Sept. 20 2024

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#### **Burritos**

• Monads are like burritos

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#### **Burritos**

- Monads are like burritos
- Monads are not like burritos

- 1. Get a line
- 2. Get a line
- 3. "Return" the lines concatenated together

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• How to write this in applicative style?

- 1. Get a line
- 2. Get a line
- 3. Print the lines concatenated together

```
myAction = do

a <- getLine</li>
b <- getLine</li>
print $ a ++ b
= (++) <$> getLine <*> getLine

Actions
```

- 1. Get a line
- 2. Get a line
- 3. Print the lines concatenated together

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b <- getLine</li>
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What to do with the results
```

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• Why doesn't this work?

- (\x y -> print \$ x ++ y) <\$> getLine <\*> getLine
  - Get a line a, apply (\x y -> print \$ x ++ y) to a (to get (\y -> print \$ a ++ y)), and wrap it up in an IO box

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- myAction :: IO ()

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- myAction :: IO ()
- myAction' :: IO (IO ())

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  - We never actually ran print \$ a ++ b!
- myAction :: IO ()
- myAction' :: IO (IO ())
  - To run print \$ a ++ b, we need to take it out of the box

• Wikipedia: Throughout this article *C* denotes a category. A monad on *C* consists of an endofunctor  $T: C \to C$  together with two natural transformations:  $\eta: 1_C \to T$  (where  $1_C$  denotes the identity functor on *C*) and  $\mu: T^2 \to T$  (where  $T^2$  is the functor  $T \circ T$  from *C* to *C*).

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 μ: T<sup>2</sup> → T (where T<sup>2</sup> is the functor T ∘ T from C to C).

• Remember categories:

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- Remember categories:
  - category = objects + morphisms
    - objects = types
    - morphisms = functions

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  - endofunctor = functor that maps a category to that same category

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  - endofunctor = functor that maps a category to that same category
    - Our only category is Hask, so all functors are endofunctors

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- natural transformation = morphism of functors
  - Let us call  $\eta$  unit (or return), and  $\mu$  join

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- $\bullet$  natural transformation = morphism of functors
  - Let us call  $\eta$  unit (or return), and  $\mu$  join
    - If Haskell syntax allowed it, we could say return :: Identity -> T and join :: T<sup>2</sup> -> T

 Throughout this article C denotes a category. A monad on C consists of an endofunctor T together with two natural transformations: return :: a -> T a and join :: T (T a) -> T a.

• myAction' :: IO (IO ())

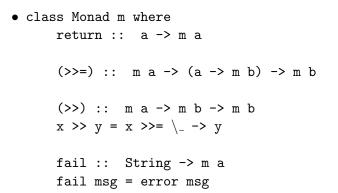
- myAction' :: IO (IO ())
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• class (Applicative m) => Monad m where return :: a -> m a

(>>=) :: m a -> (a -> m b) -> m b

(>>) :: m a -> m b -> m b x >> y = x >>=  $\setminus_{-}$  -> y

fail :: String -> m a
fail msg = error msg

• Since GHC v7.10, Applicative is a superclass of Monad

- class (Applicative m) => Monad m where return :: a -> m a (>>=) :: m a -> (a -> m b) -> m b (>>) :: m a -> m b -> m b  $x \rightarrow y = x \rightarrow z \rightarrow y$ fail :: String -> m a fail msg = error msg
  - What happened to join? What are (>>=), (>>), and fail doing here?

• (>>=) :: m a -> (a -> m b) -> m b

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- (>>=) ::  $m a \rightarrow (a \rightarrow m b) \rightarrow m b$
- (=<<) = flip (>>=)
  - (=<<) :: (a -> m b) -> m a -> m b

- (>>=) :: m a -> (a -> m b) -> m b
- (=<<) = flip (>>=)
  - (=<<) ::  $(a \rightarrow m b) \rightarrow m a \rightarrow m b$

• (<\*>) :: f (a -> b) -> f a -> f b

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  - (=<<) (and (>>=)) are maps for monadic functions

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    Functions that create their own boxes

- (>>=) :: m a -> (a -> m b) -> m b
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- (<\$>) :: (a -> b) -> f a -> f b
  - (=<<) (and (>>=)) are maps for monadic functions
    Functions that create their own context

• g >>= f = join (fmap f g) :: m a -> (a -> m b) -> m b

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• f :: a -> m b is a monadic function

• g >>= f = join (fmap f g) :: m a -> (a -> m b) -> m b

- f :: a -> m b is a monadic function
- fmap f lifts it to type m a -> m (m b)

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- f :: a -> m b is a monadic function
- fmap f lifts it to type m a -> m (m b)
- g :: m a is a value of type a in a box
- fmap f g :: m (m b) outputs a value of type b in two nested boxes

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- f :: a  $\rightarrow$  m b is a monadic function
- fmap f lifts it to type m a -> m (m b)
- g :: m a is a value of type a in a box
- fmap f g :: m (m b) outputs a value of type b in two nested boxes
- join (fmap f g) extracts a monadic value of type m b from the outermost box

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• join x = x >>= id

- class (Applicative m) => Monad m where return :: a -> m a (>>=) :: m a -> (a -> m b) -> m b (>>) :: m a -> m b -> m b  $x \rightarrow y = x \rightarrow = \langle - \rangle y$ fail :: String -> m a fail msg = error msg
  - Shorthand for when we don't need to bind the value inside x to evaluate y

• class (Applicative m) => Monad m where return :: a -> m a

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Error handler for pattern matching in do expressions

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