Monad (3A)

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8/11/17

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This document was produced by using OpenOffice.

Based on

Haskell in 5 steps
https://wiki.haskell.org/Haskell_in_5_steps

Generator

```
let removeLower x = [c| c <- x, c `elem` ['A'..'Z']]
```

a **list comprehension**

```
[c | c <- x, c `elem` ['A'..'Z']]
```

c <- x is a **generator**

(x : argument of the function **removeLower**)

c is a **pattern**

matching from the elements of the list x

successive binding of c to the elements of the list x

c `elem` ['A'..'Z']

is a **predicate** which is applied to each successive binding of c

Only c which passes this predicate will appear in the output list

```
do { x1 <- action1
   ; x2 <- action2
   ; mk_action3 x1 x2 }
```

https://stackoverflow.com/questions/35198897/does-mean-assigning-a-variable-in-haskell

Assignment in Haskell

Assignment in Haskell : declaration with initialization:

You declare a variable;
Haskell doesn't allow uninitialized variables,
so an initial value must be supplied in the declaration
There's no mutation, so the value given in the declaration
will be the only value for that variable throughout its scope.

https://stackoverflow.com/questions/35198897/does-mean-assigning-a-variable-in-haskell

Generator

```
[c| c <- x, c `elem` ['A'..'Z']]
```

```
filter (`elem` ['A' .. 'Z']) x
```

```
[c| c <- x]
```

```
do c <- x
   return c
```

```
x >>= ( \c -> return c )
```

```
x >>= return
```

```
action1 >>= (\ x1 ->
  action2 >>= (\ x2 ->
    mk_action3 x1 x2 ))
```

https://stackoverflow.com/questions/35198897/does-mean-assigning-a-variable-in-haskell

Anonymous Functions

```
(\x -> x + 1) 4
5 :: Integer
```

```
(\x y -> x + y) 3 5
8 :: Integer
```

```
inc1 = \x -> x + 1
```

```
incListA lst = map inc2 lst
   where inc2 x = x + 1
```

```
incListB lst = map (\x -> x + 1) lst
```

```
incListC = map (+1)
```

https://wiki.haskell.org/Anonymous_function

Then Operator (>>) and do Statements

```
putStr "Hello"  >>
putStr " "      >>
putStr "world!" >>
putStr "\n"
```

```
do { putStr "Hello"
   ; putStr " "
   ; putStr "world!"
   ; putStr "\n" }
```

https://en.wikibooks.org/wiki/Haskell/do_notation

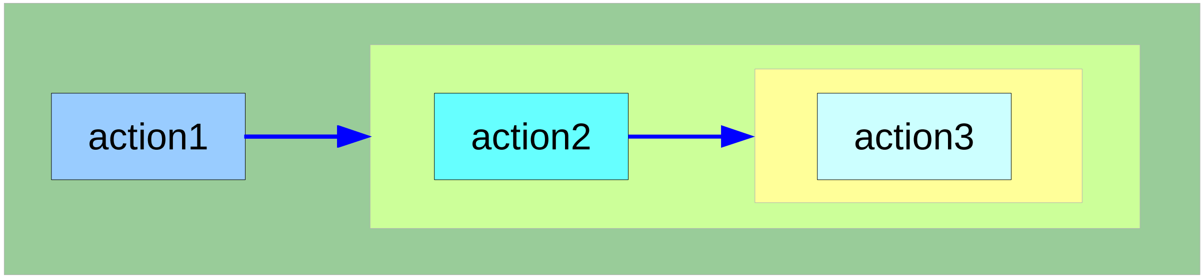
Translating in **do** notation

```
do { action1
   ; action2
   ; action3 }
```

```
action1 >>
do { action2
   ; action3 }
```

```
do { action1
   ; do { action2
        ; action3 } }
```

```
do { action1
   ; do { action2
        ; do { action3 } } }
```



can **chain** any actions
as long as all of them are
in **the same monad**

https://en.wikibooks.org/wiki/Haskell/do_notation

Bind Operator (>==) and **do** statements

The bind operator (**>>=**)

passes a value (the result of an action or function),

downstream in the binding sequence.

```
action1 >>= (\ x1 ->
  action2 >>= (\ x2 ->
    mk_action3 x1 x2 ))
```

anonymous function

(lambda expression)

is used

do notation assigns a variable name

to the passed value using the **<-**

```
do { x1 <- action1
   ; x2 <- action2
   ; mk_action3 x1 x2 }
```

https://en.wikibooks.org/wiki/Haskell/do_notation

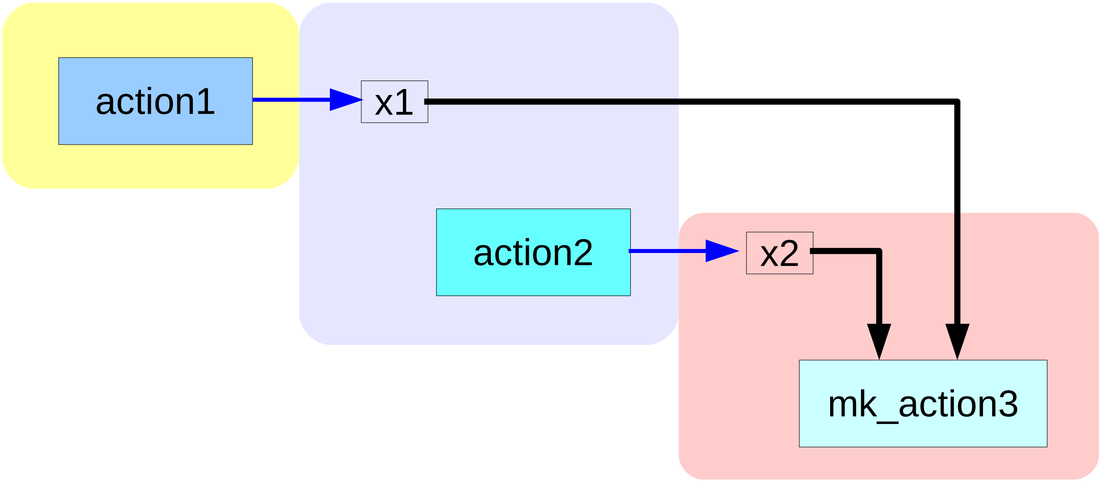
Translation using the bind operator (>>=)

```
do { x1 <- action1
   ; x2 <- action2
   ; mk_action3 x1 x2 }
```

```
action1 >>= (\ x1 -> action2 >>= (\ x2 -> mk_action3 x1 x2 ))
```

```
action1
  >>=
    (\ x1 -> action2
       >>=
         (\ x2 -> mk_action3 x1 x2 ))
```

```
action1 >>= (\ x1 ->
  action2 >>= (\ x2 ->
    mk_action3 x1 x2 ))
```



https://en.wikibooks.org/wiki/Haskell/do_notation

https://www.schoolofhaskell.com/user/EFulmer/currying-and-partial-application

http://www.idryman.org/blog/2014/01/23/yet-another-monad-tutorial/

A Type Monad

Haskell does not have states

But its powerful type system enable to construct the stateful program flow

Defining a Monad type is like defining a class in an object oriented language
A Monad can do much more than a class:

A Monad is a type that can be used for

- exception handling
- constructing parallel program workflow
- a parser generator

http://www.idryman.org/blog/2014/01/23/yet-another-monad-tutorial/

Types: rules and data

types are the **rules** associated with the **data**, not the actual data itself.

Object-Oriented Programming enable us

to use classes/interfaces

to define **types**,

the **rules** (**methods**) that interacts with the actual **data**.

to use **templates**(c++) or **generics**(java)

to define more **abstracted rules** that are more <u>reusable</u>

Monad is pretty much like **generic class**.

http://www.idryman.org/blog/2014/01/23/yet-another-monad-tutorial/

Monad Rules

A type is just a set of rules, or methods in Object-Oriented terms

A Monad is just yet another type, and the definition of this type is defined by four rules:

1) **bind (>>=)**
2) **then (>>)**
3) **return**
4) **fail**

http://www.idryman.org/blog/2014/01/23/yet-another-monad-tutorial/

Monad Applications

1. Exception Handling

2. Accumulate States

3. IO Monad

http://www.idryman.org/blog/2014/01/23/yet-another-monad-tutorial/

Monad Class Function >>= & >>

both **>>=** and **>>** are functions from the Monad class.

Monad Sequencing Operator with value passing

>>= **passes** the result of the expression on the left
as an argument to the expression on the right,
in a way that respects the context the argument and function use

Monad Sequencing Operator

>> is used to **order** the evaluation of expressions within some context;
it makes evaluation of the right depend on the evaluation of the left

https://www.quora.com/What-do-the-symbols-and-mean-in-haskell

Data Constructor

data **Color** = **Red | Green | Blue**

Color is a type
Red is a *constructor* that contains a *value* of type **Color**.
Green is a *constructor* that contains a *value* of type **Color**.
Blue is a *constructor* that contains a *value* of type **Color**.

data **Color** = **RGB** *Int Int Int*

Color is a type
RGB is not a value but a *function* taking three Ints and *returning a value*

RGB :: Int -> Int -> Int -> Colour

RGB is a **data constructor** that is a *function*
taking three Int values as its arguments,
and then uses them to construct a new value.

https://stackoverflow.com/questions/18204308/haskell-type-vs-data-constructor

Type Constructor (1)

Consider a binary tree to store Strings

data **SBTree** = **Leaf** String | **Branch** String **SBTree** **SBTree**

a type

SBTree is a type
Leaf is a **data constructor** (a function)
Branch is a **data constructor** (a function)

Leaf :: String -> SBTree
Branch :: String -> SBTree -> SBTree -> SBTree

Consider a binary tree to store Bool

data **BBTree** = **Leaf** Bool | **Branch** Bool **BBTree** **BBTree**

https://stackoverflow.com/questions/18204308/haskell-type-vs-data-constructor

Type Constructor (2)

Type constructors

Both **SBTree** and **BBTree** are type constructors

```
data SBTree = Leaf String | Branch String SBTree SBTree
data BBTree = Leaf Bool   | Branch Bool BBTree BBTree
```

```
data BTree a = Leaf a | Branch a (BTree a) (BTree a)
```

Now we introduce a type variable a as a parameter to the type constructor.

BTree has become a function.
It takes a type as its argument and it returns a new tUype.

https://stackoverflow.com/questions/18204308/haskell-type-vs-data-constructor

Monad Definition

A **monad** is defined by

a **type constructor** m;
a function **return**;
an operator (**>>=**) "**bind**"

The function and operator are methods of the Monad type class and have types

```
return :: a -> m a

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

and are required to obey three laws

https://en.wikibooks.org/wiki/Haskell/Understanding_monads

Monad Definition

```
class Monad m where
    return :: a -> m a

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

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

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

https://en.wikibooks.org/wiki/Haskell/Understanding_monads

Maybe Monad

the Maybe monad.

The **type constructor** is m = **Maybe**,

```
return :: a -> Maybe a

return x  = Just x



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

m >>= g        = case m of
                   Nothing -> Nothing
                   Just x  -> g x
```

https://en.wikibooks.org/wiki/Haskell/Understanding_monads

Monad Class Function >>= & >>

Maybe is the monad
return brings a value into it
by wrapping it with **Just**

(**>>=**) takes
a value   m :: **Maybe** a
a function   g :: a -> **Maybe** b

if m is **Nothing**,
    there is nothing to do and the result is **Nothing**.
Otherwise, in the **Just** x case,
    the underlying value x is wrapped in **Just**
    g is applied to x, to give a **Maybe** b result.

    Note that this result *may* or *may not* be **Nothing**,
    depending on what g does to x.

```
(>>=)  :: Maybe a -> (a -> Maybe b) -> Maybe b
m >>= g = case m of
           Nothing -> Nothing
           Just x  -> g x
```

https://en.wikibooks.org/wiki/Haskell/Understanding_monads

Monad Class Function >>= & >>

```
(>>=)  :: Maybe a -> (a -> Maybe b) -> Maybe b
m >>= g = case m of
           Nothing -> Nothing
           Just x  -> g x
```

if there is an underlying value of type a in m,
we apply **g** to it, which brings the underlying value back into the **Maybe** monad.

The key first step to understand how return and (>>=) work is tracking
which values and arguments are monadic and
which ones aren't.

As in so many other cases, type signatures are our guide to the process.

https://en.wikibooks.org/wiki/Haskell/Understanding_monads

Maybe Monad Examples

a family database that provides two functions:

father :: Person -> **Maybe** Person
mother :: Person -> **Maybe** Person

Input the name of someone's father or mother.

If some relevant information is missing in the database
Maybe returns a **Nothing** value
to indicate that the lookup failed,
rather than crashing the program.

https://en.wikibooks.org/wiki/Haskell/Understanding_monads

Maybe Monad Examples

functions to query various grandparents.
the following function looks up the maternal grandfather (the father of one's mother):

```
maternalGrandfather :: Person -> Maybe Person
maternalGrandfather p =
    case mother p of
        Nothing -> Nothing
        Just mom -> father mom
```

```
maternalGrandfather p = mother p >>= father
```

https://en.wikibooks.org/wiki/Haskell/Understanding_monads

Maybe Monad Examples

https://en.wikibooks.org/wiki/Haskell/Understanding_monads

```
bothGrandfathers :: Person -> Maybe (Person, Person)
bothGrandfathers p =
  case father p of
      Nothing -> Nothing
      Just dad ->
          case father dad of
              Nothing -> Nothing
              Just gf1 ->                           -- found first grandfather
                  case mother p of
                      Nothing -> Nothing
                      Just mom ->
                          case father mom of
                              Nothing -> Nothing
                              Just gf2 ->           -- found second grandfather
                                  Just (gf1, gf2)
```

```
bothGrandfathers p =
   father p >>=
      (\dad -> father dad >>=
         (\gf1 -> mother p >>=   -- gf1 is only used in the final return
            (\mom -> father mom >>=
               (\gf2 -> return (gf1,gf2) ))))
```

Maybe Monad Examples

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

a type definition: **Maybe** a
a parameter of a type variable a,

https://stackoverflow.com/questions/18808258/what-does-the-just-syntax-mean-in-haskell

Maybe Monad Examples

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

two constructors: **Just** a and **Nothing**

a value of **Maybe** a type must be constructed via either **Just** or **Nothing**
there are no other (non-error) possibilities.

Nothing has no parameter type,
names a constant value that is a member of type **Maybe** a for all types a.

Just constructor has a type parameter,
acts like a function from type a to **Maybe** a,
i.e. it has the type a -> **Maybe** a

https://stackoverflow.com/questions/18808258/what-does-the-just-syntax-mean-in-haskell

Maybe Monad Examples

the (data) constructors of a type build a value of that type;

when using that value,
pattern matching can be applied

- Unlike functions, constructors can be used in pattern binding expressions
- **case analysis** of values that belong to types with more than one constructor.
- need to provide **a pattern** for each constructor

```
case maybeVal of
    Nothing   -> "There is nothing!"
    Just val  -> "There is a value, and it is " ++ (show val)
```

a pattern for each constructor

https://stackoverflow.com/questions/18808258/what-does-the-just-syntax-mean-in-haskell

Maybe

Maybe : Algebraic Data Type (ADT)

Widely used because it effectively extends a type
Integer into a new context in which it has an extra value (Nothing)
that represents a lack of value

Check for that extra value before accessing the possible Integer

Good for debugging

Many other languages have this sort of "no-value" value via NULL references.

The Haskel Maybe type handle this no-value more effectively.

https://stackoverflow.com/questions/18808258/what-does-the-just-syntax-mean-in-haskell

Maybe as a functor

Functor type class:

- transforming one type to another
- transforming operations of one type to those of another

Maybe a has a useful instance of a **functor** type class

Functor provides **fmap** method

maps functions of the base type (such as Integer)

to *functions* of the lifted type (such as Maybe Integer).

https://stackoverflow.com/questions/18808258/what-does-the-just-syntax-mean-in-haskell

Maybe as a functor

A *function* **f** transformed with **fmap**
cab work on a Maybe value

```
case maybeVal of
  Nothing  -> Nothing          -- there is nothing, so just return Nothing
  Just val -> Just (f val)     -- there is a value, so apply the function to it
```

```
    father :: Person -> Maybe Person
    mother :: Person -> Maybe Person
```

```
       f :: Int                  -> Int
fmap  f :: Maybe Integer -> Maybe Integer
```

a **Maybe Integer** value: **m_x**

fmap f m_x

In fact, you could apply a whole chain of
lifted Integer -> **Integer** functions to **Maybe Integer** values
and only have to worry about explicitly checking for **Nothing** once when you're finished.

https://stackoverflow.com/questions/18808258/what-does-the-just-syntax-mean-in-haskell

Maybe as a functor

In fact, you could apply a whole chain of
lifted Integer -> **Integer** functions to **Maybe Integer** values
and only have to worry about explicitly checking for **Nothing** once when you're finished.

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Maybe as a monad

the type signature **IO a** looks remarkably similar to **Maybe a**.

- IO doesn't expose its constructors
- only be "run" by the Haskell runtime system
- a Functor
- a Monad

a Monad is just a special kind of Functor with some extra features

Monads like **IO** *map* types to new types
that represent "computations that result in values"

Can *lift* **functions** into **Monad types**
via a very fmap-like function called **liftM**
that turns a regular function into a
"computation that results in the value obtained by evaluating the function."

https://stackoverflow.com/questions/18808258/what-does-the-just-syntax-mean-in-haskell

Maybe as a monad

Maybe is also a Monad
represents "computations that could fail to return a value"

Just like with the fmap example,
this lets you do a whole bunch of computations
without having to explicitly check for errors after each step.

And in fact, the way the Monad instance is constructed,
a computation on Maybe values stops as soon as a Nothing is encountered,

an immediate abort or
a valueless return
in the middle of a computation.

https://stackoverflow.com/questions/18808258/what-does-the-just-syntax-mean-in-haskell

Monad – List Comprehension Examples

```
[x*2 | x<-[1..10], odd x]
```

```
do
  x <- [1..10]
  if odd x
     then [x*2]
     else []
```

```
[1..10] >>= (\x -> if odd x then [x*2] else [])
```

https://stackoverflow.com/questions/44965/what-is-a-monad

Monad – I/O Examples

```
do
  putStrLn "What is your name?"
  name <- getLine
  putStrLn ("Welcome, " ++ name ++ "!")
```

https://stackoverflow.com/questions/44965/what-is-a-monad

Monad – A Parser Example

```
parseExpr = parseString <|> parseNumber

parseString = do
        char '"'
        x <- many (noneOf "\"")
        char '"'
        return (StringValue x)

parseNumber = do
    num <- many1 digit
    return (NumberValue (read num))
```

https://stackoverflow.com/questions/44965/what-is-a-monad

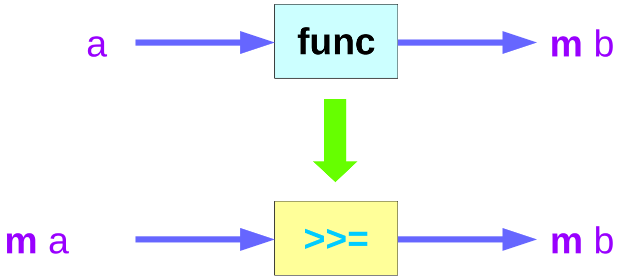
Monad – Asynchronous Examples

```
let AsyncHttp(url:string) =
    async {  let req = WebRequest.Create(url)
             let! rsp = req.GetResponseAsync()
             use stream = rsp.GetResponseStream()
             use reader = new System.IO.StreamReader(stream)
             return reader.ReadToEnd() }
```

https://stackoverflow.com/questions/44965/what-is-a-monad

Monad – Asynchronous Examples

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



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References

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[2] https://www.umiacs.umd.edu/~hal/docs/daume02yaht.pdf