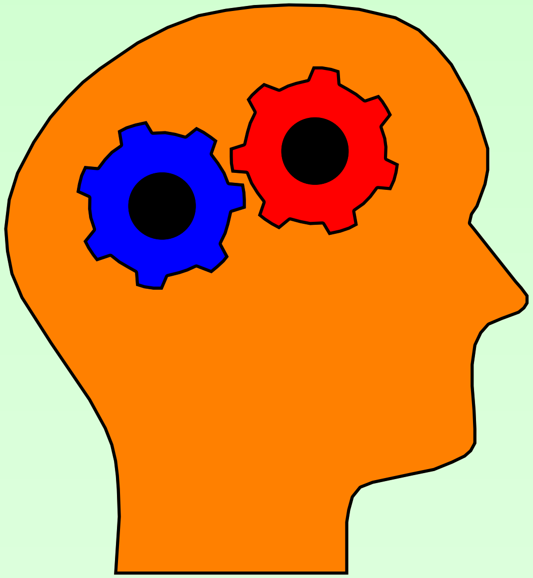
CS2104: Programming Languages Concepts

Lecture 6 : **Towards Monads**



"Imperative Programming in a Pure Language"

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Can be challenging but You are Not Alone

- The midnight Monad, a journey to enlightenment.

  https://www.lambdacat.com/the-midnight-monad-a-journey-to-enlightenment/

- Functors, Applicatives and Monads in Picture form:

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

- A Fistful of Monads.

  http://learnyouahaskell.com/a-fistful-of-monads

Referential Transparency vs Opacity

Referential transparency and referential opacity are properties of parts of computer programs. An expression is called referentially transparent if it can be replaced with corresponding value without changing the program's behavior..

```
let v = e
in ..v..v..
```

```
..v..v..
```

Pure vs Impure Code

- Imperative Programming (with side effects) - Opaque

```
print :: String -> ()
```

```
let c = print("hello")
in c ; c
```

```
print("hello");
print("hello")
```

different

- Pure Monadic Programming - Transparent

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

```
let c = print("hello")
in c >> c
```

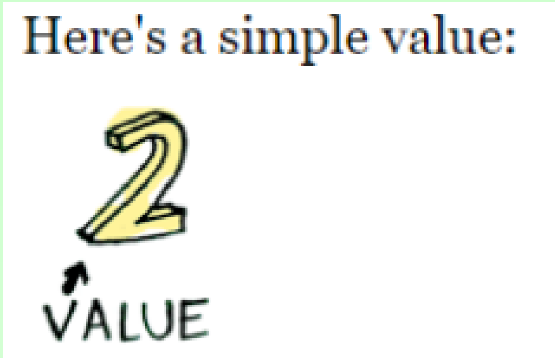
```
print("hello") >>
print("hello")
```

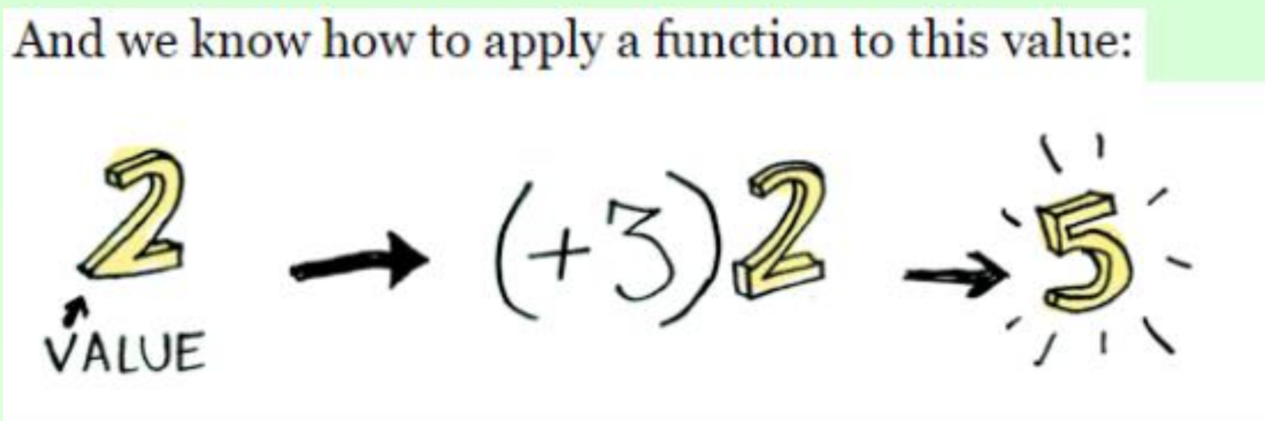
equivalent

Pictorial Introduction for Functors, Applicatives and Monads

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

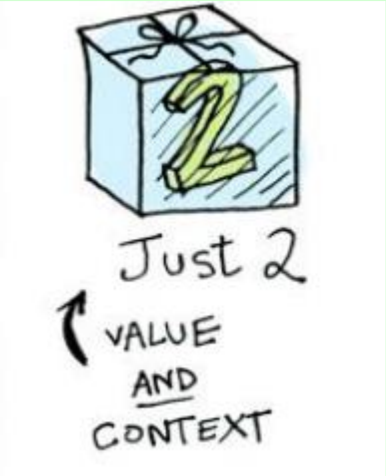
Pure Value World



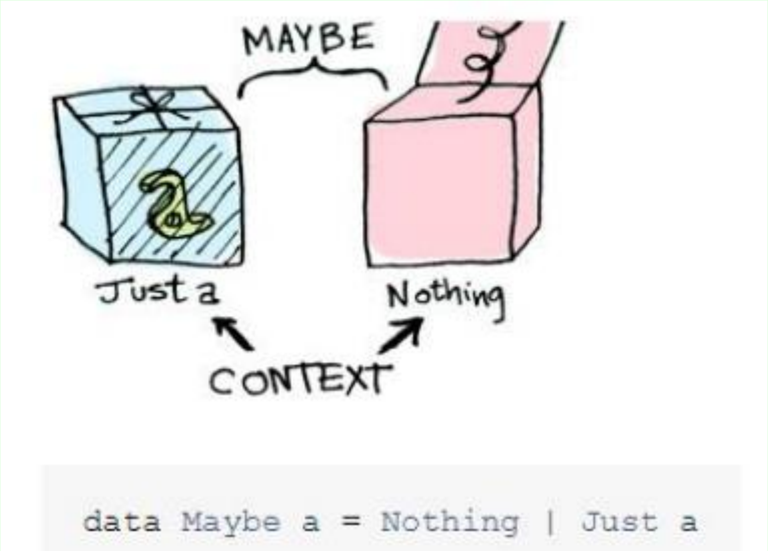


Value within Some Context

- Value and a Context.



- Maybe Type where
  where
  `Nothing`
  denotes error

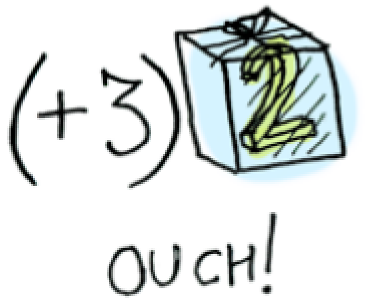


Other Examples of Context

- `[a]`
  - for non-determinism
- `state -> (state,a)`
  - for imperative state that can be updated
- `Parser a = String -> [(a,String)]`
  - For non-deterministic parsing
- `IO a`
  - for input-output interaction

Why Functor?

When a value is wrapped in a context, you can't apply a normal function to it:

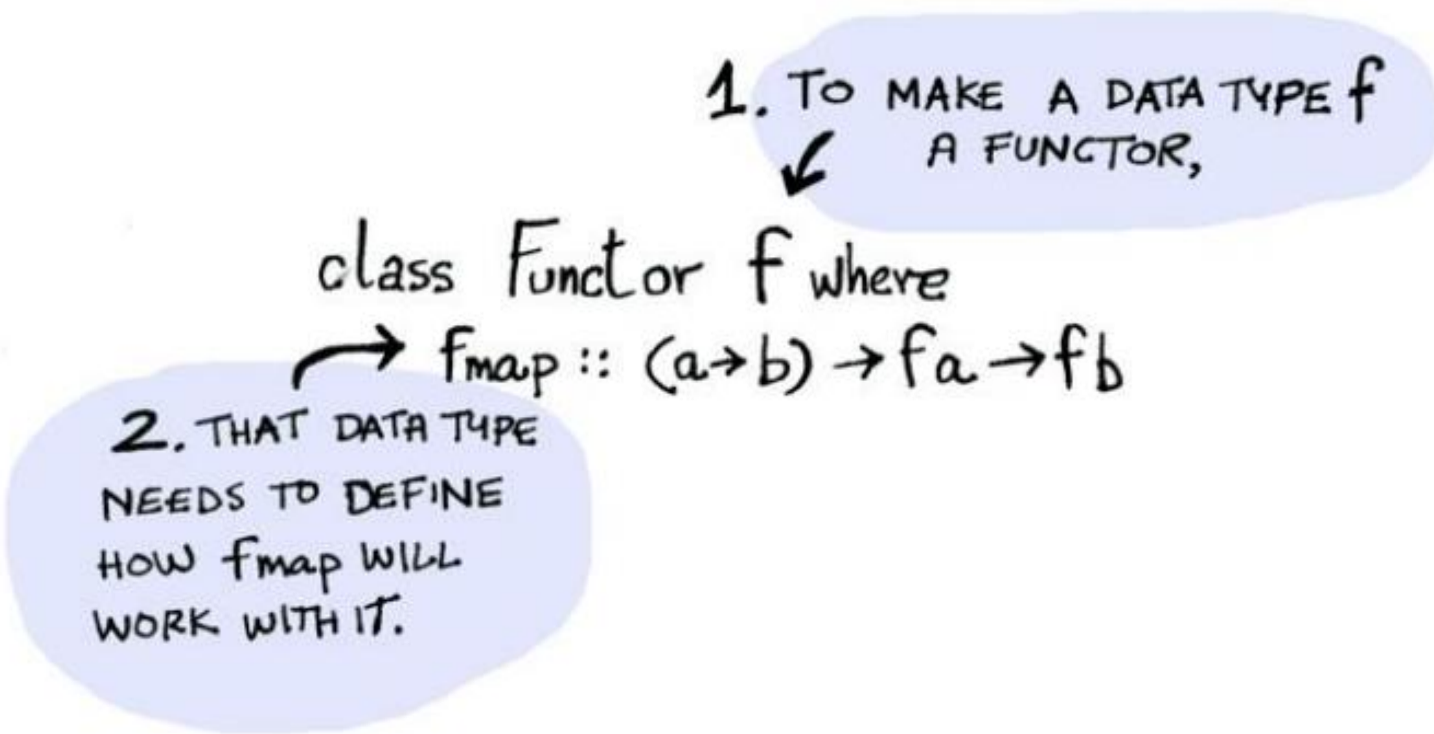


- Solution : Functor.

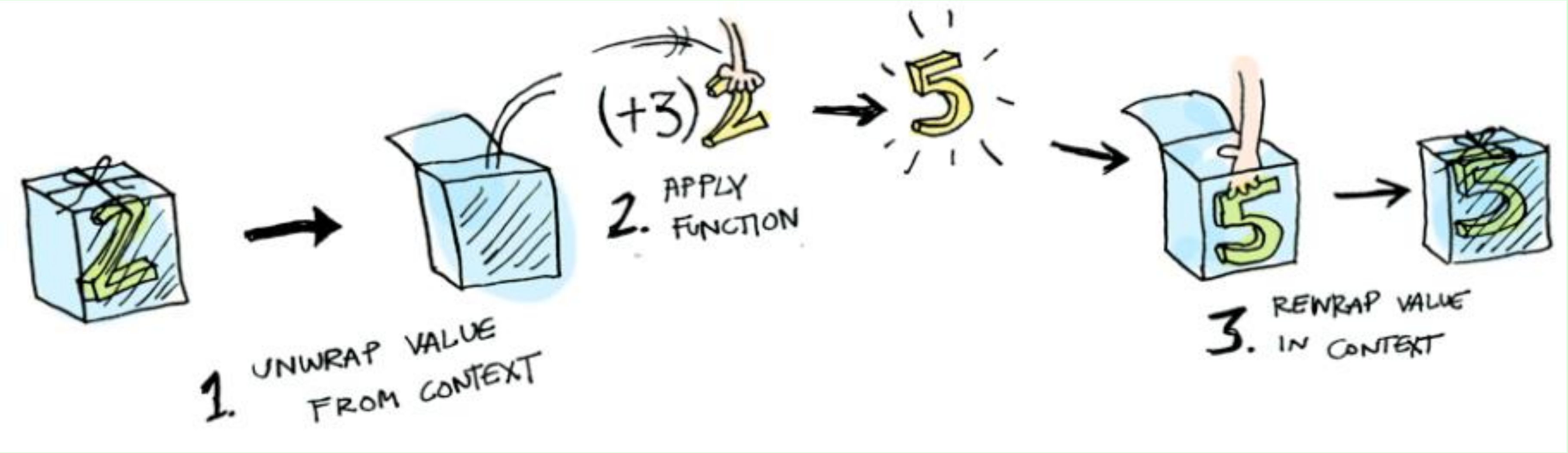
```
> fmap (+3) (Just 2)
Just 5
```

What is a Functor?

`Functor` is a typeclass. Here's the definition:

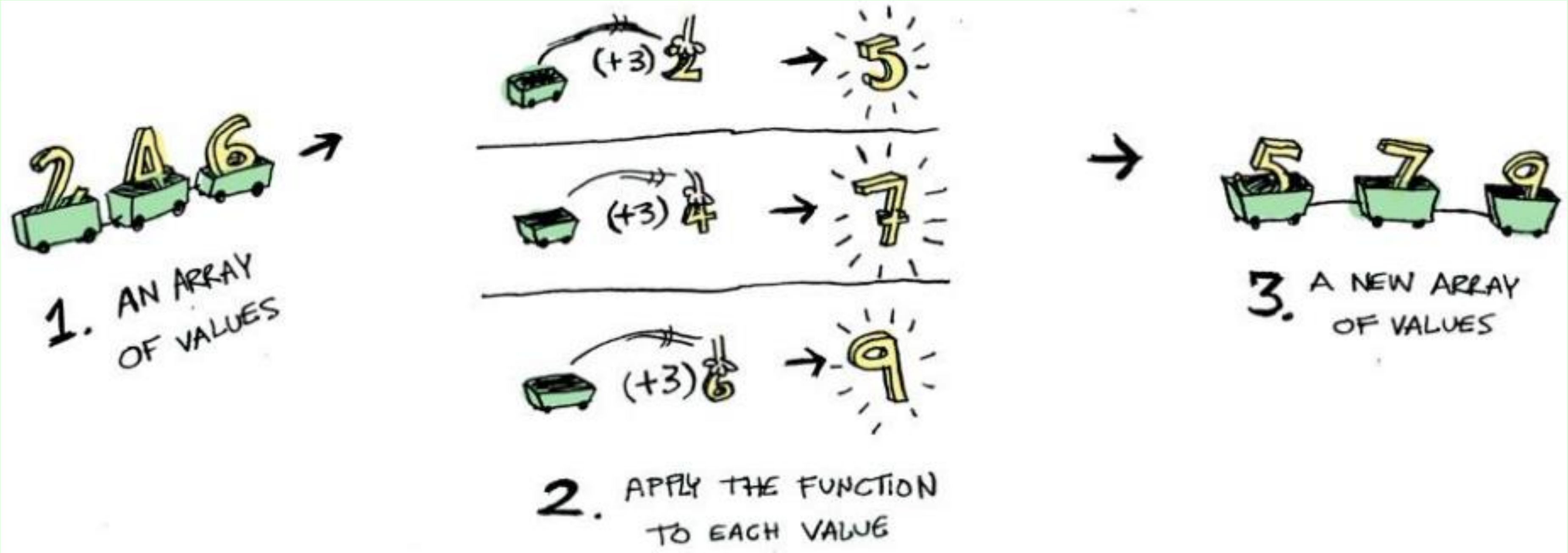


Behind the Scene




```
instance Functor Maybe where
    fmap func (Just val) = Just (func val)
    fmap func Nothing = Nothing
```

List/Arrays are also Functors




```
fmap   (+3)   [2,4,6]      ➔      [5,7,9]

(+3)    <$>   [2,4,6]      ➔      [5,7,9]
```

infix variant

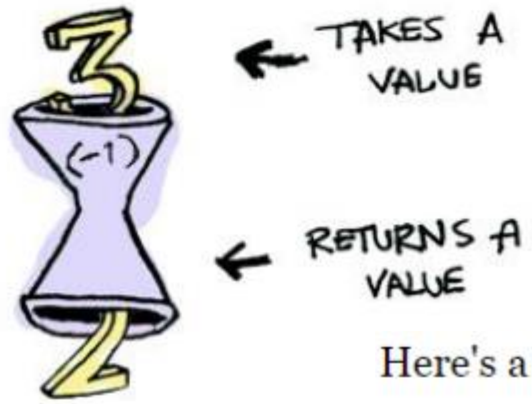
List as Functors

```
instance Functor [] where
    fmap = map
```

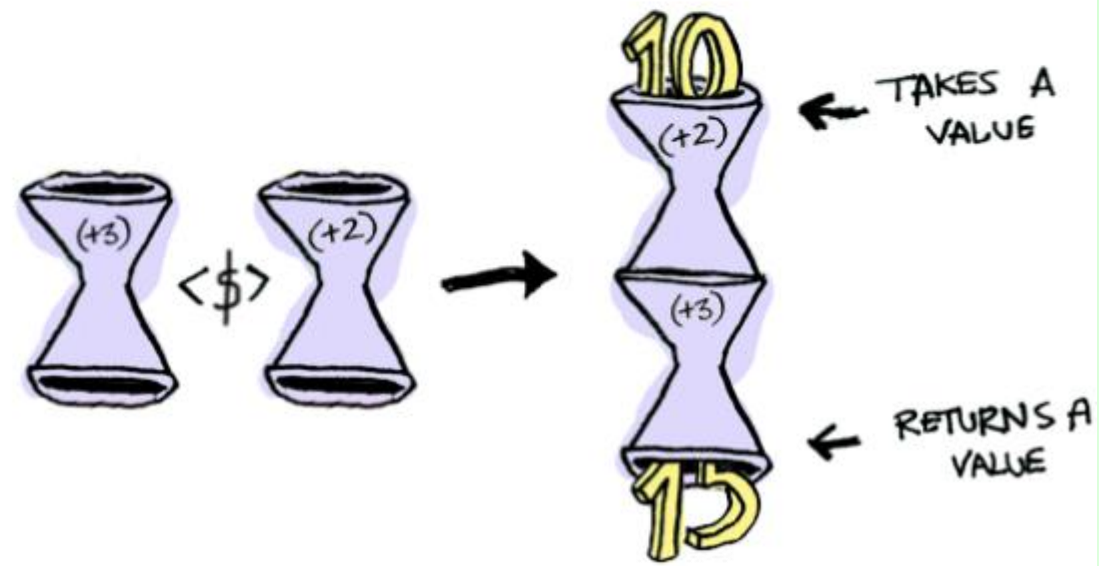
- List denotes non-determinism
- Examples:
  - `[]` means no solution
  - `[r1,r2,r3]` means three possible solutions

Functions are also Functors

Here's a function:



Here's a function applied to another function:



Functions as Functors ..

```
> let foo = fmap (+3) (+2)
> foo 10
15
```

- Implementation

```
instance Functor ((->) r) where
    fmap f g = f . g
```

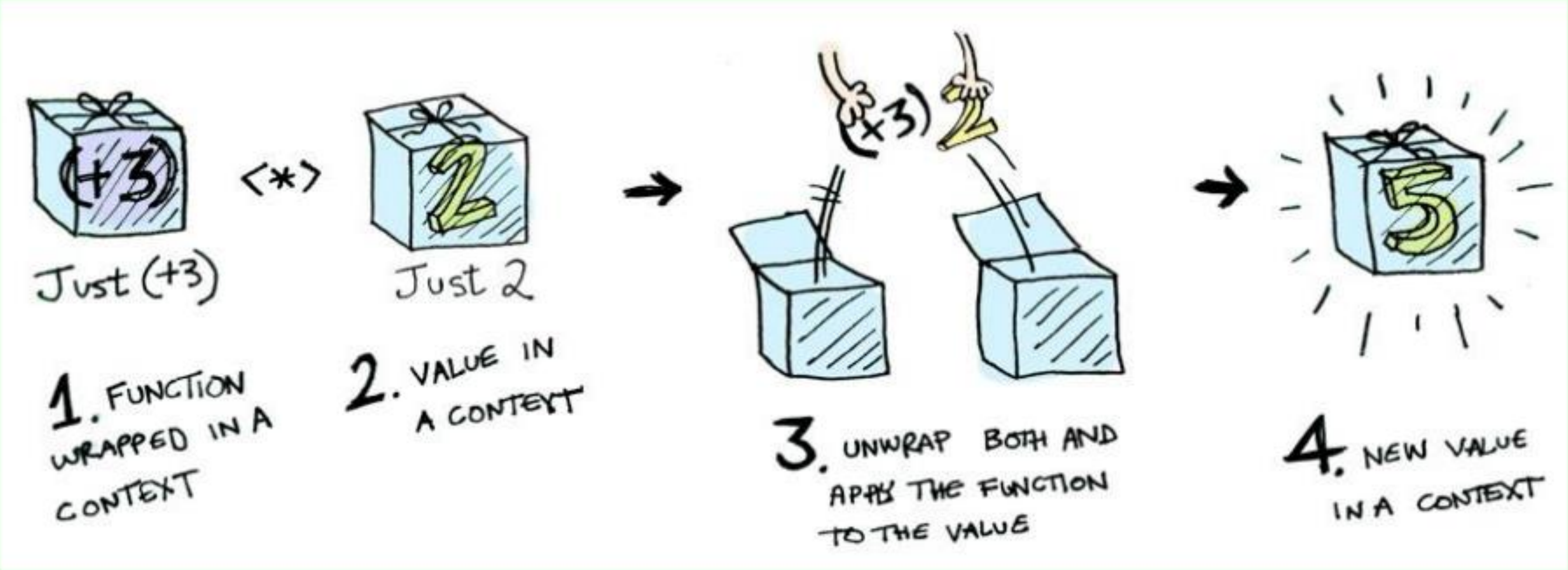
What IF Functions are Wrapped in Context?

`Maybe (Int -> Int)` **`Maybe (Int)`**

Cannot use `fmap`

$$fmap :: (a \to b) \to f\,a \to f\,b$$

Applicative to the Rescue

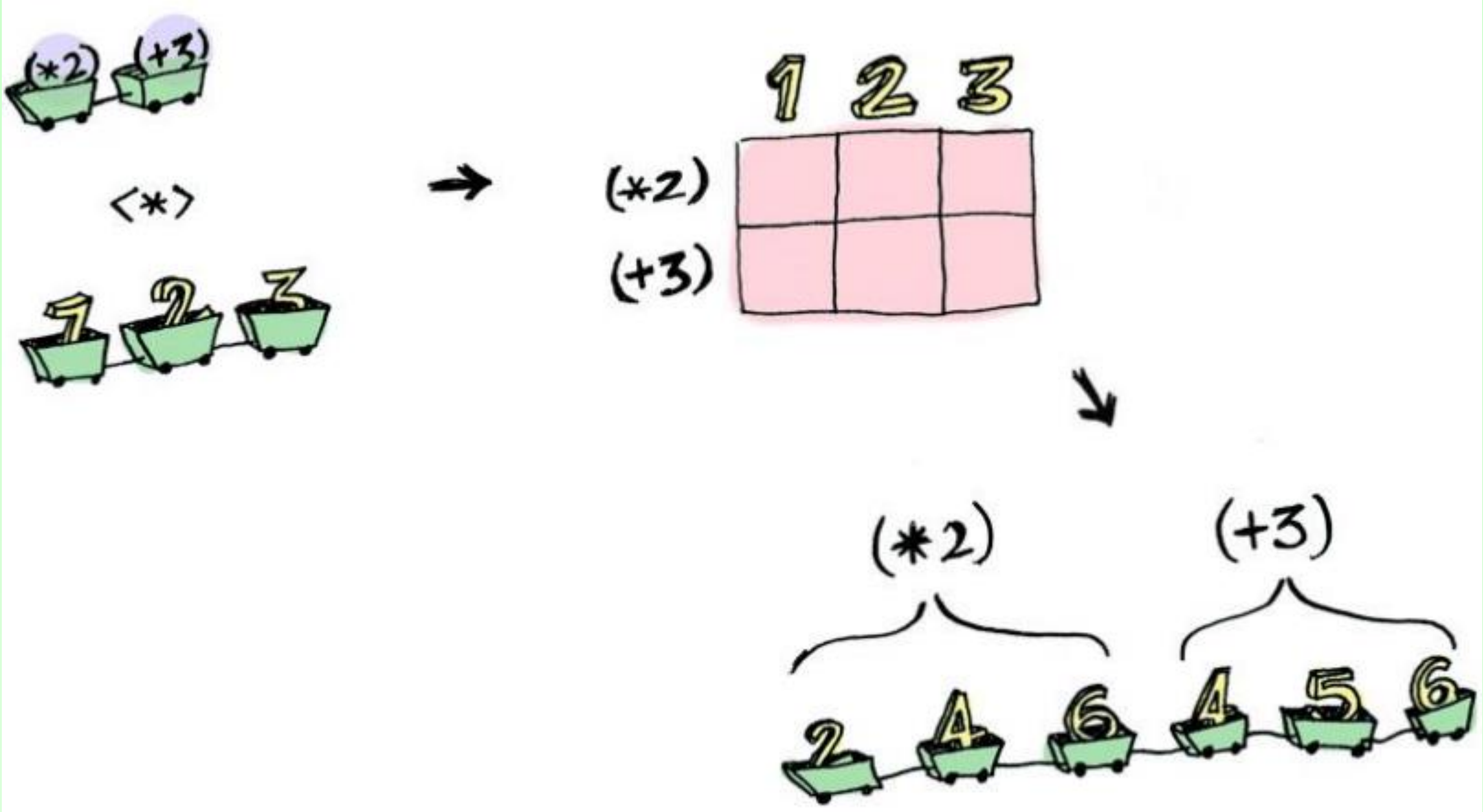



```
Just (+3) <*> Just 2 == Just 5
```

Applicative Class

```
class Functor f => Applicative (f:: *->*) where
  (<*>) :: f (a->b) -> f a -> f b
```

Applicative in List Context




```
> [(*2), (+3)] <*> [1, 2, 3]
[2, 4, 6, 4, 5, 6]
```

Why do we Need Applicative?

- Applicative can work with functions of any no. of arguments
  - Use fmap first

```
> let f = fmap (+) [1,2,3]
➢ :t f
➢ f :: Num a => [(a -> a)]
```

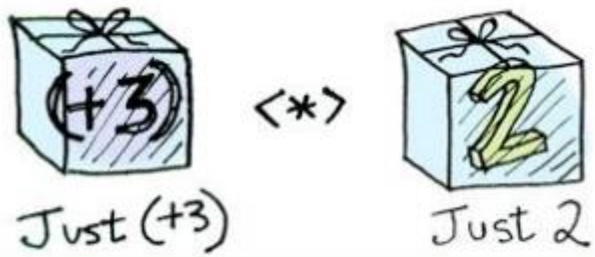
  - Use Applicative now

```
> f <*> [4,5]
➢ => [5,6,6,7,7,8]
```

Recap

Functors apply a function to a wrapped value:

Applicatives apply a wrapped function to a wrapped value:



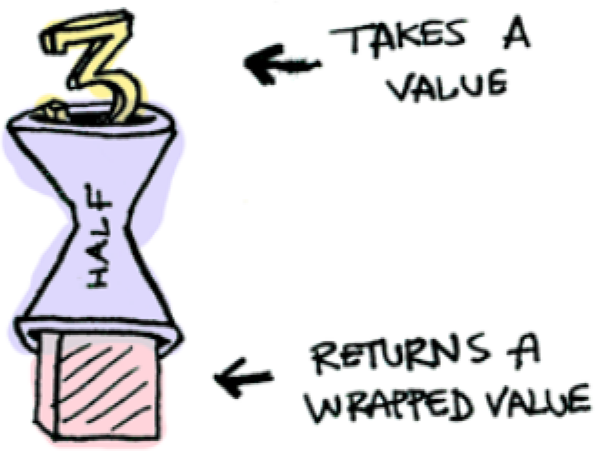
Essence of Monads

- How do we supply a wrapped value `(M a)`
  to a function which returns a wrapped value **`(a -> M b)`**

  `half :: Int -> Maybe Int`

Suppose `half` is a function that only works on even numbers:

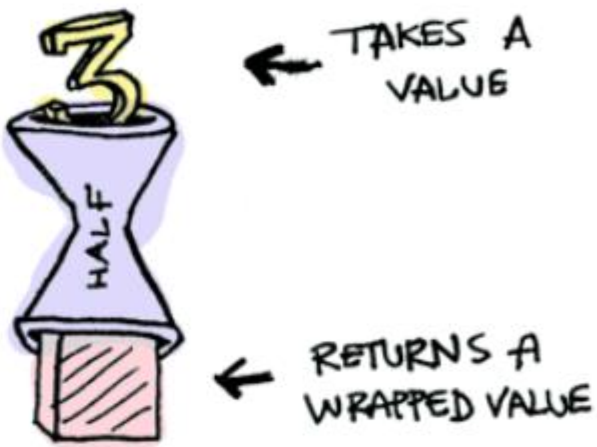
```
half x = if even x
           then Just (x `div` 2)
           else Nothing
```



What if we Apply on a Wrapped Value?

Suppose `half` is a function that only works on even numbers:

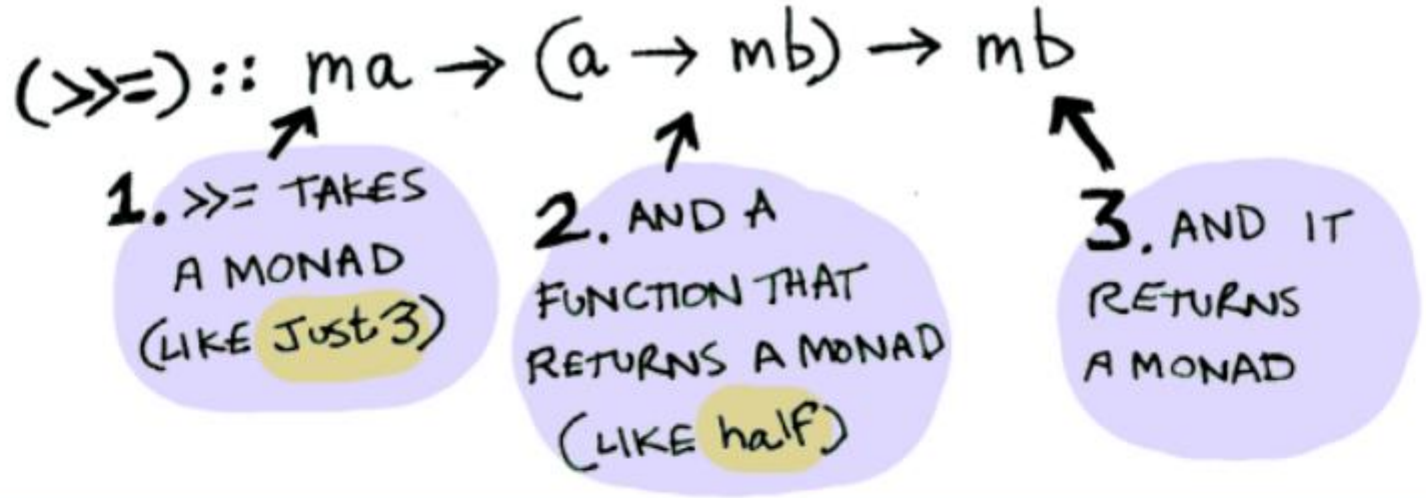
```
half x = if even x
           then Just (x `div` 2)
           else Nothing
```



Monad as a Type Class

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

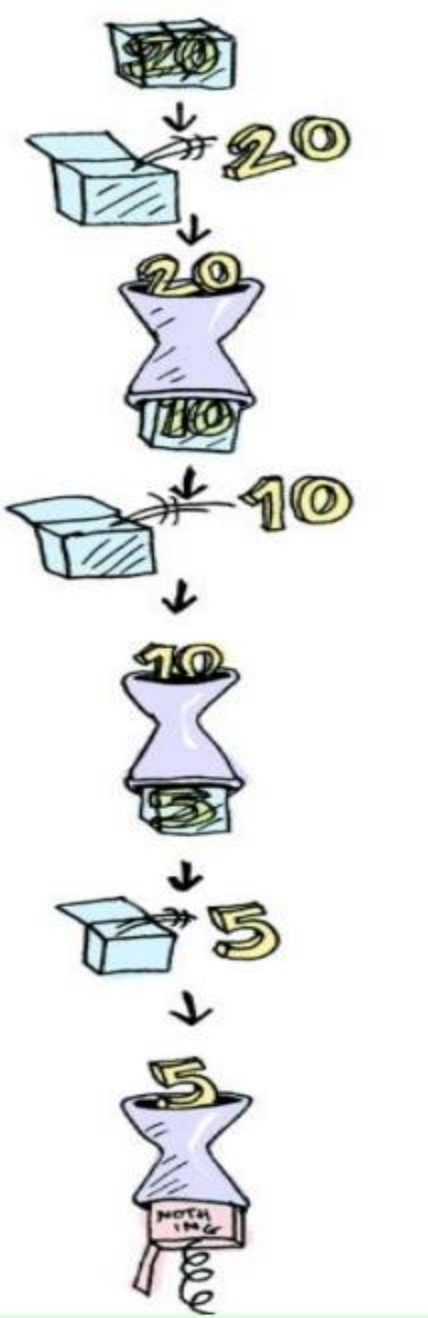
Where `>>=` is:



Chaining via Monads

```
> Just 20 >>= half >>= half >>= half
Nothing
```

```
instance Monad Maybe where
    Nothing >>= func = Nothing
    Just val >>= func  = func val
```



Input-Output as a Monad

`getLine` *takes no arguments and gets user input.*

IO Monad Operation

`readFile` *takes a string (a filename) and returns that file's contents*


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

IO Monad Operation

`putStrLn` takes a string and prints it:


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

Chaining IO Operation

Chaining

```
getLine >>= readFile >>= putStrLn
```

Syntactic Sugar

```
foo = do
    filename <- getLine
    contents <- readFile filename
    putStrLn contents
```

Do Comprehension

- Syntactic sugar notation for Monads.

- List is an instance of monad, and List comprehension is an instance of Do-comprehension!

```
[(x,y) | x <- xs, test x, y<-ys]

  do
    x <- xs
    filter test
    y <- ys
    return (a,b)

  filter test = \ x ->
      if test x then return a else empty
```

Monads

Monads Formally

- Another example of higher-order type class is:

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

  >> :: (m a) -> (m b) -> m b
  m1 >> m2    = m1 >>= (\ _ -> m2)
```

- Laws of `Monad` class:

```
(return a) >>= k     = k a
 m >>= return        = m
(m >>= (\a -> (k a) >>= (\b -> h b))
        = (m >>= (\a -> k a) >>= (\b -> h b)
```

- IO is an instance of Monad …

Input/Output

Input/Output

- The I/O system in Haskell is purely functional but has all the expressive power of conventional imperative languages.

- Actions are *defined* rather than *invoked* in an expression-oriented style.

- These actions are modelled as *monads* of type `IO t` which is a conceptual structure with some properties that supports imperative actions.

Basic I/O Operations

- Every I/O action returns a value, e.g :

```
getChar        :: IO Char
```

- Some IO actions also take input(s)

```
putChar        :: Char -> IO ()
```

- `IO` is an instance of the the `Monad` class.

- Actions are sequenced by bind operator:

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

Basic I/O Operations

- The do statement captures a sequence of actions, e.g :

```
main   :: IO ()
main   = do c <- getChar
            putChar c
```

- Syntactic sugar for the following:

```
main   = getChar >>=
           (\ c -> putChar c)
```

- How to return a value from sequence of actions?.

```
ready  = IO Bool
ready  = do c <- getChar
            c ==‘y’
```

```
return (c ==‘y’)
```

Bigger I/O Operations

- Function to get a string of char may use recursion, as follows:

```
getLine   :: IO String
getLine   = do c <- getChar
               if c=='\n' then return ""
               else do l <- getLine
                       return (c:l)
```

- A pure value can be converted into an action by return, but the not the converse. Illegal to use:

```
x + print y
```

- Function `f::Int -> Int -> Int` cannot do any IO at all, unless we make use of unsafe operations.

Building Actions

- IO operations are ordinary Haskell values that can be passed to functions, placed into data structures and returned as results etc.
- Example : we can build a list of actions.

```
todoList :: [IO ()]
todoList = [ putChar 'a',
             do {putChar 'b'; putChar 'c'},
             do {x <- getChar; putChar x} ]
```

- Can combine them into a single action using:

```
sequence_ :: [IO ()] -> IO ()
sequence_ = foldr (>>) (return ())
```

Imperative Programming

- I/O programming in Haskell is very close to that being done for ordinary imperative programming.

- As a comparison, imperative `getLine` is simply:

```
function getLine() {
     c := getChar();
     if c=='\n' then return ""
     else  {l:=getLine();
            return c:l} }
```

- Main difference is that no special semantics is needed and the entire code is still purely functional. Monad cleanly separates the pure from imperative.

Recap / Comparison

- Imperative `getLine` in C:

```
function getLine() {
     c := getChar();
     if c=='\n' then return ""
     else  {l:=getLine();
            return c:l} }
```

- Monadic IO in Haskell

```
getLine  :: IO String
getLine  = do c <- getChar
              if c=='\n' then return ""
              else do l <- getLine
                      return (c:l)
```