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Functional Programming in

(What the hell is a monad?)

Procedural Programming

- Program is made of several steps the computer is to carry out
- You tell the computer **what** to do (imperative)
- What you're probably used to
  - Python, Java, C, JavaScript, Lua

Functional Programming

- Program is made of functions that map values onto other values
- You tell the computer **what you want** (declarative)
  - Lisp, Erlang, Elixir, OCaml, F#, Scala

$$f(x) = x^2$$

Haskell is purely functional

- You have to give up lots of things you're used to
  - Mutation (x = 1; x =2;)
  - Looping (use recursion instead)
  - Side effects (IO, globals and state)
    - (not really, but it's kind of funky)

Why?

- Being used more in mainstream languages
- Often results in code that is shorter and easy to read
- Allows you to do complex operations very easy
- Clout

Diving in

```haskell
reverseList :: [a] -> [a]
reverseList [] = []
reverseList (x:xs) = reverseList xs ++ x

-- λ reverseList [4,3,2,1]
-- [1,2,3,4]
-- λ reverseList "abc"
-- "cba"
```

Types

- Haskell has a powerful type system that's clear to read
- `mult :: Int -> Int -> Int`
  - Takes two ints, returns an int
- `multBy :: Int -> (Int -> Int)`
  - Takes an int, returns a function which takes an int and returns an int

Types

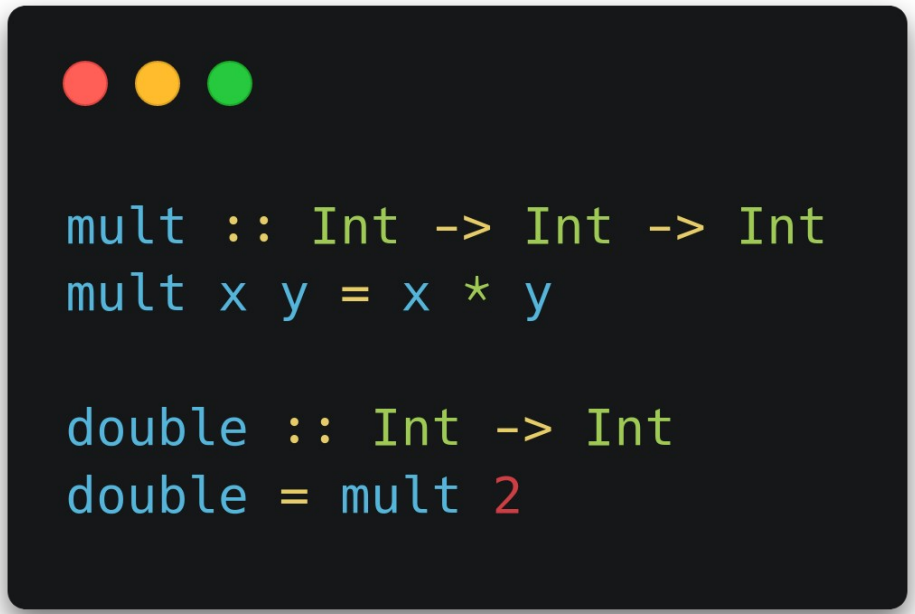
- `reverseList :: [a] -> [a]`
  - Takes a list of anything, and returns a list of anything
- `allSame :: Eq a => [a] -> Bool`
  - Takes a list of anything that is an instance of Eq, returns a boolean
  - Being an instance of Eq means two of a type can be equal (`==`) or not equal (`/=`)

Currying

- In Haskell, functions can only take on parameter
- But, functions can return functions
- Similar to idea of closures in procedural languages
- You can still use them as though they're taking multiple arguments, without having to worry about currying behind the scenes

Currying

- Allows for partial application



```
mult :: Int -> Int -> Int
mult x y = x * y

double :: Int -> Int
double = mult 2
```

Currying

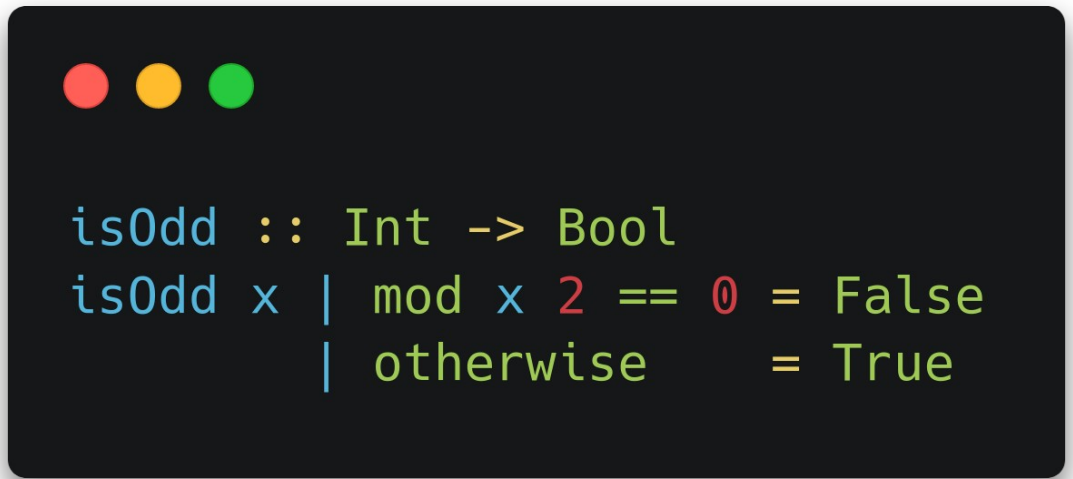
- To Haskell, parentheses in type definitions **do not matter** unless taking functions as parameters
  - `mult :: Int -> Int -> Int`
  - `multBy :: Int -> (Int -> Int)`
  - Both of these mean the exact same thing
- But they usually help a reader better understand what your function is supposed to mean

Function parameters

- Haskell offers many ways to give and accept parameters
- Regular
- Guards
- Pattern matching

Guarded parameters

- Think of splitting an if-else block into separate functions



```haskell
isOdd :: Int -> Bool
isOdd x | mod x 2 == 0 = False
        | otherwise    = True
```

Pattern matching

- Possibilities are attempted, going down
- If none match, error is thrown
  - A side effect (gross)

```
int2str :: Int -> String
int2str 0 = "Zero"
int2str 1 = "One"
int2str 2 = "Two"
int2str 3 = "Three"
int2str 4 = "Four"
```

Pattern matching, multiple arguments

- Underscore discards argument

```haskell
mult :: Int -> Int -> Int
mult 0 _ = 0
mult _ 0 = 0
mult = (*)
```

Pattern matching, lists

- (x:xs) pattern puts first element in x, rest in xs

```haskell
sum :: [Int] -> Int
sum [] = 0
sum (x:xs) = x + sum xs

length :: [a] -> Int
length [] = 0
length (_:xs) = 1 + length xs
```

Lists

- Lists and recursion are your replacement for loops
- All elements are of same type
- Lists are constructed one element at a time, with `:`
- Lists can be concatenated with `++`
- Random access with `[1,2,3,4] !! 0`

List functions


```
λ x = [1..4]
λ x
-- [1,2,3,4]

-- Get first element
λ head x
-- 1
-- Last elements
λ tail x
-- [2,3,4]

-- Take n elements
λ take 2 x
-- [1,2]
-- Drop n elements
λ drop 2 x
-- [3,4]
```

```
-- Get last element
λ last x
-- 4
-- Drop last element
λ init x
-- [1,2,3]

-- Check if list is empty
λ null x
-- False

-- Check if element in list
λ elem 3 x
-- True
-- P.S. You can use functions with two args
-- like operators by doing this:
λ 5 `elem` x
-- False
```

List comprehensions

- Generate a new list from an existing one very easily

```
λ [int2str i | i <- [1..5]]
-- ["One","Two","Three","Four","Five"]
λ [int2str i | i <- [1..10], i `mod` 2 == 0]
-- ["Two","Four","Six","Eight","Ten"]
λ [(int2str x, int2str y) | x <- [1..3], y <- [4..5]]
-- [("One","Four"),
--  ("One","Five"),
--  ("Two","Four"),
--  ("Two","Five"),
--  ("Three","Four"),
--  ("Three","Five")]
```

Advanced list functions


```
-- Map a function over a list
λ map int2str [1..4]
-- ["One","Two","Three","Four"]

-- Type of [1..4] is [Int]
-- Type of int2str is Int -> String
-- Type of output is [String]
-- Type of map is (a -> b) -> [a] -> [b]
```

```
-- Filter a list with a predicate
λ filter isOdd [1..4]
-- [1..3]
-- Type of filter is (a -> Bool) -> [a] -> [a]

-- Combine two lists into tuples
λ zip [1..3] [4..6]
-- [(1,4),(2,5),(3,6)]
```

Lambda functions

- Quick and dirty functions, ideal for map and filter

```
λ (\a -> a + 2) 1
-- 3

λ (\a b -> a + b) 3 5
-- 8

λ filter (\a -> isOdd a && a > 4) [1..10]
-- [5,7,9]
```

Function composition

- (.) operator works similarly to function composition from math

```haskell
halve :: Int -> String
halve = int2str . (\x -> div x 2)

-- Type of (.) is (b -> c) -> (a -> b) -> (a -> c)
-- so it can't work on functions with more than one arg.
-- You can take advantage of currying and do this:

myDiv :: Int -> Int -> String
myDiv = (int2str . ) . div

-- But it's probably more readable to do it the more
-- obvious way:

myDiv x y = int2str (div x y)
```

Folding

- Many recursive functions follow a common pattern:
  - Base case
  - Operation that takes next element and accumulation

- When applied to [1..4]:
  - (1 + (2 + (3 + (4 + 0))))
  - (1 + (2 + (3 + (4))))
  - (1 + (2 + (7)))
  - (1 + (9))
  - (10) → 10

```haskell
sum :: [Int] -> Int
-- foldr takes a function, and a base case
sum = foldr (\x acc -> x + acc) 0
```

foldl1

- Order of ops reversed (folds left)
- 1 variant uses first element as base case

```
subList :: [Int] -> Int
subList = foldl1 (\acc x -> acc - x)

λ subList [10,7,2]
-- 1
```

Defining your data

- Structuring your own data is easy, and there are several tools for you
  - Types
  - Data
  - Typeclasses and Newtypes

Types

- Just an alias for an existing type, good for readability

```haskell
type Pair a = (a, a)
type Pos = Pair Int

-- Haskell will consider all of these to be
-- the same type
-- (5, 5)
-- (4, 3) :: Pair Int
-- (-1, 2) :: Pos
```

Data

- Similar to a struct in C, with some new tricks

```
data Person = PersonPhone String String Int | PersonEmail String String String
    deriving Show
-- deriving Show automatically makes it an instance of the Show typeclass, so it can
-- be printed to the console

λ PersonPhone "John" "Doe" 1234567890
-- PersonPhone "John" "Doe" 1234567890
-- It works, but you have to remember what goes where,
-- and to use it in functions you have to do this:
-- f (PersonPhone fstName lstName phone) = ...

data BetterPerson = BPersonPhone { bppFirstName :: String
                                 , bppLastName  :: String
                                 , bppPhone     :: Int }
                  | BPersonEmail { bpeFirstName :: String
                                 , bpeLastName  :: String
                                 , bpeEmail     :: String }
    deriving Show

-- Now you can do this
λ jdoe = BPersonEmail { bpeFirstName = "John", bpeLastName = "Doe", bpeEmail = "jdoe@gmail.com"}
λ bpeFirstName jdoe
-- "John"
```

Recursive data


```haskell
data NaturalNumber = Zero | Succ NaturalNumber
    deriving Show

nat2int :: NaturalNumber -> Int
nat2int Zero = 0
nat2int (Succ n) = 1 + nat2int (n-1)

int2nat :: Int -> NaturalNumber
int2nat 0 = Zero
int2nat n = Succ (int2nat (n-1))

λ int2nat 3
-- Succ (Succ (Succ Zero))
λ nat2int (Succ (Succ Zero))
-- 2
```

Typeclasses

- Defines a set of functions for a given type

```haskell
class Eq a where
    (==) :: a -> a -> Bool
    (/=) :: a -> a -> Bool
    x == y = not (x /= y)
    x /= y = not (x == y)

instance Eq NaturalNumber where
    Zero == Zero = True
    Zero == _ = False
    _ == Zero = False
    (Succ n1) == (Succ n2) = nat2int n1 == nat2int n2
```

Newtypes

- Similar to data, but only allows for one constructor and field
- Used to wipe typeclass definitions for an existing type
- Also comes with some performance benefits

```haskell
newtype MyList a = MyList { getList :: [a] }

-- Can't use !!, :, or ++ with MyLists
-- We're free to define them ourselves now
```

The hard stuff

- Functors 😀
- Applicatives 😐

The hard stuff

- Monads

The Maybe type

- Easy way to model a computation that may fail

```haskell
data Maybe a = Just a | Nothing
    deriving (Eq, Ord)

safeDiv :: Int -> Int -> Maybe Int
safeDiv _ 0 = Nothing
safeDiv x y = Just (x `div` y)
```

Maybe as a functor

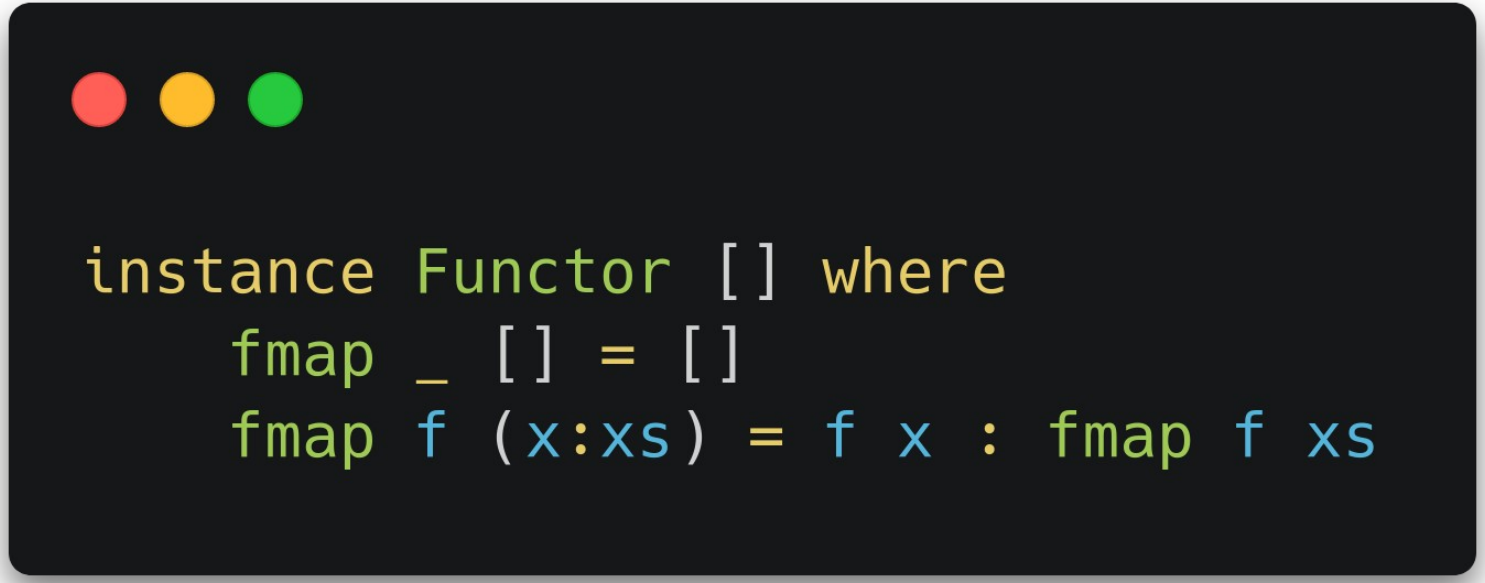
- With a functor, we can map a function onto its inner value(s)

```
instance Functor Maybe where
    fmap f (Just x) = Just (f x)
    fmap f Nothing = Nothing

λ fmap (+2) (safediv 9 3)
-- Just 5
λ fmap (+2) (safediv 9 0)
-- Nothing
```

Lists as a functor

- map is fmap for lists



```haskell
instance Functor [] where
    fmap _ [] = []
    fmap f (x:xs) = f x : fmap f xs
```

Applicatives

- Functors are cool, but they only work on functions with one argument
- Applicatives solve this problem
- They allow you to wrap a function within a type (pure), and then feed it parameters

Maybe as an applicative


```
instance Applicative Maybe where
    pure = Just
    Nothing <*> _ = Nothing
    (Just f) <*> something = fmap f something

λ pure (+) <*> Just 2 <*> Just 3
-- Just 5

-- A little bit of sugar
λ (*) <$> Just 3 <*> Just 4
-- Just 12
λ (\a b c -> a * b + c) <$> Just 10 <*> Just 5 <*> Just 25
-- Just 75

λ (+) <$> Nothing <*> Just 4
-- Nothing
λ (*) <$> Just 3 <*> Nothing
-- Nothing
```

Modeling a chain of computation

- We have a process that could fail at any step
- Let's use Maybe
- Each step needs to be able to pass on failure (Nothing) from the step before

Modeling a chain of computation

- Could do it all in one function like this, but I'd rather not

```
divFour :: Int -> Int -> Int -> Int -> Maybe Int
divFour a b c d = if a == 0
                  then Nothing
                  else
                    if b == 0
                    then Nothing
                    else
                      if c == 0
                      then Nothing
                      else
                        if d == 0
                        then Nothing
                        else Just (div (div (div a b) c) d)
```

Modeling a chain of computation

- Can we use functors?
  - No, because that only applies the function to the inner value. If the function fails, we'd still get an exception, or at best, `Just Nothing`
- What about applicatives?
  - No, because we have to start with a function and feed values into it. We can't chain the output of one function to the output of another

Modeling a chain of computation

- We need to be able to:
  - Chain together as many functions as we want
  - Be able to propate failure to the end of the chain, from anywhere in the chain
    - Each function needs to be able to return Nothing
    - But we also want our functions to be as generic as possible, so their parameters shouldn't be wrapped in Maybe
    - Their types should be `a -> Just a`
    - But now, how do we pass output (Just a) to the next function (which expects an a)?

Modeling a chain of computation

- Let's make an intermediary function to handle it

```haskell
bind :: Maybe a -> (a -> Maybe a) -> Maybe a
bind Nothing _ = Nothing
bind (Just x) f = f x

safeDiv :: Int -> Int -> Maybe Int
safeDiv _ 0 = Nothing
safeDiv x y = Just (x `div` y)

divBy :: Int -> Int -> Maybe Int
divBy x y = safeDiv y x

λ safeDiv 24 2 `bind` divBy 2 `bind` divBy 3
-- Just 2
λ safeDiv 24 0 `bind` divBy 2 `bind` divBy 3
-- Nothing
λ safeDiv 24 2 `bind` divBy 0 `bind` divBy 3
-- Nothing
λ safeDiv 24 2 `bind` divBy 2 `bind` divBy 0
-- Nothing
```

Monads

- This is really handy, someone should name this!
- `monad`
- Oh
- But hey, that wasn't so bad, was it?

Monads

- In practice, `bind` is replaced with >>=
- And there are many different monads, Maybe is just one of them
- But they all follow a similar idea, of being able to pass failure, or really any context, down a pipeline

Doin' stuff

- Haskell functions are pure, they have no side effects
- … but every way we could interact with a program is a side effect
- So is Haskell actually pure?

Doin' stuff

- *Every* Haskell function *is* pure
- So to get around it, we can make a type called IO, which is a side effect
- Functions can now return side effects, **but the function itself is not what causes a side effect to happen**

Doin' stuff

- To execute a side effect, set `main` equal to it

```
main = putStrLn "Hello, World!"

λ :type main
-- IO ()

-- IO types can also wrap a value
λ :type getLine
-- IO String

main = getLine >>= (\s -> putStrLn ("Hello, " ++ s))
```

Doin' stuff

- The flow of your program can be represented purely, so you're not really breaking any "purely functional" rules
- Haskell just executes the IO action you've given it, and uses the rules you've defined in your functions

Doin' lots of stuff

- You'll probably want to do more than one or two things in your main action
- This sucks

```
main = putStrLn "First name?" >>
    getLine >>= (\firstName ->
    putStrLn "Last name?" >>
    getLine >>= (\lastName ->
    putStrLn "Email?" >>
    getLine >>= (\email ->
    putStrLn (lastName ++ ", " ++ firstName ++ " (" ++ email ++ ")"))))
```

(do)in' stuff

- Haskell offers some more sugar
- This translates straight to what was seen earlier, just easier to read
- In fact, do syntax works on any monad, not just IO

```haskell
contactStr :: String -> String -> String -> String
contactStr f l e = l ++ ", " ++ f ++ " (" ++ e ++ ")"

main = do
    putStrLn "First name?"
    -- bind result of IO to a variable
    firstName <- getLine
    putStrLn "Last name?"
    lastName <- getLine
    putStrLn "Email?"
    email <- getLine
    let result = contactStr firstName lastName email
    -- could also do:
    -- result <- return (contactStr firstName lastName email)
    -- which wraps the String from contactStr in IO
    -- but there's no point to it since we're binding it right after
    putStrLn result
```

Laziness

- Since mutability is not supported, a function will always return the same output for the same input
  - Don't worry about IO for now
- Because of this, an expression will always evaluate the same
  - Also makes parallelization/concurrency very easy
- Haskell is lazy: it doesn't evaluate an expression until it absolutely needs to

Laziness


```
hardMathProblem :: Int
hardMathProblem = (code to actually calculate it)

λ let x = hardMathProblem
-- Interpreter sets x equal to hardMathProblem. No calculation
-- is actually performed because Haskell doesn't have to show
-- you the result yet.
λ x
-- Now, Haskell needs to figure out what x really is. This is
-- where computation starts, and where the interpreter would pause.
λ 3.14159.......
```

Laziness

- This has performance benefits (sometimes), since unnecessary computation isn't performed
  - Also makes debugging harder :(
- But it also allows for one very cool trick that is impossible (or at least much less natural) in a non-lazy language

Laziness: Infinite data


```
λ x = [1..]
-- x is now the list of all integers, starting at 1
λ take 5 x
-- [1,2,3,4,5]

-- Of course, this doesn't work, but Haskell will still try
-- sum :: [Int] -> Int
λ sum x

-- You can also make your own infinite data structures.
-- This hurts my head, but Haskell doesn't blink.
primes = filterPrime[2..]
    where filterPrime (p:xs) =
        p : filterPrime [x | x <- xs, x `mod` p /= 0]

λ take 5 primes
-- [2,3,5,7,11]
```

Laziness and IO


```
-- Let's say you have a config file on your drive, and you have a function
-- to open and parse it into a type Config:
let conf = parseConfigFile "config.json"
-- conf's type is IO Config
-- Now let's say you try to use it, but since typing the above line, you've
-- deleted the config file.
λ conf
-- Error! File not found
-- Haskell didn't try to open the file until it really needed to

-- However, by instead binding the result of parseConfigFile:
conf <- parseConfigFile "config.json"
-- IO Config is unwrapped into just Config, and Haskell is forced to get its
-- true value even if you don't necessarily need it yet.
```

The Haskell Ecosystem

- Glasgow Haskell Compiler (GHC)
  - The GCC of Haskell
  - Can also interpret, run a REPL
- Hackage: Package index
- Stack: Build system, package manager
- Cabal: Older build system
  - Still updated, but falling out of favor for Stack
- Haddock: Documentation generator
  - Like JavaDoc, Doxygen

Further resources

- Learn You a Haskell For Great Good!
  - Miran Lipovaca
  - Available for free online
- Programming in Haskell
  - Graham Hutton (of Computerphile fame)
- Real World Haskell
  - O'Reilly
- Tsoding on YouTube

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