Functional Programming
Lecture 10

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Mutating the world

I/O operations are fundamentally mutating:

```
> putStrLn "Hello World"    | stdout: Hello World

> putStrLn "Hello World"    | stdout: Hello World
                                      Hello World
```

Unless the whole world is an argument to our functions:

```haskell
putStrLn :: String -> World -> World
getLine :: World -> (String, World)
```

Mutating the world

```
putStrLn :: String -> World -> World
getLine :: World -> (String, World)
```

With the definitions above we can write pure I/O functions:

```
helloworld :: World -> World
helloworld w1 = w4 where
  w2         = putStrLn "What is your name?" w1
  (name, w3) = getLine w2
  w4         = putStrLn ("Hello " ++ name) w3
```

Mutating the world

In practice we don't mutate the world, but we use monads.

```
helloworld :: IO ()
helloworld = do
  putStrLn "What is your name?"
  name <- getLine
  putStrLn ("Hello " ++ name)
```

Monads extend far beyond I/O and mutation. Common examples are: `Maybe`, list `[]`, `State`.

IO actions

IO actions

Haskell separates the part of the program with side effects using values of special types

`IO` is a functor satisfying further properties (monad) such that

a value of type `IO a` is an action, which when executed produces a value of type `a`

```
type IO a = World -> (a, World)
```

```
putStrLn :: String -> IO ()
getLine :: IO String
```

The IO actions can be composed to build up more complex actions.

Hello World

Haskell executes only one IO action in a program, the action returned by the function `main`.

```haskell
main :: IO ()
main = putStrLn "Hello, World!"
```

```
$ ghc <filename.hs>; ./<filename>
$ runghc <filename.hs>
```

IO actions (not only the one returned by `main`) can be also executed in GHCi by evaluating them.

Hello World

We can try to rewrite `helloworld` in terms of `IO`:

```
helloworld :: IO ()
helloworld =
  let ac_name = getLine  -- IO String
  -- This fails! We cannot ++ with an action!
  in putStrLn ("Hello " ++ ac_name)
```

What we need is:

```
??? :: IO String -> (String -> IO ()) -> IO ()
```

Sequencing computations

Last time we saw how to compose failing computations by

```haskell
andThen :: Maybe a -> (a -> Maybe b) -> Maybe b
```

$$a \xrightarrow{h} \text{Maybe } b$$

$$d \xrightarrow{g} \boxed{\text{Maybe } a} \xrightarrow{\text{andThen}} \boxed{\text{Maybe } b}$$

`andThen` is in fact the bind operator `>>=` making the functor `Maybe` into a monad.

Monads

Monads

`Maybe, IO, []` are instances of a type class called monad:

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

`>>=` pulls out the result stored in `m a` and pass it to another computation represented by a function of type `a -> m b`.

`>>` composes two computations and the second one ignores the result of the first one.

`return` allows to embed "pure" values into the computational context.

Monads are functors

`>>` can be implemented in terms of `>>=` as follows:

```
x >> f = x >>= \_ -> f
```

Every monad is a functor since

```
fmap f x = x >>= return . f
```

Note that

```
x :: m a
f :: a -> b
return :: b -> m b
return . f :: a -> m b
```

IO Monad

```haskell
(>>) :: IO a -> IO b -> IO b
```

composes two IO actions (the first action is performed only for its side-effect), e.g.

```haskell
putStrLn "Hello" >> putStrLn "World"
```

```haskell
(>>=) :: IO a -> (a -> IO b) -> IO b
```

`x >>= f` is the action performing first `x`, passing its result to `f` that returns a second action to be performed, e.g.

```haskell
getLine >>= putStrLn
```

Hello World again

`helloworld` in terms of `>>=`:

```
helloworld :: IO ()
helloworld =
  putStrLn "What is your name?" >>
  getLine >>=
  \name -> putStrLn ("Hello " ++ name)
```

return

```
return :: a -> IO a
```

creates an IO action that does nothing except produces the given value.

Useful when we need to combine results of previous actions by a pure function:

```
getSquare :: IO Int
getSquare = putStrLn "Enter number:"
            >> getLine
            >>= \line -> let n = read line
                         in return (n*n)
```

Maybe monad

```haskell
(>>=) :: Maybe a -> (a -> Maybe b) -> Maybe b

x >>= f = case x of
            Nothing -> Nothing
            Just y -> f y
return x = Just x

safeSecond :: [a] -> Maybe a
safeSecond xs = safeTail xs >>= safeHead

sumFirstTwo :: Num a => [a] -> Maybe a
sumFirstTwo xs = safeHead xs
                 >>= \first -> safeSecond xs
                 >>= \second ->
                     return (first + second)
```

Separation of IO side-effects

We can access the value stored in `Maybe` monad via the data constructor `Just`.

```haskell
getMaybe :: Maybe Int -> Int
getMaybe (Just x) = x
getMaybe _ = 0
```

However, we cannot do the same for `IO`. There is no accessible data constructor allowing to do pattern matching on values of type `IO a`. Thus there is no function of type

```haskell
unsafe :: IO a -> a
```

Consequently, all the values obtained as results of impure actions with side-effects have to be closed inside `IO`.

We can manipulate them only via `>>=`.

Do notation

`do` is a syntax block, such as `where` and `let`

- action on a separate line gets executed
- `v <- x` runs action `x` and binds the result to `v`
- `let a = b` defines `a` to be the same as `b` until the end of the block (no `in` is used)

```haskell
getSquare2 :: IO Int
getSquare2 = do putStrLn "Enter number:"
                line <- getLine
                let n = read line
                return (n*n)
```

List monad

```
(>>=) :: [a] -> (a -> [b]) -> [b]

xs >>= f = concat $ map f xs
return x = [x]

> [1,2,3] >>= \x -> [x,10*x,100*x]
[1,10,100,2,20,200,3,30,300]
```

Monadic sequencing

Suppose we have a list of monadic actions and we want to evaluate all of them.

```
sequence :: Monad m => [m a] -> m [a]

sequence_ :: Monad m => [m a] -> m ()

ioActions :: [IO ()]
ioActions = [ print "Hello!"
            , putStrLn "just kidding",
            , getLine >> print]

> sequence_ ioActions
```

Monadic maps

Monadic analogs of `map`

```
mapM :: Monad m => (a -> m b) -> [a] -> m [b]

mapM_ :: Monad m => (a -> m b) -> [a] -> m ()
```

```
> mapM putStrLn ["a","b","c"]
a
b
c
[(),(),()]
```

Homework assignment 4 — Parser of λ-programs

Aim: To practice monadic parsing in Haskell, together with HW3 build a complete λ-calculus interpreter

```
0 := (\s.(\z.z))
S := (\w.(\y.(\x.(y ((w y) x)))))
1 := (S 0)
2 := (S 1)
((2 S) 1)
```

Points: 13

Deadline: June 8

Penalty: after deadline -1 points every day (at most -12)

Description: all details can be found in CW

Summary

- Results of IO actions are enclosed in `IO` monad.
- We can manipulate them only via monadic operators.
- Monads are special functors allowing to sequence monadic actions/computations via the bind operator `>>=`.
- Other monads are e.g. `Maybe`, `[]`.
- Action sequencing can be also done in do-blocks.
- There are monadic variants of `map`: `mapM`, `mapM\_`.
- A list of actions can composed by `sequence` or `sequence\_`.

Functors as computational context

Functors as computational context

Functor is a type constructor `f` having an implementation of

```
fmap :: (a -> b) -> f a -> f b
```

It can be also viewed as computational context. `f a` stores the result of a computation.

- `Maybe a` — result of a possibly failing computation
- `[a]` — all possible results of a non-deterministic computation
- `IO a` — result of a computation having an IO side-effect

`IO` functor allows haskell programs to execute computations having IO side-effects. It has to satisfy futher properties than being a functor. It must be a monad.

Computational contexts

Suppose we have a computation `g :: d -> f a` whose result is stored in `f a`. Then we can transform its result by any "pure" function `h`.

$$
\begin{tikzcd}
 & a \arrow[r, "h"] & b \\
d \arrow[r, "g"] & \boxed{f\,a} \arrow[r, "\mathrm{fmap}\ h"] & \boxed{f\,b}
\end{tikzcd}
$$

Computational contexts

Suppose `h :: a -> f b` is not "pure" and we want to chain both computations `g` followed by `h`. Now `fmap` alone does not suffice.

$$
\begin{tikzcd}
a \arrow[r, "h"] & f\ b
\end{tikzcd}
$$

$$
\begin{tikzcd}
d \arrow[r, "g"] & \boxed{f\ a} \arrow[r, "fmap\ h"] & \boxed{f\ (f\ b)}
\end{tikzcd}
$$

We don't want results of type `Maybe (Maybe a)` or `IO (IO a)`.