Functional Programming for Logicians - Lecture 4

IO, Randomness, Trees, Practical Stuff

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```haskell
module L4 where

import Data.Char
import System.Random
```

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Questions about yesterday?

Recall that:

- A `Functor` is something that we can `fmap` over.
- An `Applicative` is a `Functor` plus `pure` and `<*>` called *sequence*.
- A `Monad` is an `Applicative` plus `>>=` called *bind*.

Examples: `Maybe`, `[]` and `IO` are monads!

Another `Monad` function we saw:

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

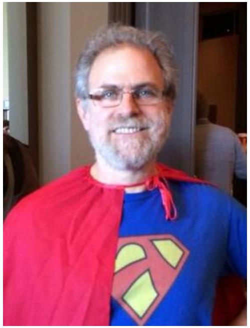
History of the IO Monad

Since 1992 the most famous Monad is `IO`.

https://youtu.be/re96UgMk6GQ?t=31m20s

(watch this from 31:20 until 38:22)

Invention vs. Discovery



"Most of you use languages that were invented, and you can tell, can't you. This is my invitation to you to use programming languages that are discovered."

Philip Wadler: Propositions as Types

Real World Haskell *

Here are some useful standard IO functions:

```
λ> :t readFile
readFile :: FilePath -> IO String
λ> :t writeFile
writeFile :: FilePath -> String -> IO ()
λ> :t getLine
getLine :: IO String
λ> :t putStr
putStr :: String -> IO ()
λ> :t putStrLn
putStrLn :: String -> IO ()
```

(* This is also the title of the Haskell book by Bryan O'Sullivan, Don Stewart, and John Goerzen. See http://book.realworldhaskell.org/.)

Hello World 2.1

```haskell
dialogue :: IO ()
dialogue = do
  putStrLn "Hello! Who are you?"
  name <- getLine
  putStrLn $ "Nice to meet you, " ++ name ++ "!"
  let capName = map toUpper name
  putStrLn $ "Or should I say " ++ capName ++ "?"
```

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```

Note that it is not* possible to "get out ouf `IO`" again. You should not try to write functions like `f :: IO String -> String`.

(* It is, but `unsafePerformIO` is called like that for a reasons.)

sequence

The simplest thing one can do with a set of actions is put them in sequence. The command for this collects a list of monadic actions into a monadic list of actions. Read the last sentence again.

In *do* notation:

```
sequence :: Monad m => [m a] -> m [a]
sequence []     = return []
sequence (x:xs) = do v <- x
                     vs <- sequence xs
                     return (v:vs)
```

sequence with IO

```
λ> :t replicate
replicate :: Int -> a -> [a]
λ> sequence (replicate 3 getLine)
bob
alice
carol
["bob","alice","carol"]
```

sequence with IO

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```

Since GHC 7.10 the `sequence` function was generalised from lists to a whole type class of `Traversable` structures. So its real type is this:

```
λ> :t sequence
sequence :: (Monad m, Traversable t) => t (m a) -> m (t a)
```

Primitives

If you are curious about what GHC actually does internally, read this blog post:

https://www.fpcomplete.com/blog/2015/02/primitive-haskell

Randomness

Random Integers

Getting a random integer involves interaction with the outside world, because some aspect of the world (be it known or unknown to us) determines the output. (In UNIX this is usually `/dev/random` or `/dev/urandom`.)

```haskell
getRandomInt :: Int -> IO Int
getRandomInt n = getStdRandom (randomR (0,n))
```

This gives:

```
λ> getRandomInt 20
16
λ> getRandomInt 20
18
```

Random Integer Lists

The following generates an integer list with entries in the range `[0..k]` and lengths in the range `[0..n]`:

```
getInts :: Int -> Int -> IO [Int]
getInts _ 0 = return []
getInts k n = do
  x <-  getRandomInt k
  xs <- getInts k (n-1)
  return (x:xs)
```

Again, we can also write this without `do`:

```
getInts' :: Int -> Int -> IO [Int]
getInts' _ 0 = return []
getInts' k n = getRandomInt k  >>= \ x  ->
               getInts k (n-1) >>= \ xs -> return (x:xs)
```

Finally, we can also choose the parameters randomly:

```
genIntList :: IO [Int]
genIntList = do
  k <- getRandomInt 20
  n <- getRandomInt 10
  getInts k n
```

This gives, e.g.:

```
λ> genIntList
[0,0,0,0]
λ> genIntList
[-1,-5,-3,-2,-1,6,2,-8]
λ> genIntList
[15,-10,7,-15,5,-13,15,11,13,-11]
```

Trees

Example: trees

Binary-branching trees with things of type a at the leafs:

```
data Tree a = Leaf a | Branch (Tree a) (Tree a)
     deriving (Eq,Ord,Show)
```

instance Functor Tree

First, trees can be viewed as functors. Let's put this in a declaration, and define `fmap` for trees.

```
instance Functor Tree where
-- fmap :: (a -> b) -> Tree a -> Tree b
   fmap f (Leaf x)            = Leaf (f x)
   fmap f (Branch left right) = Branch (fmap f left)
                                       (fmap f right)
```

Try this out, do an example in ghci.

Note that `fmap` can never change the shape of the tree! How does this compare to what `fmap` does in the `Maybe` monad?

instance Applicative Tree

```haskell
instance Applicative Tree where
-- pure ::   a -> Tree a
   pure = Leaf
-- (<*>) :: Tree (a -> b) -> Tree a -> Tree b
   (<*>) ftree (Leaf x)        = fmap ($ x) ftree
   (<*>) ftree (Branch xl xr) = Branch (ftree <*> xl)
                                        (ftree <*> xr)
```

Think about what this does, try out an example!

An alternative instance would use the following sequence function, recursing first on the of functions and then making full copies of the `Tree a`:

```haskell
star :: Tree (a -> b) -> Tree a -> Tree b
star (Leaf f)        atree = fmap f atree
star (Branch fl fr) atree = Branch (fl `star` atree)
                                   (fr `star` atree)
```

⇒ Exercise: Check whether both ways to implement `instance Applicative Tree` fulfil the laws for `Functor` and `Applicative` mentioned in the previous lecture.

instance Monad Tree

Wrapping up an arbitrary thing in a tree is done by means of `Leaf`.

Binding a leaf `Leaf x` to a function `f :: a -> Tree b` is just a matter of applying `f` to `x`.

Binding a tree `Branch left right` to `f` is just a matter of recursing over the branches. This gives the following instance declaration of trees as monads:

```
instance Monad Tree where
-- return :: a -> Tree a
   return = Leaf
-- (>>=) :: Tree a -> (a -> Tree b) -> Tree b
   (>>=) (Leaf x)            f = f x
   (>>=) (Branch left right) f = Branch (left >>= f) (right >>= f)
```

Other Trees

If you also want things of type `a` at the intermediate nodes and allow arbitrary number of branches, this type works:

```
data ArbTree a = Node a [ArbTree a]
```

Note that we no longer need an extra `Leaf` case. Leafs are just `Node`s where the `[ArbTree a]` list of children is empty.

⇒ Exercise: Can you also make `ArbTree` a `Functor` etc.?

More Practical Stuff

stack and cabal

For projects with more than one `.hs` or `.lhs` file you should have a `stack.yaml` file in the same folder and a `.cabal` package description.

A minimal `stack.yaml:` is this:

```
resolver: lts-11.11
```

This will also make sure that your code still works next year. 🤞

And a minimal `.cabal` file:

```
name:            lectures
version:         0.0.0
build-type:      Simple
cabal-version:   >= 1.10

library
  default-language: Haskell2010
  exposed-modules:  L1, L2, L3, L4, E1, E2, E3
  ghc-options:      -Wall
  build-depends:    base >=4.9 && <5
                  , QuickCheck
                  , random
                  , tf-random
```

Report Example

You can use https://github.com/funcspec/report-example as a template for your project, or create a new package with lots of boilerplate by running `stack new`.

git

If you want to work in pairs, it makes sense to use the version control system `git` to collaborate. It takes half an hour to learn, but then you will never have a "Dropbox problem" overwriting each others work.

For a tutorial, click here, for a cheat sheet, click here.

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Git Hosting

The most widely used hosted services for *git* are *github* and *gitlab*.

You may submit your report via email, but using git and a service like `github` or `gitlab` is strongly preferred if you want to get help or comments on your code from us during the next week.

If you are having problems setting up a (private) repository, please email us your username and we will create a repository for you at https://github.com/funcspec or https://gitlab.com/funcproglog.

🥗 🍝

See you again at 14:00 in F1.15.