ADVANCED

FUNCTIONAL PROGRAMMING

OUTLINE

- Organization
- Intro to FP: Recap
- Monad stacks

MEET YOUR INSTRUCTOR

- Ekaterina Verbitskaia
- Researcher @ JetBrains Research PLAN, Programming Languages and Program Analysis Lab
- Interested in:
  - Functional and Relational Programming
  - Partial Evaluation, Metacomputations
- @kajigor

ORGANIZATION

- 2 classes per week
- Written exam (50% of your mark)
- Work during the term (50% of your mark)
  - Homework assignments (40/100 points)
  - 75-minutes presentation on a research topic of your choice (40/100 points)
  - Active participation during classes (40/100 points)

WHAT YOU NEED TO START

- Install with GHCup:
  - GHC 9.6.6 – compiler
  - Stack 3.1.1 – build system
  - HLS 2.9.0.1 – language server
- VSCode
  - Haskell extension

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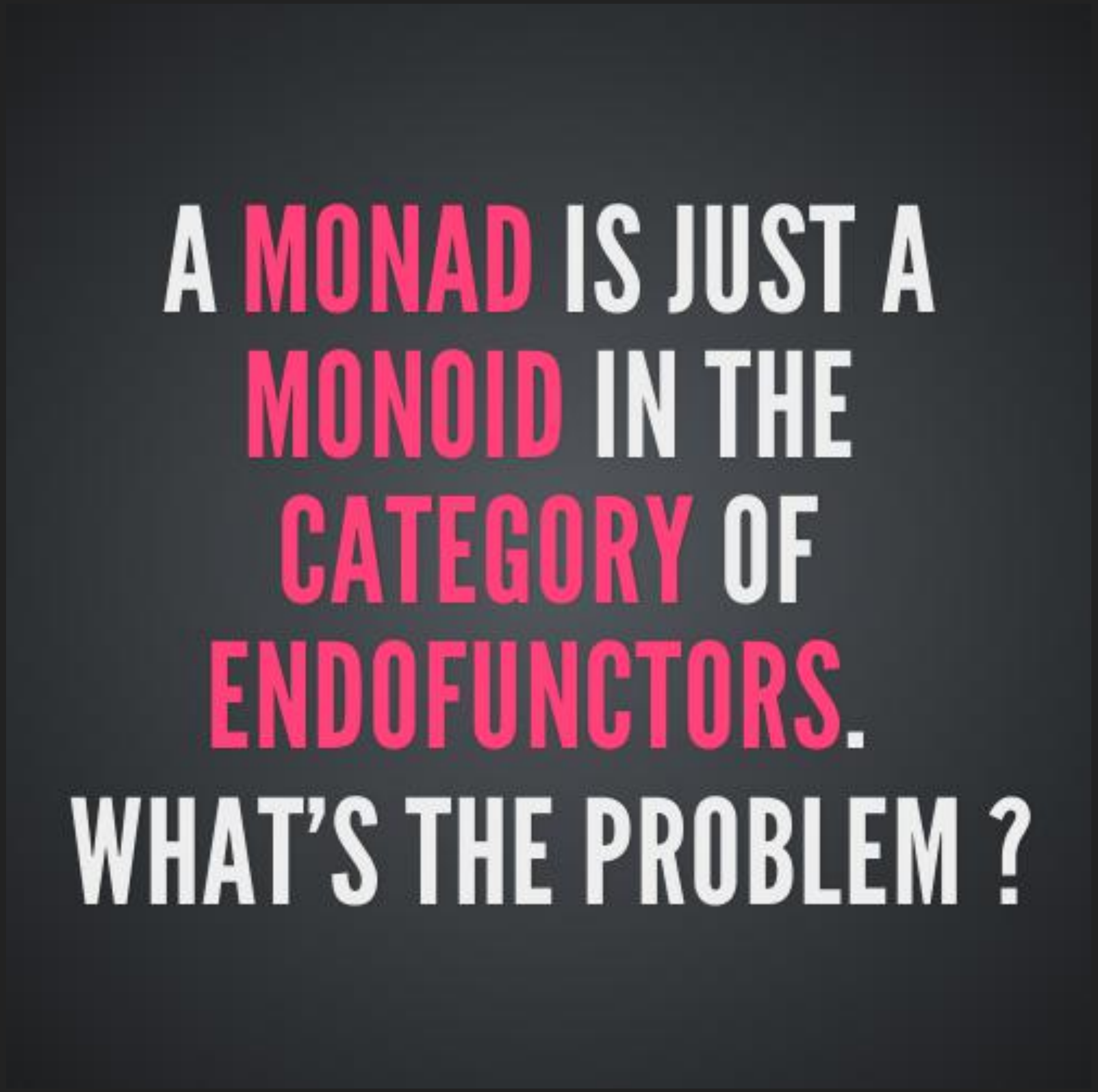
WHAT IS FUNCTIONAL PROGRAMMING?

WHAT IS A FUNCTION?

IS MAIN A PURE FUNCTION?

WHAT IS A MONAD?



A MONAD IS JUST A MONOID IN THE CATEGORY OF ENDOFUNCTORS. WHAT'S THE PROBLEM ?

WHY DO WE USE MONADS?

- To represent impure computations
  - Errors
  - Non-determinism
  - State
  - IO
- To represent sequential computation
- **To hide boilerplate behind do-notation**

ERRORS

NONDETERMINISM

ENVIRONMENTS, LOGGING, STATE

IO MONAD

- Implementation is hidden
- You can think of it as a State monad over some RealWorld representation

```
newtype IO a
  = IO { runIO :: RealWorld
                → (RealWorld, a)}
```

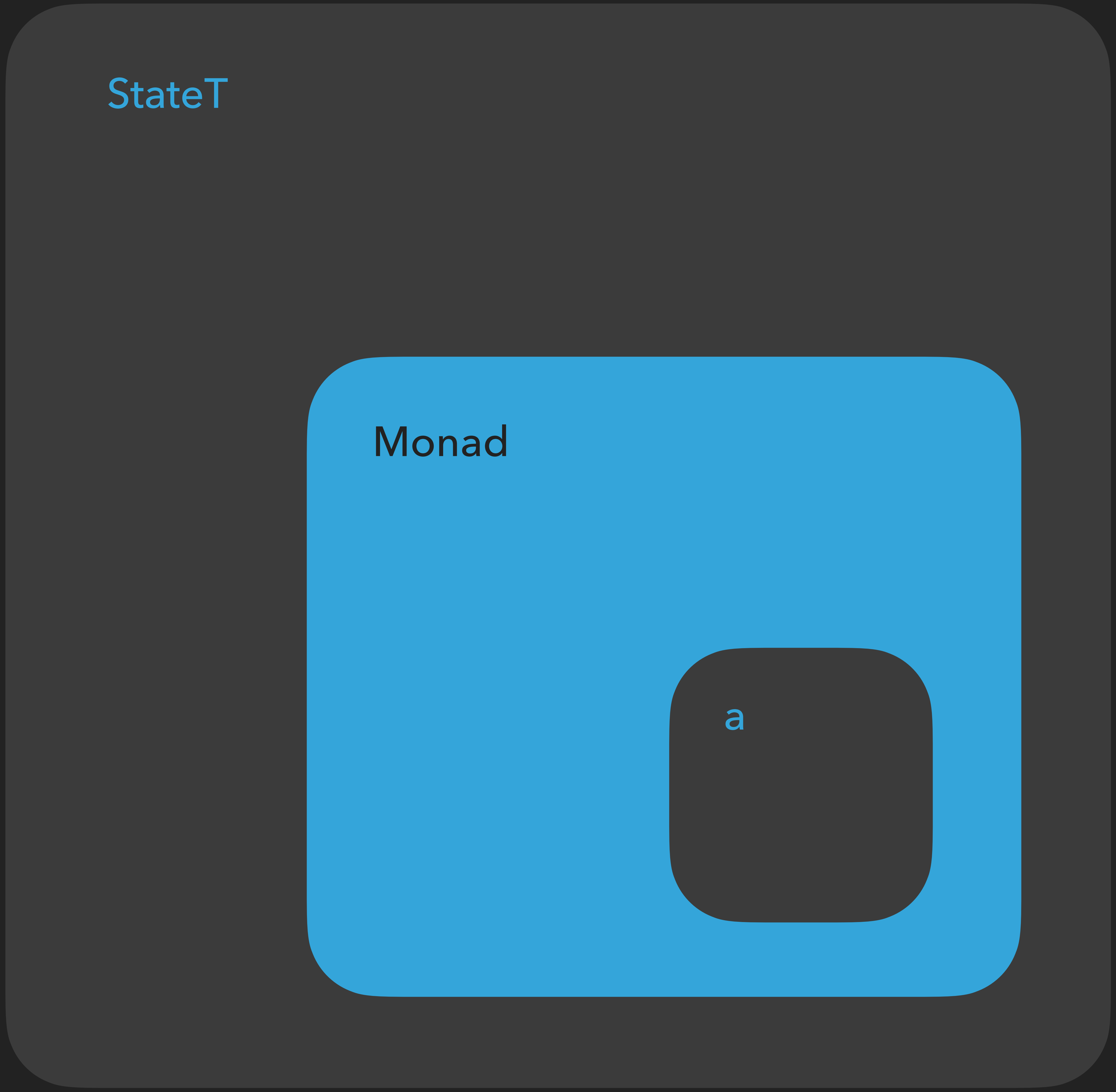
EXERCISE

- Implement an interpreter for the formulas in Reverse Polish Notation (see RPN.hs)

```
ghci> eval "1 2 +"
3
ghci> eval "1 2 *"
2
ghci> eval "1 2 -"
-1
ghci> eval "1 2 + 3 * 4 -"
5
```

HOW CAN WE COMBINE EFFECTS?

- Our `eval` function can sometimes fail, but it also needs to have access to mutable state
- Let's combine the two monads into a **stack**
- Which `>>=` do we use?



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MONAD TRANSFORMER

- Should define a monad
- Should provide a way to use the features of both monads
- Should implement `lift`
  - Don't forget about the laws

```haskell
class (forall m. Monad m ⇒ Monad (t m))
  ⇒ MonadTrans t where
  lift :: Monad m ⇒ m a → t m a

  -- lift . return = return
  -- lift (m >>= f) = lift m >>= (lift . f)
```

THE ORDER OF MONADS IN A STACK

- `StateT Maybe a`
  - `~ s → Maybe (a, s)`
  - We lose both state and the result in case of an error
- `MaybeT (State s)`
  - `~ s → (Maybe a, s)`
  - Error only in the result; state survives

```haskell
class (forall m. Monad m ⇒ Monad (t m))
  ⇒ MonadTrans t where
  lift :: Monad m ⇒ m a → t m a

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```

EXERCISE

- Implement `MyMaybeT` – monad transformer for `Maybe`
- Redefine the evaluator for RPN to use `MyMaybeT` as the outer monad

```haskell
class (forall m. Monad m ⇒ Monad (t m))
  ⇒ MonadTrans t where
  lift :: Monad m ⇒ m a → t m a

  -- lift . return = return
  -- lift (m >>= f) = lift m >>= (lift . f)

newtype MyMaybeT m a =
  MyMaybeT { runMyMaybeT :: m (Maybe a) }
```

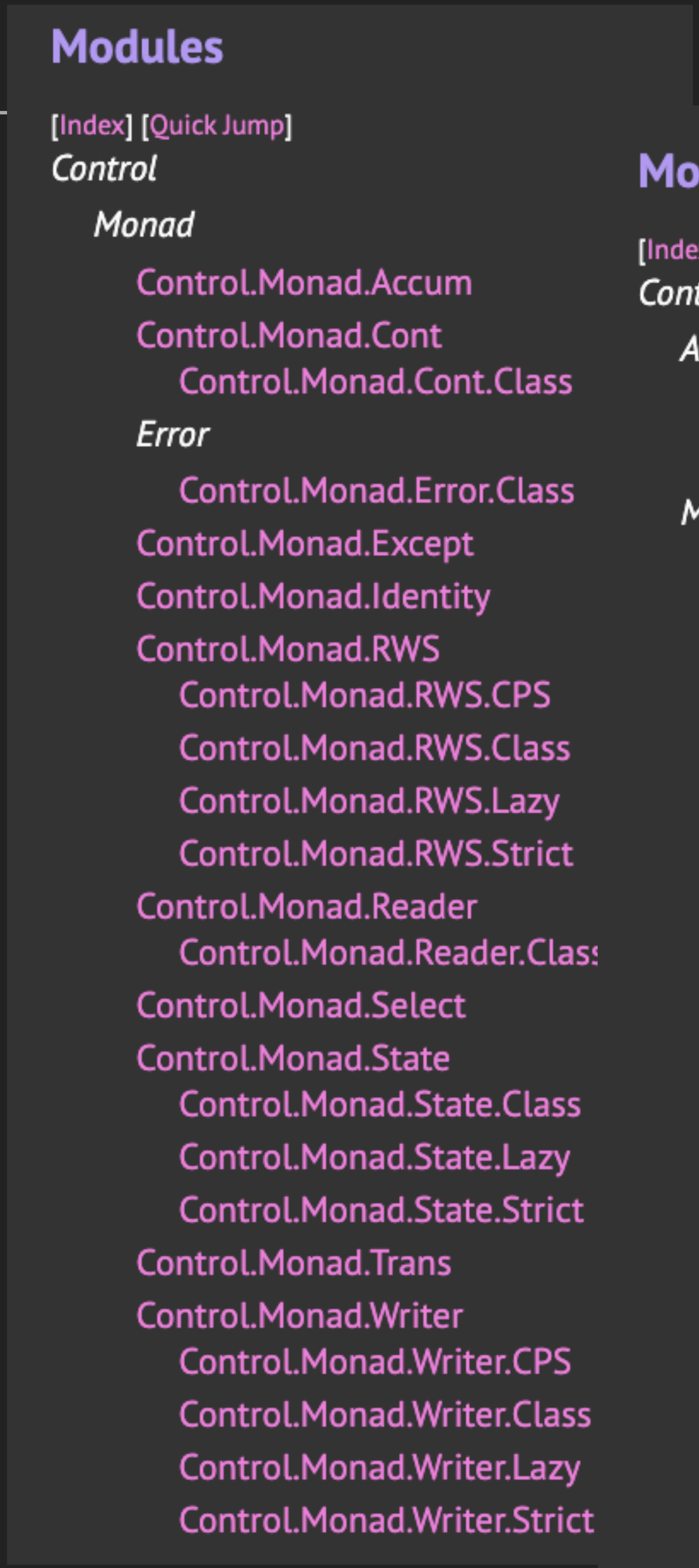
LIFTING IS EXHAUSTING

- Using `lift` means we delegate some functionality to another monad
  - `lift (lift m)`
  - `lift (lift (lift m))`
- This is fragile if we change the monad stack
- Solution: use monad-specific interfaces
  - Any `MonadState` method within a monad stack build with `MaybeT` is silently lifted

```haskell
class Monad m ⇒ MonadState s m | m → s where
  get :: m s
  get = state (\s → (s, s))

  put :: s → m ()
  put s = state (\_ → ((), s))

  state :: (s → (a, s)) → m a

instance MonadState s m ⇒
  MonadState s (MaybeT m)  where

  state = lift . state
```

COMMON TRANSFORMERS

- Packages
  - mtl
  - transformers
- `IdentityT`
- `MaybeT, ExceptT`
- `ReaderT, WriterT, StateT, RWST`
- `AccumT`
- `ContT`



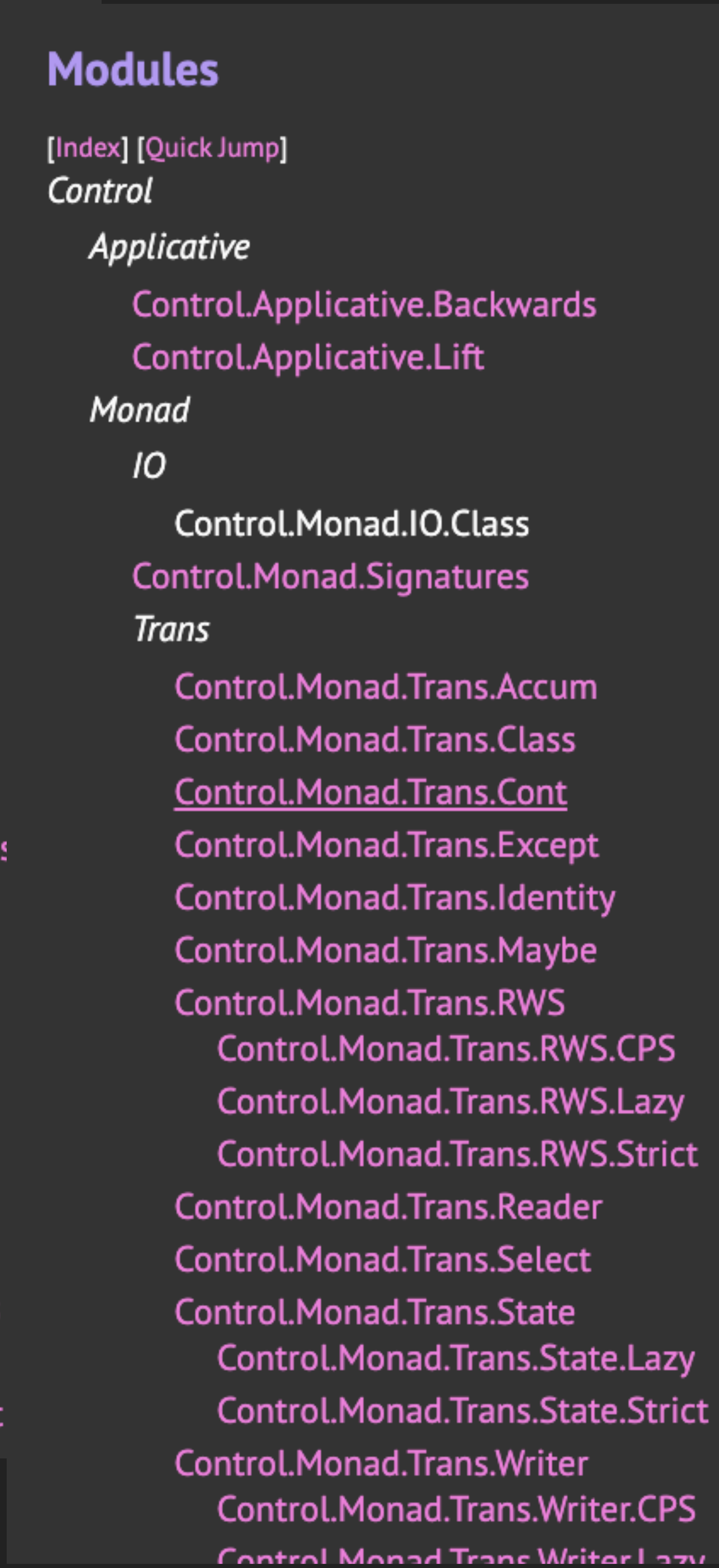
Modules

[Index] [Quick Jump]

Control

Monad

Control.Monad.Accum
Control.Monad.Cont
Control.Monad.Cont.Class
Error
Control.Monad.Error.Class
Control.Monad.Except
Control.Monad.Identity
Control.Monad.RWS
Control.Monad.RWS.CPS
Control.Monad.RWS.Class
Control.Monad.RWS.Lazy
Control.Monad.RWS.Strict
Control.Monad.Reader
Control.Monad.Reader.Clas
Control.Monad.Select
Control.Monad.State
Control.Monad.State.Class
Control.Monad.State.Lazy
Control.Monad.State.Strict
Control.Monad.Trans
Control.Monad.Writer
Control.Monad.Writer.CPS
Control.Monad.Writer.Class
Control.Monad.Writer.Lazy
Control.Monad.Writer.Strict



Modules

[Index] [Quick Jump]

Control

Applicative

Control.Applicative.Backwards
Control.Applicative.Lift
Monad
IO
Control.Monad.IO.Class
Control.Monad.Signatures
Trans
Control.Monad.Trans.Accum
Control.Monad.Trans.Class
Control.Monad.Trans.Cont
Control.Monad.Trans.Except
Control.Monad.Trans.Identity
Control.Monad.Trans.Maybe
Control.Monad.Trans.RWS
Control.Monad.Trans.RWS.CPS
Control.Monad.Trans.RWS.Lazy
Control.Monad.Trans.RWS.Strict
Control.Monad.Trans.Reader
Control.Monad.Trans.Select
Control.Monad.Trans.State
Control.Monad.Trans.State.Lazy
Control.Monad.Trans.State.Strict
Control.Monad.Trans.Writer
Control.Monad.Trans.Writer.CPS

EXCEPTT

- Did you miss exceptions?
- Now you can have them in Haskell

```haskell
newtype ExceptT e m a =
  ExceptT (m (Either e a))

throwE :: Monad m ⇒ e → ExceptT e m a

catchE ::
    Monad m
    ⇒ ExceptT e m a
    → (e → ExceptT e' m a)
    → ExceptT e' m a

handleE ::
    Monad m
    ⇒ (e → ExceptT e' m a)
    → ExceptT e m a
    → ExceptT e' m a
```

ACCUMT

- Limited version to `StateT`
    - Only uses `<>` to modify state
- Or `Writer` with the additional ability to see the result of previous `tells`
- Works faster than the default `StateT`

```haskell
newtype AccumT w m a = AccumT (w → m (a, w))

look :: m w

add :: w → m ()

accum :: (w → (a, w)) → m a
```