old collection that has not yet been processed

It is important to note that the `sync` version of the `Iteration` may be implemented completely in parallel as the old immutable collection is the only requirement, whereas the `async` version cannot be parallelised so easily because if needs a combination of the old and new collections, effectively making the processing sequential

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Some Demos
Also, Thank you!