

Introducing The Monads

Aditya Siram

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- A monad primer (explain the common interface to all monads)
- A tour of the important monads and how to use them to get stuff done.
- Uses a cookbook approach so no theory or implementation details.
- Show that Haskell can be eminently practical and readable.

Brief IO Example

- This small function writes a text file, reads it back, uppercases its contents and prints them to stdout.

```
import Data.Char
main :: IO ()
main = do
    writeFile "test.txt" "a,b,c,d,e"
    x <- readFile "test.txt"
    y <- return (map toUpper x)
    print y
```

- Programmers with no Haskell knowledge can guess what it does.
- We'll explore this in detail later ...
- First the basics.

Simple Haskell datatypes

A data type in Haskell is essentially one or more tags:

```
data Fruit = Apple | Orange | Grapefruit ...
```

- `:type Apple ==> Fruit`
- `:type Orange ==> Fruit`

The tags are called “data constructors” because they can take values :

```
data Fruit a = Apple a | Orange a | Grapefruit ...
```

- `:type (Apple "hello") ==> Fruit String`
- `:type (Orange 1) ==> Fruit Int`

The Maybe Type

The Maybe type is very simple type that models success and failure

```
data Maybe a = Just a | Nothing
```

- `Just <some-value>` = success,
- `Nothing` = failure (approx. 'null' in other languages)
- `:type (Just 1) => Maybe Int`
- `:type (Just "hello") => Maybe String`
- `:type Nothing => Maybe ??` (it is determined in context)

I bring it up because Maybe is also a monad.

Monad implementation basics

- All monads provide the following functions:

```
return :: a -> m a
```

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

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

- Parentheses around the function name (func) make it infix
 - $(\gg=) x y == x \gg= y$
- And any type that implements these functions is a monad. From one perspective that's it!
- Notice that the type signatures are very simple
- This gives a flexible interface for the monad designer.
- And leads to a consistent and elegant programming experience for the monad user.
- Now we look at each of these functions in detail.

The 'return' function

- The return function takes a value and puts it in the context of the current monad. It is now a "monadic value".
- Another way to think about it: it packs a value into the monad container.
- The way it does this depends entirely on the monad.
- In the context of Maybe, the signature for 'return' is :

```
return :: a -> Maybe a
```

```
- return 1 :: Maybe Int
```

```
=> Just 1
```

```
- Nothing :: Maybe Int
```

```
=> Nothing
```


The bind ($\gg=$) function

The ($\gg=$) function

- 1 Removes a value from the context of the current monad (unpacks a value from the monad)
 - 2 Gives it to a function which does something to it and puts it back into the context of the current monadic. (apply and repack)
- In the context of Maybe, the type signature for ($\gg=$) is:

$(\gg=) :: \text{Maybe } a \rightarrow (a \rightarrow \text{Maybe } b) \rightarrow \text{Maybe } b$

For example,

```
(return 1 >>= \x ->
  return (x+1)) :: Maybe Int
=> Just 2
```

Chaining with the bind ($\gg=$) function (1/2)

- The ($\gg=$) function can then be chained together:

```
(return 1 >>= \x ->
  return (x+1) >>= \y ->
  return (y+1)) :: Maybe Int
=> Just 3
```

- The mantra of ($\gg=$) is "Unpack, hand over, unpack, hand over ..."
- This applies to **all** monads.

Chaining with the bind ($\gg=$) function (2/2)

- But what about when one of the functions in the chain is Nothing?

```
(return 1 >>= \x ->  
  Nothing >>= \y ->  
  return (x+1)) :: Maybe Int  
=> Nothing
```
- If **any** of the functions is Nothing (fails), the entire chain is Nothing.
- It would have been impossible to guess that from the type signatures alone.
- A lot is left up to the implementation and documentation.
- I guess this is the trade-off for simplicity, consistency and flexibility!

Chaining with (\gg) function

- The (\gg) function is very similar to ($\gg=$) but the mantra is slightly different:

“Unpack, don't hand over, unpack, don't hand over ...”

```
(return 1 >>= \x ->
  return (x+1) >>
  return 1024) :: Maybe Int
=> Just 1024
```

- All computation before 'return 1024' is ignored.
- This is useful when doing something that has side-effects.

```
(print "hello world" >>
  print "goodbye world") :: IO ()
=> "hello world"
   "goodbye world"
```

- 'print' just writes to stdout so there is nothing to hand over.

Do-notation (1/2)

- do-notation is a nicer way of writing monadic code without ($\gg=$) and (\gg)
- Here's an example using Maybe :

```
func :: Maybe Int
func = do
  x <- return (1 :: Int)
  y <- return (2 :: Int)
  return (x+y)
```

- is the same as ...

```
func' :: Maybe Int
func' = return (1 :: Int) >>= \x ->
      return (2 :: Int) >>= \y ->
      return (x+y)
```

- And here's an example in the IO monad :

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

- is the same as ...

```
func' = print "What is your name?" >>  
    getLine >>= \name ->  
    print ("Hello " ++ name)
```

- And speaking of which ...

- The IO monad is Haskell's eyes, ears and mouth.
- Haskell can only communicate with the outside world through the IO Monad.
- Here again is the example where we write a text file, read it back, uppercase its contents and write them to stdout.

```
import Data.Char
main :: IO ()
main = do
    writeFile "test.txt" "a,b,c,d,e" :: IO ()
    x <- readFile "test.txt" :: IO String
    y <- (return :: String -> IO String)
        (map Data.Char.toUpper x :: String)
    print y :: IO ()
-- => "A,B,C,D,E"
```

- The type signatures within "main" are usually omitted. But very useful for learning and debugging.

- Querying a Sqlite database

```
import Database.HDBC
import Database.HDBC.Sqlite3
import Control.Exception
testdb emp_id = do
  res <- dbQuery "select * from employees where id=?"
           [toSql emp_id]
  print res
where
  dbConnect :: IO Connection
  dbConnect = connectSqlite3 "test.sqlite"
  dbQuery :: String -> [SqlValue] -> IO [[SqlValue]]
  dbQuery sql values =
    bracket dbConnect disconnect
      (\conn -> quickQuery' conn sql values)
```


Basic State Manipulation Monads

- In impure languages threading state is the norm

```
func (state) {  
    var i = 0;  
    i = func1(state);  
    i = func2(state);  
    return (i, state);  
}
```

- 'state' seen by 'func1' may be different from 'state' seen by 'func2'
- In Haskell, 'state' and 'i' are not mutable so output is the original 'i' and 'state' - not what you wanted!
- The three basic state manipulation monads Reader, Writer and State offer (the illusion of) mutable state in Haskell.

- A Reader type consists of some state and the result.
- The state in the Reader type is read-only. It cannot be changed within the monad.
- 'ask' extracts the state from the monad for inspection.
- 'runReader' takes a Reader monad and a state and outputs the final result.
- Now a code example ...

- A simple authentication example:

```
import "mtl" Control.Monad.Reader
type Env = [(String,String)]
simpleAuth :: String -> String -> Reader Env Bool
simpleAuth user pass = do
  env :: Env <- ask :: Reader Env Env
  case (lookup user env) of
    Nothing -> return False
    Just p -> return (p == pass)
main = print $ runReader auth env
  where
    auth = simpleAuth "deech" "mypass"
    env = [("deech","mypass"),("admin","adminPass")]
-- => True
```

- A Writer type also consists some state and the result.
- State is append-only, cannot be over-ridden.
- New state accumulated during the computation is tacked onto the end of the old.
- State cannot be inspected either. No 'ask' function for the Writer monad.
- 'runWriter' returns a tuple consisting of the new state and the result of the computation.

- State is appended using 'tell'
- A simple example showing how a Writer can be used to maintain a log.

```
import "mtl" Control.Monad.Writer
test :: Writer [String] Int
test = do
  x :: Int <- return 1 :: Writer [String] Int
  tell $ ["x is " ++ (show x)]
  y :: Int <- return 2 :: Writer [String] Int
  tell $ ["y is " ++ (show y)]
  z :: Int <- return (x + y) :: Writer [String] Int
  tell $ ["z is " ++ (show z)]
  return (z :: Int) :: Writer [String] Int
main = print $ runWriter test
-- => (3, ["x is 1", "y is 2", "z is 3"])
```

- Like the Reader and Writer, the State type consists of a state and a final result
- Unlike the Reader and Writer, state can be inspected, modified and replaced mid-stream
- 'get' retrieves the current state
- 'put' replaces the current state with its argument
- 'modify' transforms the current state using the given function.
- Like Writer, 'runState' takes the State computation and returns a tuple consisting of the new state and the result of the computation.
- Now for some code ...

- Unlike Reader and Writer, 'runState' **has** to be initialized with a starting state, even if you plan on replacing it.

```
import "mtl" Control.Monad.State
test :: State Int String
test = do
  put 2
  modify (\s -> s + 100)
  x <- get
  return "hello"
main = print $ runState test 1
-- => ("hello",102)
```

- Simulating an imperative for-loop with mutable counters
- The code finds the index of the minimum element in a list.

```
import "mtl" Control.Monad.State
-- mapM_ f [1,2,3,4] == f 1 >> f 2 >> f 3 >> f 4
-- zip [0,1,2] ['a','b'] == [(0,'a'),(1,'b')]
test :: (Ord a) => [a] -> ((),Int)
test [] = error "Empty List"
test xs = runState (mapM_ min (zip [0..] xs)) 0
  where
    min (i,n) = do
      curr_min_i <- get
      if (n < (xs !! curr_min_i)) then put i
      else return ()
  main = print $ test [4,2,5,6,-1,-9]
-- => ((),5)
```

- This is **not** idiomatic Haskell!

Basic State Manipulation Wrap-up (1/2)

- Reader, Writer and State all thread state through the computation
- But they give you different levels of control.
- Reader is read-only state
- Writer is append-only state
- State gives you complete control.

Basic State Manipulation Wrap-up (2/2)

- So technically you only need State!
- But using the other types gives nice guarantees about what a function cannot do.
- For example, given this function :

```
func :: Reader Env Bool  
func ...
```
- You **know** that Env isn't changed after running it.

Combining Monads

- So far we've seen single-use monads (IO, or Maybe or State but not all three)
- Monads are combined using "monad transformers"
- They are a lot simpler to use than they sound.
- There are "monad transformer" versions for all the monads we've seen so far - just append a 'T' to the type name.
 - Reader => ReaderT,
 - Writer => WriterT,
 - State => StateT

ReaderT and IO (1/3)

- A ReaderT type takes a state and an embedded monad.
- 'runReaderT' extracts the embedded monad from the ReaderT monad. Analogous to 'runReader'.
- Consider the function :

```
func :: ReaderT [(String,String)] IO ()
```
- 'func' can do two things :
 - 1 look up an immutable string->string map using 'ask'
 - 2 actions of type IO using 'liftIO'.
- 'runReaderT func' => something of type IO ()

- For example here's an interactive version of the Reader authentication example we saw earlier :

```
import "mtl" Control.Monad.Reader
test :: ReaderT [(String,String)] IO ()
test = do
  user <- liftIO $ print "Enter username" >> getLine
  pass <- liftIO $ print "Enter password" >> getLine
  env <- ask
  case (lookup user env) of
    Nothing -> liftIO $ print "That username isn't found!"
    Just p -> if (p == pass) then liftIO $ print "Welcome!"
               else liftIO $ print "Incorrect Password!"
main = runReaderT test [("deech","mypass"),
                       ("admin","adminPass")]
```

- The result of running the above code is :

```
"Enter username"
```

```
deech
```

```
"Enter password"
```

```
mypass
```

```
"Welcome!"
```

WriterT and IO (1/2)

- The idea is exactly same as ReaderT.
- 'runWriterT' extracts a result from the WriterT monad. Analogous to 'runWriter'.
- Given the function

```
func :: WriterT [String] IO ()
```
- func can do two things :
 - 1 append a string to a list of strings using 'tell'
 - 2 actions of type IO using 'liftIO'
- 'runWriterT func' => something of type IO ()

WriterT and IO (2/2)

- For example, here's a version of the logging function we say earlier.

```
import "mtl" Control.Monad.Writer
test :: String -> WriterT [String] IO Int
test file = do
  x <- return 1
  tellAndLog $ "x is " ++ (show x)
  y <- return 2
  tellAndLog $ "y is " ++ (show y)
  z <- return (x + y)
  tellAndLog $ "z is " ++ (show z)
  return z
where
  tellAndLog s = tell [s] >>
    (liftIO $ appendFile file $ s ++ "\n")
main = runWriterT (test "test.txt")
-- => (3, ["x is 1", "y is 2", "z is 3"])
```


ReaderT, WriterT and IO (1/3)

- The embedded monad can itself be a monad transformer!
- For instance the function:

```
func :: ReaderT [(String,String)] (WriterT [String] IO) ()
```

- It can do three things :
 - 1 look up an immutable string->string map using 'ask'
 - 2 append a string to a list of strings using 'tell'
 - 3 actions of type IO using 'liftIO'
- But how do you extract a value?
 - 'runReaderT func' => (WriterT [String] IO ())
 - Therefore 'runWriterT (runReaderT func)' => IO ()
- Next a code example ...

ReaderT, WriterT and IO (2/3)

```
import "mtl" Control.Monad.Reader
import "mtl" Control.Monad.Writer
test :: ReaderT [(String,String)] (WriterT [String] IO) ()
test = do
  user <- liftIO $ print "Username?" >> getLine
  tellAndLog $ "Username entered : " ++ (show user)
  pass <- liftIO $ print "Password?" >> getLine
  tellAndLog $ "Password entered : " ++ (show pass)
  env <- ask
  case (lookup user env) of
    Nothing -> tellAndLog "bad username"
    Just p -> if (p == pass) then tellLogPrint "accepted"
              else tellLogPrint "denied!"
where
  tellAndLog s = tell [s] >>(liftIO $ appendFile "test.txt" s)
  tellLogPrint s = tellAndLog s >> (liftIO $ print s)
```

- And a function to run the computation :

```
main = runWriterT $
      runReaderT test [("deech","mypass"),
                      ("admin","adminPass")]
```

- Results in the following output :

```
"Username?"
deech
"Password?"
mypass
"accepted"
((), ["Username entered : \"deech\"",
      "Password entered : \"mypass\"",
      "accepted"])
```

Combining Monads wrap up

- Most commonly used monads have monad transformer versions
- Monads transformers can stacked as deep as you want to add functionality.

- For example :

```
func :: StateT (Writer [String] Int)
      (ReaderT [(String,String)] IO) ()
```

- 1 Keeps state of type (Writer [String] Int)
 - You now have an inspectable and modifiable running log
 - 2 Allows the inspection of an environment using 'ask'
 - 3 Does IO actions
- To extract it
 - 1 runStateT func <some Writer computation>
 - 2 runReaderT

```
=> runReaderT $ runStateT func <some Writer computation>
```
 - The trickiest part is the type signature and knowing how to run the computation.

- Software Transactional Memory is basically an in-memory shared database
- Each read and write to the database is thread-safe
- Every thread has a consistent view of the data.
- No IO can be done in the STM monad.
- Any variable of type 'TVar' is an STM variable which can only be read and written in the STM monad.
- Now an example ...

- This is an example of a function that waits until a string is non-empty.
- 'retry' is an STM monad function that 'blocks' until a condition has been met.

```
outputMessage :: MVar () -> String -> IO ()
outputMessage lock str = withMVar lock (\_ -> print str)
readShared :: MVar () -> TVar String -> STM String
readShared lock s = do
  s' <- readTVar s
  if (s' == "") then
    do
      unsafeIOToSTM $
        outputMessage lock $ " String is empty " ++
          ", waiting for change "
    retry
  else do
    return $ "Got it! " ++ s'
```

- Now an example of writing to a transactional string.

```
writeShared :: TVar String -> STM ()  
writeShared s = do  
  s' <- readTVar s  
  writeTVar s (s' ++ "hello world")  
  return ()
```

- And tying it all together a function that
 - 1 spawns a thread that creates an empty transactional string
 - 2 waits 3 seconds and spawns another thread that writes to the transactional string

```
demoRetry :: IO ()
demoRetry = do
  writeLock <- newMVar ()
  a <- atomically $ newTVar ""
  forkIO $ (atomically $ readShared writeLock a) >>= print
  threadDelay 3000000
  forkIO $ atomically $ writeShared a
  return ()
```


- The output of running 'demoRetry' is:
" String is empty , waiting for change "
<3 seconds passes>
"Got it! hello world"

Parsec (1/2)

- Parsec is used to parse complex grammars
- It is readable
- It not only parses a string but can separate it into its tokens in a single step.
- It returns an Either type:

```
data Either a b = Left a | Right b
```
- Successful parse => "Right <parsed-value>"
- Failed parse => "Left <some-error>"
- Some simple examples follow . . .

- Below is an example that parses (and lexes):
 - a simple email address, no support for comments etc.
 - a comma OR dot separated string

```
import Text.ParserCombinators.Parsec
validChar = many $ noneOf "!@#$%^&*() [] {}"
commaOrDot = many alphaNum 'sepBy' (char ',' <|> char '.')
simpleEmail = do
  local <- manyTill alphaNum (try (char '@'))
  s <- validChar 'sepBy' (char '.')
  eof
  return (local,s)
main = do
  print $ parse simpleEmail "" "alpha123@hotmail.com.org"
  print $ parse commaOrDot "" "a,b,..c,,d"
-- => Right ("alpha123",["hotmail","com"])
-- => Right ["a","b","","","c","","d"]
```

- Monads are:
 - 1 easy to use once you develop an intuition for 'return' and (`>>=`)
 - 2 and a vital part of writing and **reading** Haskell code
 - 3 used for a wide variety of functionality because of the simple interface
- The monads we talked about will get you most of the way.
- User docs (or source code) will do the rest.

The End

Thanks for listening!

- Real World Haskell
 - <http://book.realworldhaskell.org/read/>
 - The most comprehensive and practical approach to Haskell for those with a strong programming background.
 - On the downside, it is not easy, and it is a textbook not a tutorial.
- Learn You A Haskell . . .
 - <http://learnyouahaskell.com/>
 - More of a top down approach
 - Takes you upto and including monads, but does **not** include:
 - IO
 - Reader, Writer, State
 - Monad transformers
 - Very good if you learn systematically, not ideal if you learn by diving in.

- Yet Another Monad Tutorial
 - <http://mvanier.livejournal.com/3917.html#cutid1>
 - An 8-part (and counting!) tutorial that explains the theory behind monads and the existing monads in detail.
 - Very recent. The last part came out on August 27th.
 - Still doesn't cover monad transformers or the Reader and Writer (yet), but does cover State.
- You Could Have Invented Monads
 - <http://blog.sigfpe.com/2006/08/you-could-have-invented-monads-and.html>
 - The best tutorial for understanding why monads exist
 - But not a tutorial about how to use existing monads
- Haskell Monoids and their uses
 - <http://blog.sigfpe.com/2009/01/haskell-monoids-and-their-uses.html>
 - About monoids not monads, but it also turned out to be the best tutorial on the Writer monad that I've read.

- XMonad
 - XMonad is a Linux window manager written entirely in Haskell.
 - A great example of Haskell code that is:
 - well structured and idiomatic
 - combines IO with pure functions.
 - well-commented, vetted and written by some of the community big-wigs
 - showing how to develop a project that supports plugins
 - It is also small enough that it can be understood by one person.