Introduction to Monads

Lecture 06A, 2015
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Last time we saw

A library for building parsers containing:

- An abstract data type `Parser a`
- A function

```
parse ::
 Parser a -> String -> Maybe(a,String)
```

- Basic building blocks for building parsers

We also saw

A specific parser (for Expr) built from scratch, based on

type Parser a = String -> Maybe (a,String)

Recap of Parsing.hs

[See course home page for API and source]

Parser implements the Monad type class

For now, that just means that we can use "do" notation to build parsers, just like for IO and Gen

IO

```
do
 s <- getLine
 c <- readFile s
 return $ s ++ c
```

Gen

```
do
 n <- elements[1..9]
 m <- vectorOf n arbitrary
 return $ n:m
```

Parser

```
do
 c <- sat (`elem` ";,:")
 ds <- chain digit (char c)
 return ds
```

IO t	Gen t	Parser t
• Instructions for interacting with operating system • Run by GHC runtime system produce value of type t	• Instructions for building random values • Run by **quickCheck** to generate random values of type t	• Instructions for parsing • Run by **parse** to parse a string and produce a **Maybe** t

Example, a CSV file

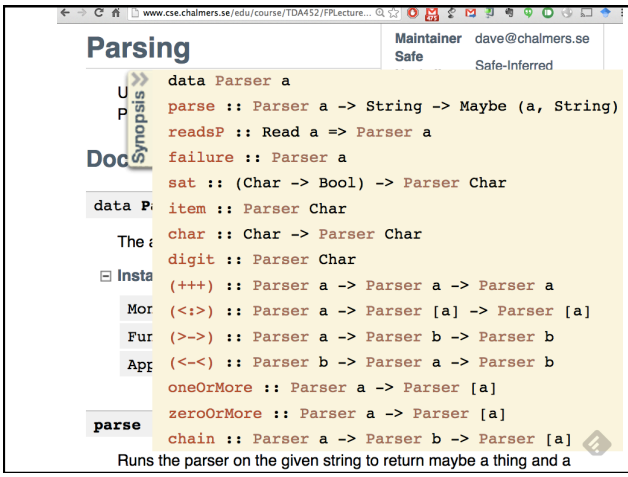
Year	Make	Model	Description	Price
1997	Ford	E350	ac, abs, moon	3000.00
1999	Chevy	Venture "Extended Edition"		4900.00
1999	Chevy	Venture "Extended Edition, Very Large"		5000.00
1996	Jeep	Grand Cherokee	MUST SELL! air, moon roof, loaded	4799.00

Example, a CSV file

The above table of data may be represented in CSV format as follows:

```
Year,Make,Model,Description,Price
1997,Ford,E350,"ac, abs, moon",3000.00
1999,Chevy,"Venture ""Extended Edition""","",4900.00
1999,Chevy,"Venture ""Extended Edition, Very
Large""",,5000.00
1996,Jeep,Grand Cherokee,"MUST SELL!
air, moon roof, loaded",4799.00
```

wikipedia



Example & Implementation

Terminology

- A *"monadic value"* is just an expression whose type is an instance of class Monad
- *"t is a monad"* means t is an instance of the class Monad
- We have often called a monadic value an *"instruction"*. This is not standard terminology
  – but sometimes they are called "actions"

Monads

David Sands

Monads and do notation

- To be an instance of class Monad you need (as a minimal definition) operations **>>=** and **return**

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

  (>>) :: m a -> m b -> m b
  x >> y = x >>= \_ -> y

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

Default implementations

Update, As of GHC 7.10

Monad is a subclass of Applicative (which is a subclass of Functor)

The class itself is a bit simpler – you just need to define >>=. For the rest you can just write:

```
import Control.Applicative (Applicative(..))
import Control.Monad       (liftM, ap)
instance Functor MyMonad where fmap = liftM
instance Applicative MyMonad where
    pure  = -- move defn of return here
    (<*>) = ap
```

Monad

- To be an instance of class Monad you need two operations: **>>=** and **return**

```
instance Monad Parser where
  return = succeed
  (>>=)  = (>*>)
   -- (>->) is equivalent to (>>)
```

- Why bother?

•First example of a home-grown monad
•Can understand and use do notation

The truth about Do

- Do syntax is just a shorthand:

```
do act1
   act2
```
==
```
act1 >> act2
```
==
```
act1 >>= \_ -> act2
```

```
do v <- act1
   act2
```
==
```
act1 >>= \v -> act2
```

Example

```
foo :: IO ()
foo = do
    filename <- getLine
    contents <- readFile filename
    putStrLn contents
```

The truth about Do

Full translation (I)

```
do act1
   …
   actn
```
==
```
act1 >> do …
          actn
```

```
do v <- act1
   …
   actn
```
==
```
act1 >>= \v -> do …
                 actn
```

```
do actn
```
==
```
actn
```

The truth about Do

Full Translation (II): Let and pattern matching

```
do let p = e
   …
   actn
```
==
```
let p = e in
do …
   actn
```

```
do pattern <- act1
   …
   actn
```
==
```
let f pattern = do …
                  actn
    f _       = fail "Error"
in  act1 >>= f
```

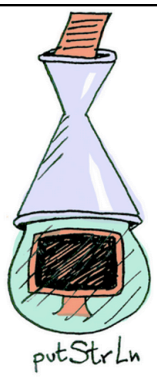
Pictures from a blog post about functors, applicatives and monads

http://adit.io/posts/2013-04-17-functors,_applicatives,_and_monads_in_pictures.html

Aditya Y. Bhargava


```
getLine :: IO String
```


```
readFile :: FilePath -> IO String
```

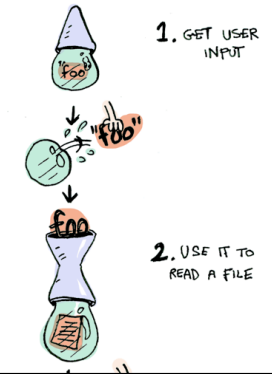



```
putStrLn :: String -> IO ()
```

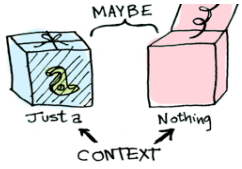
All three functions take a value (or no value) and produce an IO “wrapped” value

The function >>= allows us to join them together

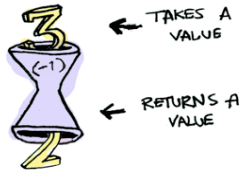
getLine >>= readFile >>= putStrLn



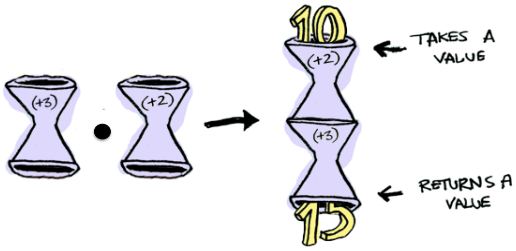
Maybe



Here is a function

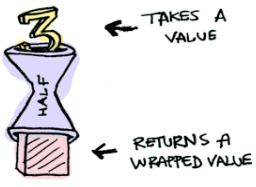


They can be composed



Here is a function

```
half x = if even x
           then Just (x `div` 2)
           else Nothing
```



What if we feed it a wrapped value?

We need to use >>= to shove our wrapped value into the function

>>=

>>=

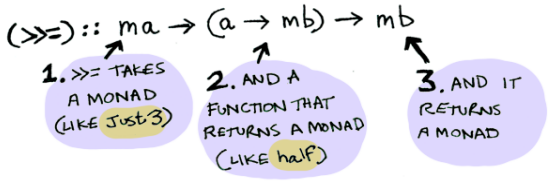
Here's how it works:

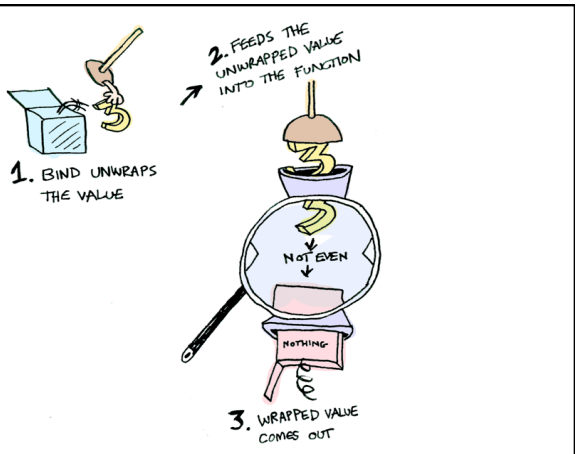
```
> Just 3 >>= half
Nothing
> Just 4 >>= half
Just 2
> Nothing >>= half
Nothing
```

What's happening inside? `Monad` is another typeclass. Here's a partial definition:

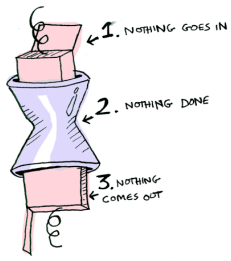
```
class Monad m where
    (>>=) :: m a -> (a -> m b) -> m b
```

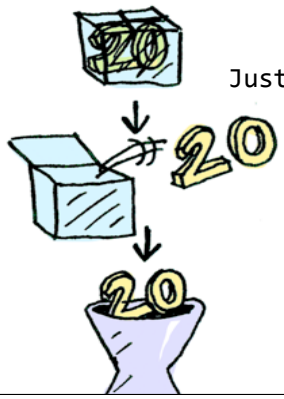
>>=



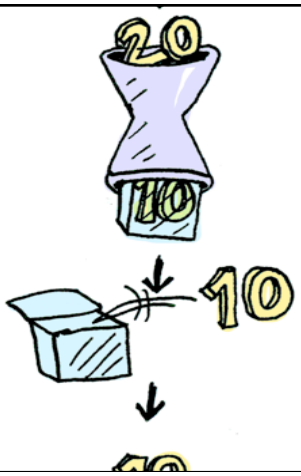


>>=






```
Just 20 >>= half >>= half
                 >>= half
```



Instance Monad Maybe

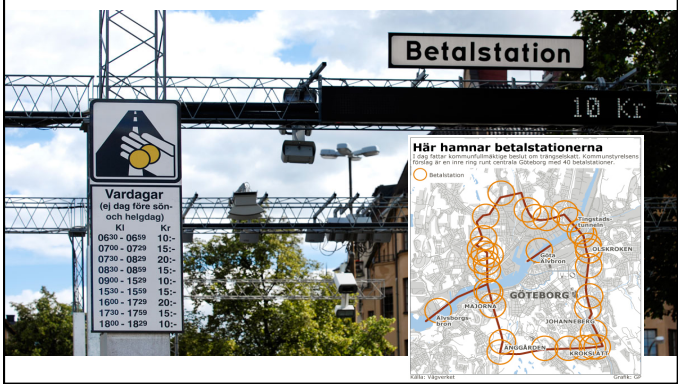
- Maybe is a very simple monad

```
instance Monad Maybe where
   Just x  >>= k = k x
   Nothing >>= _ = Nothing

   return        = Just
   fail s        = Nothing
```

Although simple it can be useful…

Congestion Charge Billing



Congestion Charge Billing

Registration number used to find the Personnummer of the owner

```
carRegister :: [(RegNr,PNr)]
```

Personnummer used to find the name of the owner

```
nameRegister :: [(PNr,Name)]
```

Name used to find the address of the owner

```
addressRegister :: [(Name,Address)]
```

Example: Congestion Charge Billing

```
type CarReg = String ; type PNr = String
type Name = String ; type Address = String

carRegister :: [(CarReg,PNr)]
carRegister
 = [("JBD 007","750408-0909"), ...]

nameRegister :: [(PNr,Name)]
nameRegister
 = [("750408-0909","Dave“), ... ]

addressRegister :: [((Name,PNr),Address)]
addressRegister =
  [(("Dave","750408-0909"),"42 Streetgatan\n Askim")
  , ... ]
```

Example: Congestion Charge Billing

With the help of
`lookup :: Eq a => a -> [(a,b)] -> Maybe b`
we can return the address of car owners

```
billingAddress :: CarReg -> Maybe (Name, Address)
billingAddress car =
 case lookup car carRegister of
   Nothing -> Nothing
   Just pnr -> case lookup pnr nameRegister of
        Nothing -> Nothing
        Just name ->
           case lookup (name,pnr) addressRegister of
                Nothing -> Nothing
                Just addr -> Just (name,addr)
```

Example: Congestion Charge Billing

Using the fact that Maybe is a member of class Monad
we can avoid the spaghetti and write:

```
billingAddress car = do
  pnr  <- lookup car carRegister
  name <- lookup pnr nameRegister
  addr <- lookup (name,pnr) addressRegister
  return (name,addr)
```

Example: Congestion Charge Billing

Unrolling one layer of the do syntactic sugar:

```
billingAddress car ==
 lookup car carRegister >>= \pnr ->
 do
  name <- lookup pnr nameRegister
  addr <- lookup (name,pnr) addressRegister
  return (name,addr)
```

- `lookup car carRegister` gives `Nothing`
then the definition of `>>=` ensures that the whole result is `Nothing`
- `return` is `Just`

Summary

- We can use higher-order functions to build Parsers from other more basic Parsers.
- Parsers can be viewed as an instance of Monad
- We can build our own Monads!
  - A lot of ”plumbing” is nicely hidden away
  - The implementation of the Monad is not visible and can thus be changed or extended

IO t	**Gen t**	**Parser t**
• Instructions for interacting with operating system • Run by GHC runtime system produce value of type t	• Instructions for building random values • Run by **quickCheck** to generate random values of type t	• Instructions for parsing • Run by **parse** to parse a string and **Maybe** produce a value of type t

Three Monads

Code

- Parsing.hs
  - module containing the parser monad and simple parser combinators.

See course home page

- We can build our own Monads!
  - A lot of ”plumbing” is nicely hidden away
  - A powerful pattern, used widely in Haskell
  - A pattern that can be used in other languages, but syntax support helps
    - F# computation expressions
    - Scala

More examples

- http://adit.io/posts/2013-06-10-three-useful-monads.html
- stack (slides/video from last year)

Another Example: A Stack

- A Stack is a stateful object
- Stack operations can push values on, pop values off, add the top elements

```
type Stack = [Int]
newtype StackOp t = StackOp (Stack -> (t,Stack))

-- the type of a stack operation that produces
-- a value of type t
pop :: StackOp Int
push :: Int -> StackOp ()
add :: StackOp ()
```

Running a StackOp

```
type Stack = [Int]
newtype StackOp t = StackOp (Stack -> (t,Stack))

run (StackOp f) = f

-- run (StackOp f) state = f state
```

Operations

```
pop :: StackOp Int
pop = StackOp $ \(x:xs) -> (x,xs) -- can fail

push :: Int -> StackOp ()
push i = StackOp $ \s -> ((),i:s)

add :: StackOp ()
add = StackOp $ \(x:y:xs) -> ((),x+y:xs) -- can fail
```

Building a new StackOp…

```
swap :: StackOp ()
swap = StackOp $ \s ->
          let (x,s') = run pop s
              (y,s'') = run pop s'
              (_,s''') = run (push x) s''
              (_,s'''') = run (push y) s'''
           in (_, s'''')
```

No thanks!

StackOp is a Monad

- Stack instructions for producing a value

```
-- (>>=) :: StackOp a -> (a -> StackOp b) -> StackOp b
instance Monad StackOp
  where return n = StackOp $ \s -> (n,s)
        sop >>= f  = StackOp $ \s ->
                               let (i,s') = run sop s
                               in run (f i) s'
```

So now we can write…

```
swap = do
     a <- pop
     b <- pop
     push a
     push b
```

Stack t

- Stack instructions producing a value of type t
- Run by **run**

Maybe t

- Instructions for either producing a value or nothing
- Run by ?? (not an abstract data type)

Two More Monads