

Compositional Application Architecture With Reasonably Priced Monads

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Monad coproducts

- Subsumes “dependency injection”,
monad transformers
- Based on *Data Types à la Carte*
(Swiestra)
- Similar to *Extensible Effects*
(Kiselyov, Sabry, Swords)

Bank transfer

User must be authorized.

If insufficient funds,

log the attempt,

raise an error.

Otherwise update both accounts.

Concerns

- Authorization
- User interaction
- Logging
- Handling errors
- Persistent storage

Meta-concerns

- Testing
- Reuse
- Extensibility
- Compositionality

“Dependency injection”

```
def transfer(amount: Long, from: Account, to: Account,  
             user: User, auth: Authorization,  
             log: Logger, err: ErrorHandler,  
             store: Storage): Unit
```

“Dependency injection”

```
def transfer(amount: Long, from: Account, to: Account,  
            user: User, context: Authorization with  
            Logger with ErrorHandler with  
            Storage): Unit
```

Idea

Return a description of what we want to do.

Coproduct

```
def transfer(amount: Long, from: Account,  
            to: Account, user: User): List[Instruction]
```

Where **Instruction** is the *coproduct* of:

- Log something
- Fail with an error
- Authorize a user to do something
- Read from storage
- Write to storage
- Interact with the user

User interaction

```
sealed trait Interact[A]
```

```
case class Ask(prompt: String)  
  extends Interact[String]
```

```
case class Tell(msg: String)  
  extends Interact[Unit]
```

User interaction

```
val prg =  
  List(Ask("What's your first name?"),  
        Ask("What's your last name?"),  
        Tell("Hello, ???"))
```

User interaction

```
val prg = for {  
  x <- Ask("What's your first name?")  
  y <- Ask("What's your last name?")  
  _ <- Tell(s"Hello, $x $y!")  
} yield ()
```

Monads

```
trait Monad[M[_]] {  
  def pure[A](a: A): M[A]  
  def flatMap[A,B](ma: M[A])(f: A => M[B]): M[B]  
}
```

Monads

```
trait Monad[M[_]] {  
  def return[A](a: A): M[A]  
  def bind[A,B](ma: M[A])(f: A => M[B]): M[B]  
}
```

Can we write bind/return?

```
sealed trait Interact[A]
```

```
case class Ask(prompt: String)  
  extends Interact[String]
```

```
case class Tell(msg: String)  
  extends Interact[Unit]
```

Free monads

```
sealed trait Free[F[_], A]

case class Return[F[_], A](a: A)
  extends Free[F, A]

case class Bind[F[_], I, A](
  i: F[I],
  k: I => Free[F, A]) extends Free[F, A]
```


Free monads

```
sealed trait Free[F[_],A] {  
  def flatMap[B](f: A => Free[F,B]): Free[F,B] =  
    this match {  
      case Return(a) => f(a)  
      case Bind(i, k) =>  
        Bind(i, k andThen (_ flatMap f))  
    }  
  def map[B](f: A => B): Free[F,B] =  
    flatMap(a => Bind(f(a)))  
}
```

Automatic lifting

```
implicit def lift[F[_],A](fa: F[A]): Free[F,A] =  
  Bind(fa, (a: A) => Return(a))
```

User interaction

```
val prg: Free[Interact, Unit] =  
  for {  
    first <- Ask("What's your first name?")  
    last  <- Ask("What's your last name?")  
    _    <- Tell(s"Hello, $first $last!")  
  } yield ()
```

Interaction

```
val prg: Free[Interact, Unit] =  
  Ask("What's your first name?").flatMap(first =>  
    Ask("What's your last name?").flatMap(last =>  
      Tell(s"Hello, $first $last!").map(_ => ())))
```

Interaction

```
val prg: Free[Interact, Unit] =  
  Bind(  
    Ask("What's your first name?"), first =>  
    Bind(  
      Ask("What's your last name?"), last =>  
        Bind(  
          Tell(s"Hello, $first $last!"), _ =>  
            Return(())))
```

Running Free

```
sealed trait ~>[F[_],G[_]] {  
  def apply[A](f: F[A]): G[A]  
}
```

```
sealed trait Free[F[_],A] {  
  def foldMap[G[_]:Monad](f: F ~> G): G[A] =  
    this match {  
      case Return(a) => Monad[G].pure(a)  
      case Bind(fx, g) =>  
        Monad[G].flatMap(f(fx)) { a =>  
          g(a).foldMap(f)  
        }  
    }  
}
```

Interaction interpreter

```
type Id[A] = A
```

```
object Console extends (Interact ~> Id) {  
  def apply[A](i: Interact[A]) = i match {  
    case Ask(prompt) =>  
      println(prompt)  
      readLine  
    case Tell(msg) =>  
      println(msg)  
  }  
}
```

Interaction interpreter

```
type Tester[A] =  
  Map[String, String] => (List[String], A)  
  
object Test extends (Interact ~> Tester) {  
  def apply[A](i: Interact[A]) = i match {  
    case Ask(prompt) => m => (List(), m(prompt))  
    case Tell(msg) => _ => (List(msg), ())  
  }  
}
```



```
implicit val testerMonad = new Monad[Tester] {  
  def pure[A](a: A) = _ => (List(), a)  
  def flatMap[A,B](t: Tester[A])(f: A => Tester[B]) =  
    m => {  
      val (o1, a) = t(m)  
      val (o2, b) = f(a)(m)  
      (o1 ++ o2, b)  
    }  
}
```

```
scala> val m =  
| Map("What's your first name?" -> "Harry",  
|     "What's your last name?" -> "Potter"))  
m: scala.collection.immutable.Map[String,String]
```

```
scala> val v = prg.foldMap(Test).apply(m)  
v: (List[String], Unit) = (List>Hello, Harry Potter!), ())
```

Let's add a feature

Ask the user for credentials.

If the user is authorized,

tell the secret.

Otherwise

tell the user to go away.

Security algebra

```
sealed trait Auth[A]
```

```
case class Login(u: UserID, p: Password)  
  extends Auth[User]
```

```
case class HasPermission(  
  u: User, p: Permission) extends Auth[Boolean]
```

What is the type here?

```
val prg2: Free[???, Unit] = for {  
  uid <- Ask("What's your user ID?")  
  pwd <- Ask("Password, please.")  
  usr <- Login(uid, pwd)  
  b <- HasPermission(usr, KnowTheSecret)  
  _ <- if (b) Tell("UDDLRBA")  
        else Tell("Go away!")  
} yield ()
```

Coprodut

```
case class Coprodut[F[_],G[_],A](  
  value: Either[F[A],G[A]])
```

```
type App[A] = Coprodut[Interact,Auth,A]
```

```
val prg: Free[App, A] = ...
```

Injection

```
sealed trait Inject[F[_],G[_]] {  
  def inj[A](sub: F[A]): G[A]  
}
```

```
object Inject {  
  implicit def refl[F[_]]: Inject[F,F] = ???  
  
  implicit def left[F[_],G[_]]:  
    Inject[F,({type λ[x]=Coproduct[F,G,x]})#λ] = ???  
  
  implicit def right[F[_],G[_],H[_]](  
    implicit I: Inject[F,G]):  
    Inject[F,({type λ[x]=Coproduct[H,G,x]})#λ] = ???  
}
```

Lifting

```
def lift[F[_],G[_],A](f: F[A])(  
  implicit I: Inject[F,G]): Free[G,A] =  
  Bind(I.inj(f), Return(_:A))
```

```
class Interacts[F[_]](implicit I: Inject[Interact,F]) {  
  def tell(msg: String): Free[F,Unit] =  
    lift(Tell(msg))  
  def ask(prompt: String): Free[F,String] =  
    lift(Ask(prompt))  
}
```


End result

```
def prg[F[_]](implicit I: Interacts[F],
              A: Auths[F]): Free[F,Unit] = {
  import I._; import A._
  for {
    uid <- ask("What's your user ID?")
    pwd <- ask("Password, please.")
    u <- login(uid, pwd)
    b <- hasPermission(u, KnowSecret)
    _ <- if (b) tell("UUDDLRLRBA") else tell("Go away!")
  } yield ()
}
```

Composite interpreter

```
sealed trait ~>[F[_],G[_]] {
  def apply[A](f: F[A]): G[A]

  def or[H[_]](f: H ~> G) =
    new ({type t[x] = Coproduct[F,H,x]})#t ~> G) {
      def apply[A](c: Coproduct[F,H,A]): G[A] =
        c.run match {
          case Left(fa) => f(fa)
          case Right(ga) => g(ga)
        }
    }
}
```

Running a program

```
val app: Free[App, Unit] = prg[App]
```

```
def runApp = app.foldMap(MyAuth or Console))
```

Storage algebra

```
sealed trait Storage[K, V, A]
```

```
case class Get[K, V](key: K)  
  extends Storage[K, V, V]
```

```
case class Put[K, V](key: K, value: V)  
  extends Storage[K, V, Unit]
```

```
case class Del[K, V](key: K)  
  extends Storage[K, V, Unit]
```

Logging algebra

```
sealed trait LogLevel
case class ErrorLevel extends LogLevel
case class WarnLevel extends LogLevel
case class InfoLevel extends LogLevel
case class DebugLevel extends LogLevel

case class Log[A](level: LogLevel, msg: String)
```

Composite type

```
type F0[A] = Coproduct[Interact, Auth, A]  
type F1[A] = Coproduct[Logging, F0, A]  
type F2[A] = Coproduct[Error, F1, A]  
type App[A] = Coproduct[Storage, F2, A]
```

```
val app: Free[App, A] = prg[App]
```

Library code

- Define your individual algebras.
- Make smart constructors to lift them into coproducts.
- Define your individual interpreters.

User code

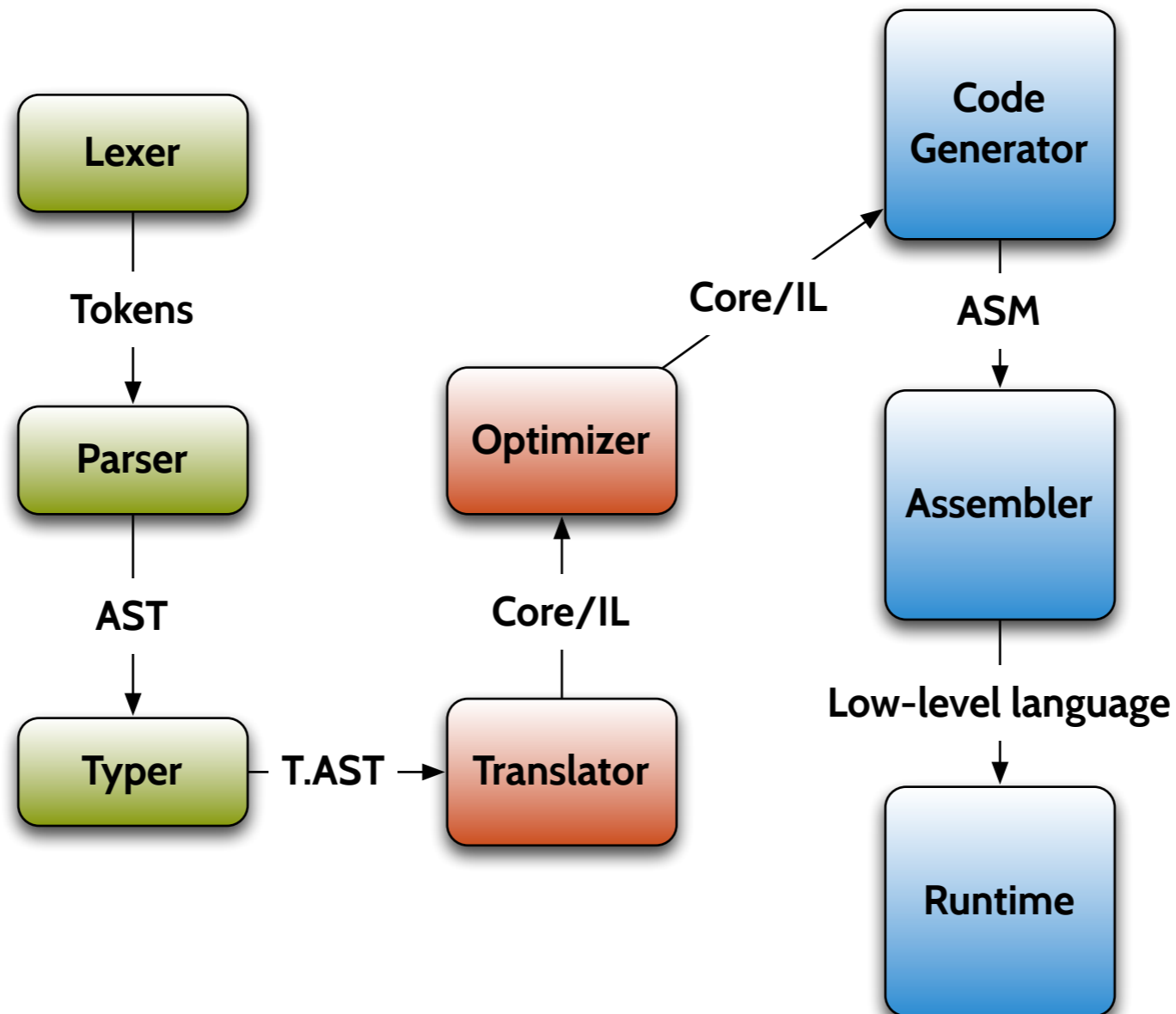
- Write your program using smart constructors.
- Compose the appropriate interpreter.
- Fold the program using the interpreter.

Stratified architecture

```
def foldMap[G[_]:Monad](f: F ~> G): G[A]
```

G could be a free monad!

Stratified architecture



Free monads

- Stack-safe
- Retry portions of the program (see `scalaz.Task`)
- Draw a diagram of the program (see github.com/puffnfresh/free-graphs)
- Step through the program, add breakpoints, etc, all programmatically.

Summary

- Write your program using exactly the language you need.
- Compose your language from smaller orthogonal languages, in a canonical way.
- Plug in interpreters that support the behavior you want.

Code from this presentation:

<http://goo.gl/qhnPk1>

scalaz.Free

<https://github.com/scalaz/scalaz>