Monad P3 : IO Monad Basics (2A)

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This document was produced by using LibreOffice/OpenOffice.

Based on

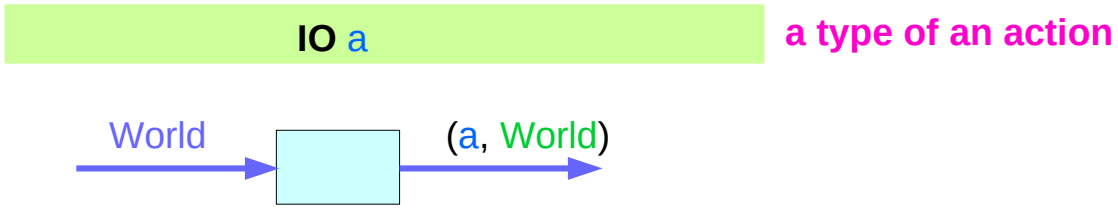
Haskell in 5 steps
https://wiki.haskell.org/Haskell_in_5_steps

IO Monad

Haskell separates **pure functions** from **computations**
where **side effects** must be considered
by encoding those **side effects**
as **values** of a particular type (**IO a**)

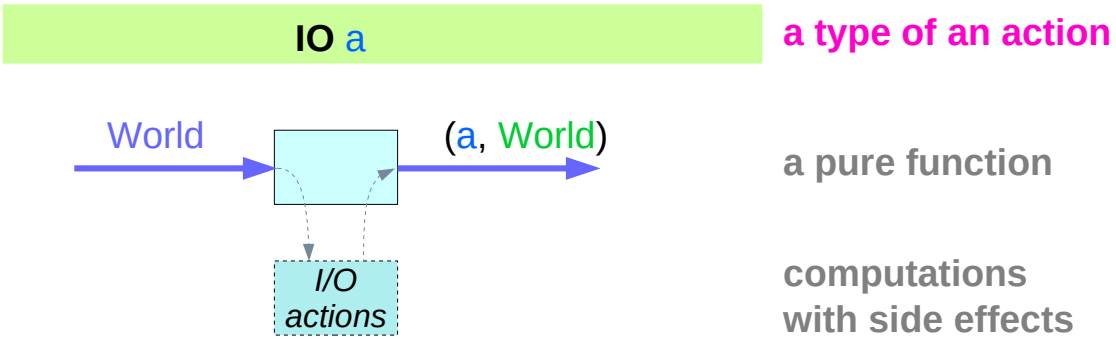
Specifically, a **value** of type (**IO a**) is an **action**,
which *if executed* would produce a **result value** of type **a**.

Execution ➡ IO actions performed
and returns a **value (result)**



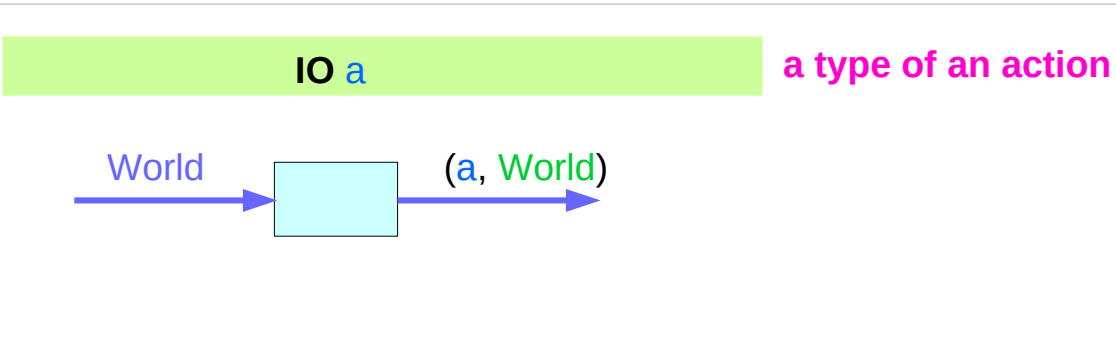
https://wiki.haskell.org/Introduction_to_IO

IO Monad – encoding side effects



Execution ➡ IO actions performed

and returns a **value (result)**



https://wiki.haskell.org/Introduction_to_IO

Computations that result in values

Monads like **IO**

map types **t** to a new type **IO t**

t → **IO t** lifted type

IO t represents computations that result in values

a **function** type: **World -> (t, World)**

the **result** type : **t**

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

```
RealWorld -> (a, RealWorld)
```

```
newtype IO a = IO (State# RealWorld -> (# State# RealWorld, a #))
```

https://wiki.haskell.org/Maybe

Type Synonym **IO t**

IO t is a **parameterized <u>function</u> type**

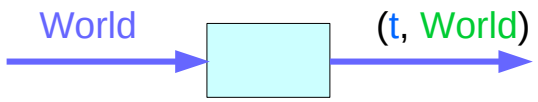
input : a World

output: a result value of the type t and a new updated World
are obtained by modifying the given World
in the process of <u>computing</u> the result value of the type t.

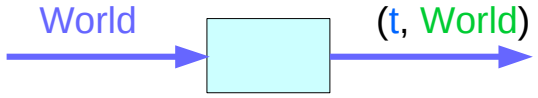
```
type  IO t  =  World  ->  (t, World)
```

type synonym

World -> (t, World)



IO t



cf) type application

RealWorld

https://www.cs.hmc.edu/~adavidso/monads.pdf

The value of type IO a

assume the value of type (IO **a**) is **func**

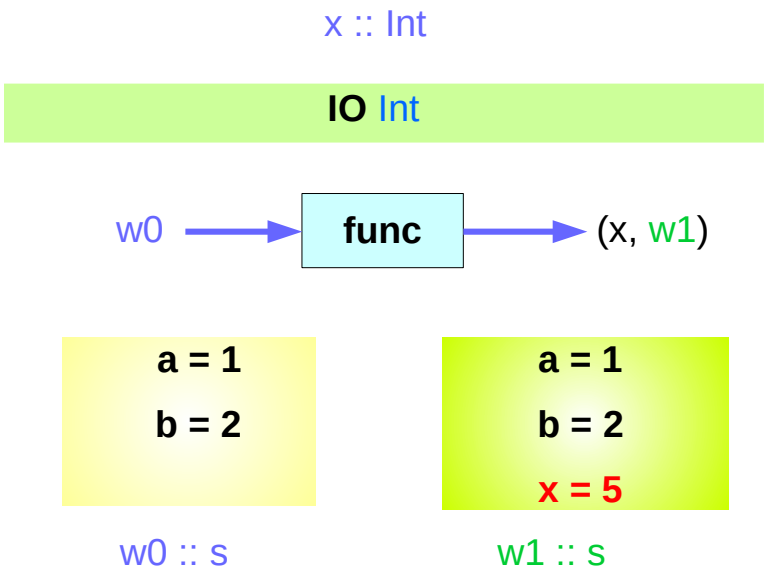
representing an action, which would produce
a **result** value of type **a**, *if executed*

func w0 returns the tuple (**x**, **w1**)
x is the a **result** value of type **a**

When IO **a** is defined as

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

The value **func** of type (IO **a**) is the **name**
of the underlying (state) function



func :: IO a
func :: IO Int

m :: IO a
m :: IO Int

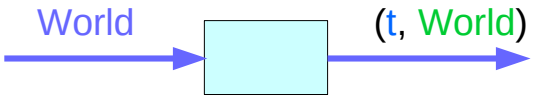
monadic value

IO t is a function type not a function value

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

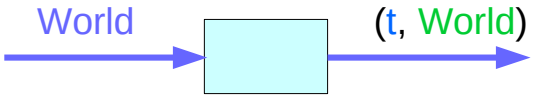
t ➡ IO t lifted type

```
World -> (t, World)
```

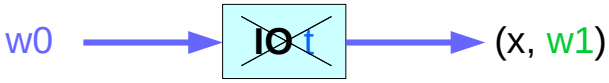



```
let (x, w1) = IO t w0
```

IO t type view



value view



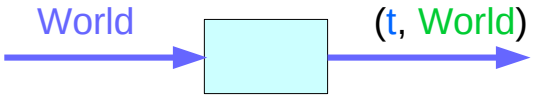

```
x :: t
w1 :: World
(x, w1) :: (t, World)
(x, w1) :: IO t  World
```

(t, World) – the return type of the function

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

World -> (t, World)

IO t



func :: **IO** t

func is a **monadic value** of the type **IO t**, then

func is also the **name** of the underlying function

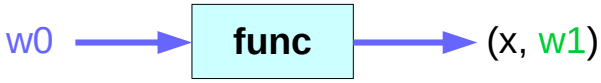
let (x, w1) = **func** w0

x :: t

w1 :: World

(x, w1) :: (t, World)

(x, w1) :: ~~**IO** t World~~

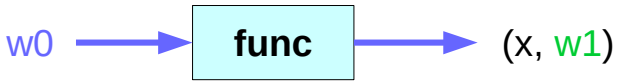


func w0 :: (t, World)

func :: **IO** t

func :: IO Int type

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



(x, w1) = func w0

func :: IO Int	the function type
func w0 :: IO Int World	the function **return** type

func :: World -> (Int, World)
func w0 :: (Int, World)

x :: Int	the **result** type
w0 :: World	the function **input type – initial state type**

let (x, w1) = func w0 the bindings of x and w1

http://learnyouahaskell.com/for-a-few-monads-more

Parameterized type **IO a**

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

```
type   IO Int    =   s   ->   (Int, s)
type   IO Char   =   s   ->   (Char, s)
         ⋮                     ⋮
```

s ← Int

```
type   IO Int    =   Int ->   (Int, Int)
```

func :: IO Int

in practice the type **s** is RealWorld

RealWorld -> (a, RealWorld)

http://learnyouahaskell.com/for-a-few-monads-more

Implementation of IO t

It is impossible

to store the extra copies of the contents of your hard drive

that each of the Worlds contains

given World → updated World

type IO a = RealWorld -> (a, RealWorld)

https://www.cs.hmc.edu/~adavidso/monads.pdf

IO Monad in GHC

Which World was given initially?

Which World was updated?

In **GHC**, a **main** must be defined somewhere with type **IO ()**

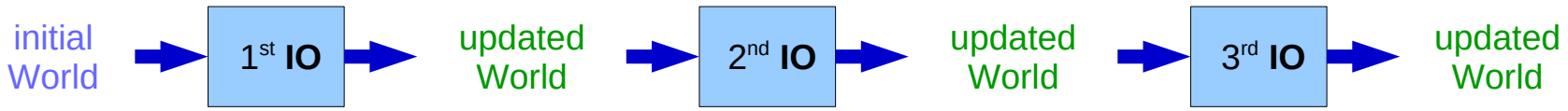
a program execution starts from the **main**

- the initial World is contained in the **main** to start everything off
- the **main** passes the updated World from each **IO**
- to the next **IO** as its initial World

an **IO** that is not reachable from **main** will never be executed

an initial / updated World is not passed to such an **IO**

The modification of the World



https://www.cs.hmc.edu/~adavidso/monads.pdf

IO Monad in GHCI

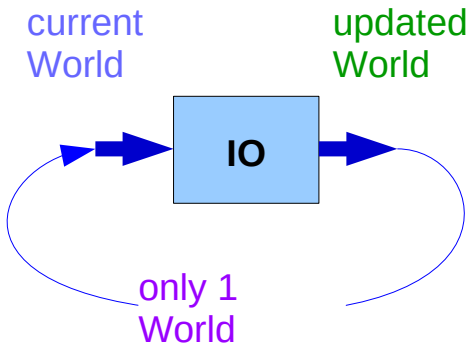
when using **GHCI**,
everything is wrapped in **an implicit IO**,
since the results get printed out to the screen.

there's only 1 World in existence at any given moment.

each **IO** takes that one and only World, consumes it,
and gives back a single new updated World.

consequently, there's no way to accidentally run out of Worlds,
or have multiple ones running around.

the implementation of bind



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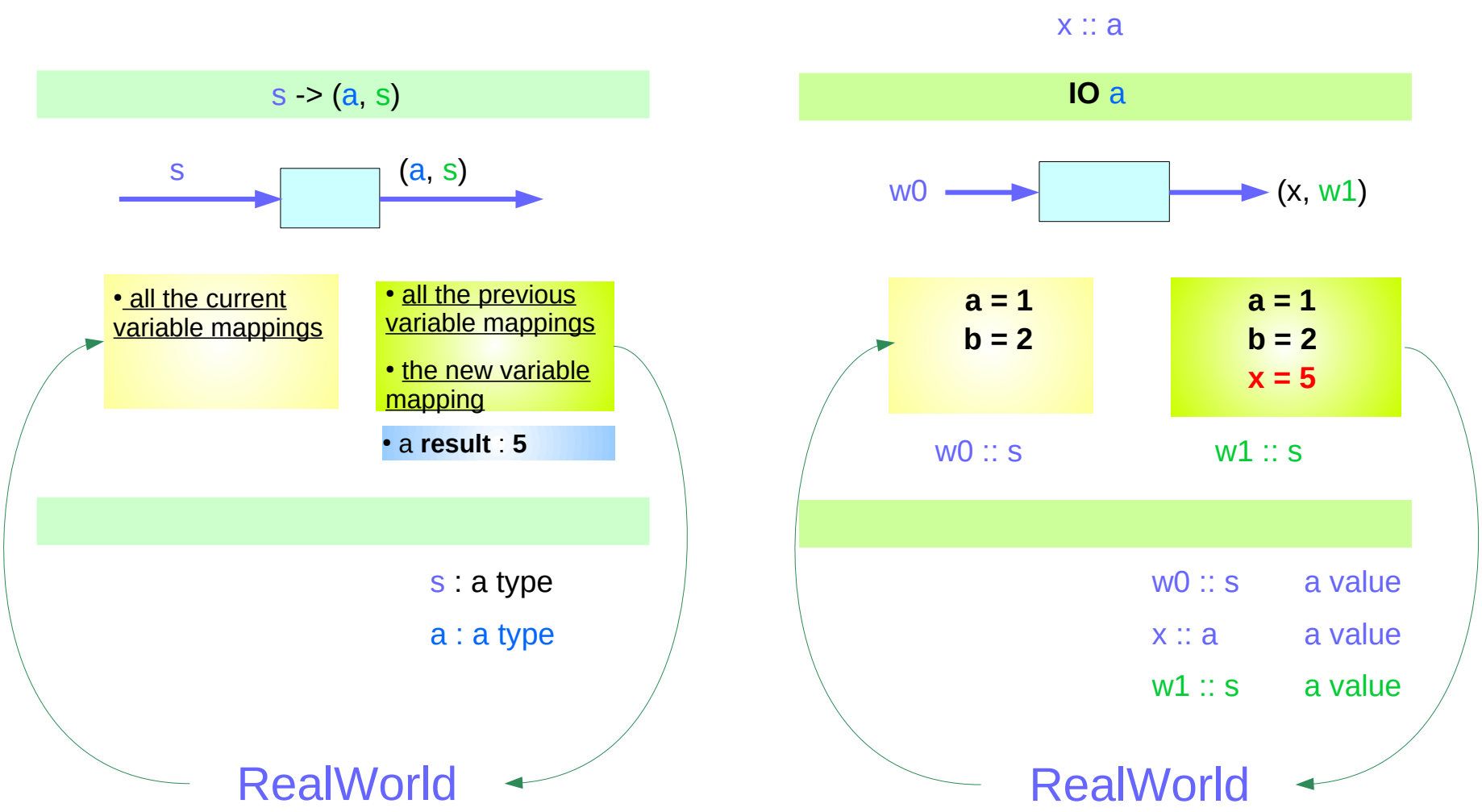
Variable Mappings : Context



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IO Monad Instance (1)

```
instance Monad IO where
   return x w0 = (x, w0)

   (ioX >>= f) w0  =
      let  (x, w1) = ioX w0
      in   f x w1          -- has type (t, World)
```

```
type   IO t   =   World   ->   (t, World)
```
type synonym

https://www.cs.hmc.edu/~adavidso/monads.pdf

IO Monad Instance (2)

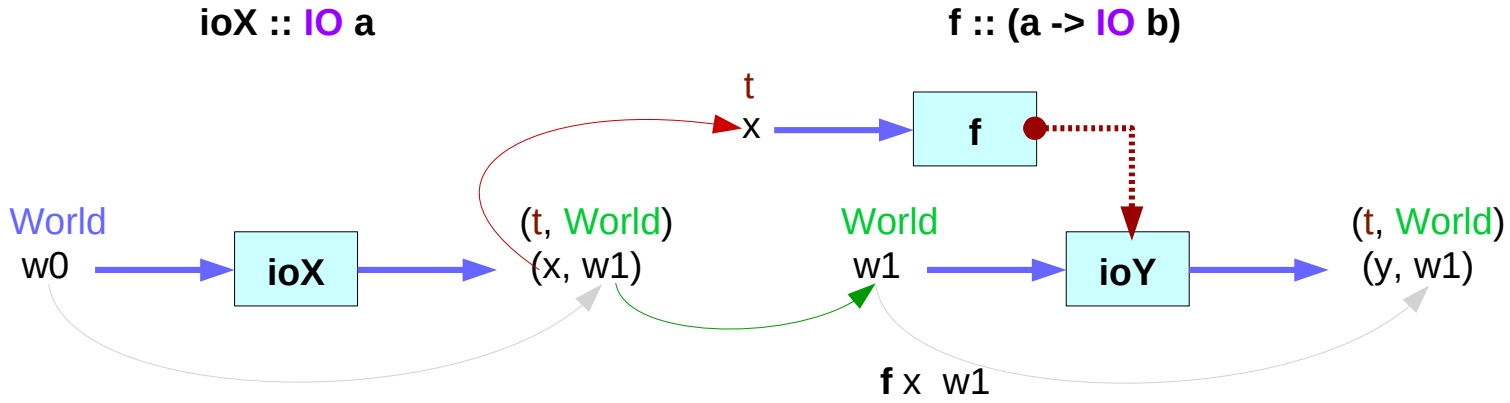
```
instance Monad IO where
   return x w0 = (x, w0)

   (ioX >>= f) w0  =
      let  (x, w1) = ioX w0
      in   f x w1          -- has type (t, World)
```

(ioX >>= f) :: IO a -> (a -> IO b) -> IO b

ioX :: IO a

f :: (a -> IO b)



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return

The **return** function takes **x**

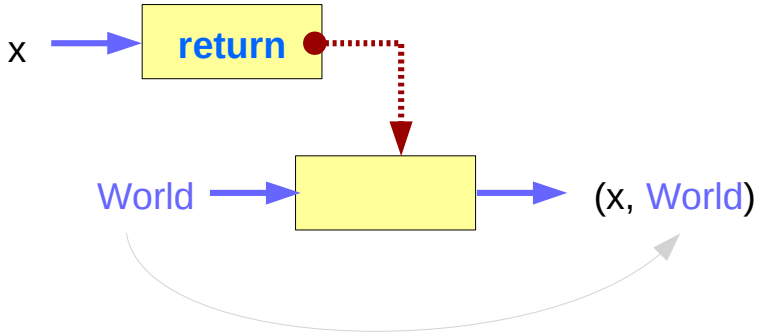
and gives back a function

that takes a World

and returns x along with the “new, updated” World

formed by not modifying the **World** it was given

return x world = (x, world)



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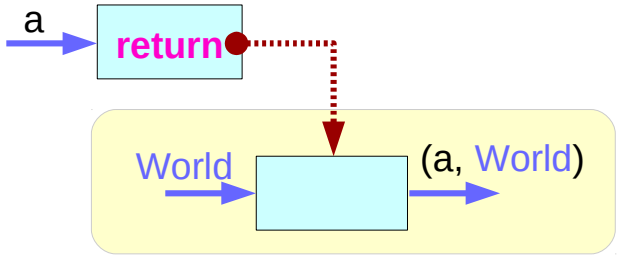
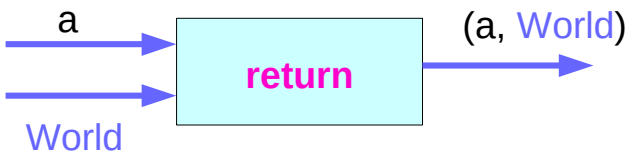
https://www.cs.hmc.edu/~adavidso/monads.pdf

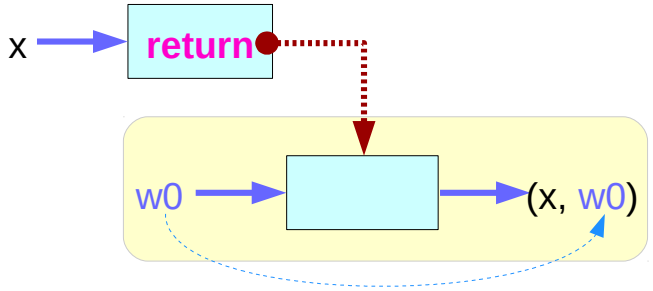
return method and partial application

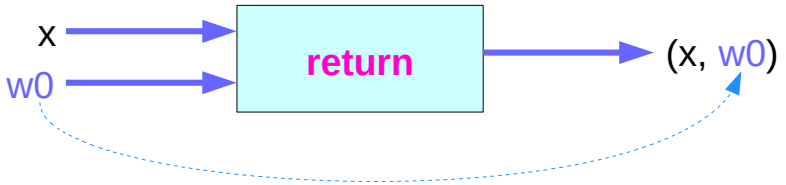
return a :: a -> IO a ⬅ **Types** ➡ **return a World :: (a, World)**





let (x, w0) = return x w0 ⬅ **Values** ➡ **let (x, w0) = return x w0**





https://www.cs.hmc.edu/~adavidso/monads.pdf

IO Monad – >>

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

(x >> y)

- if **x** and **y** are IO actions
- then it is the action that first performs **x**
- dropping the result
- then performs **y**
- returns its result.

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

```
IO ()   ->        IO ()    ->    IO ()
```

https://wiki.haskell.org/Introduction_to_IO

IO Monad – >>=

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

x >> y = x >>= const y

(x >>= f)

- to use the result of the first action (**x**)
- in order to affect what the second action **f** will do

- perform the **first action** : the action **x**
- captures its **result**
- passes it to **f**
- then **f** computes a **second action**
- performs this **second action**
- its **result** is the result of the overall computation.

```
getLine    >>= \name -> putStrLn ("Hello, " ++ name ++ "!")
  IO a     ->       (a -> IO b)                    -> IO b
```

https://wiki.haskell.org/Introduction_to_IO

Bind operator >>= and do Block

```
main = putStrLn "Hello, what is your name?"
       >> getLine
       >>= \name -> putStrLn ("Hello, " ++ name ++ "!")

main = do putStrLn "Hello, what is your name?"
          name <- getLine
          putStrLn ("Hello, " ++ name ++ "!")
```

```
getLine :: IO String
```

>>= (explicit passing)

do (implicit passing)

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

Note that there is no function like this:

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

https://wiki.haskell.org/Introduction_to_IO

iox >>= f

the expression (**ioX >>= f**) has type World -> (t, World)

a function that takes a World, called w0,

which is used to extract **x** from its **IO** monad.

This x gets passed to **f**, resulting in another **IO** monad,

which again is a function that takes a World

and returns a **y** and a new, updated World.

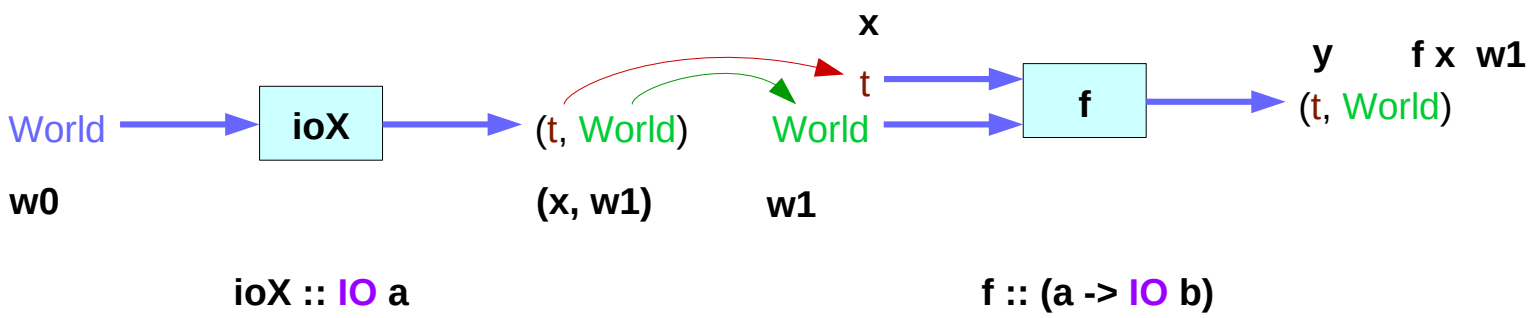
We give it the World we got back from getting **x** out of its monad,

and the thing it gives back to us is the **y** with a final version of the World

.

the implementation of bind

(ioX >>= f) :: IO a -> (a -> IO b) -> IO b



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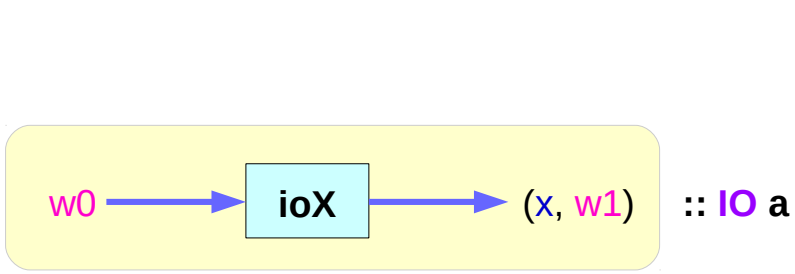
ioX and f types

```
instance Monad IO where
   return x w0 = (x, w0)

   (ioX >>= f) w0  =
      let  (x, w1) = ioX w0
      in   f x w1          -- has type (t, World)
```

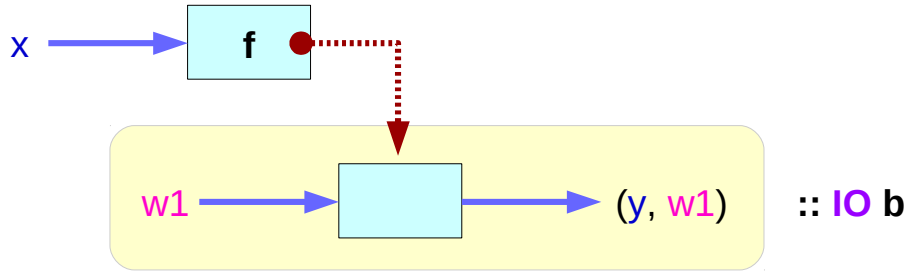
ioX >>= f :: IO a -> (a -> IO b) -> IO b

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

type synonym



ioX :: IO a



f :: (a -> IO b)

https://www.cs.hmc.edu/~adavidso/monads.pdf

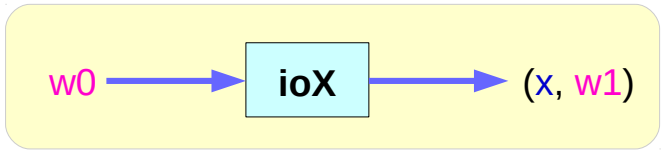
ioX w0 and f x w1

```
ioX >>= f   ::      IO a -> (a -> IO b) -> IO b

ioX :: IO a         w0 :: World       x :: a
f :: a -> IO b      w1 :: World

      ioX w0 :: (a, World)   ➡  (x, w1) :: (a, World)
      f x ::  IO b
      f x w1 :: (b, World)   ➡  (y, w1) :: (b, World)
```

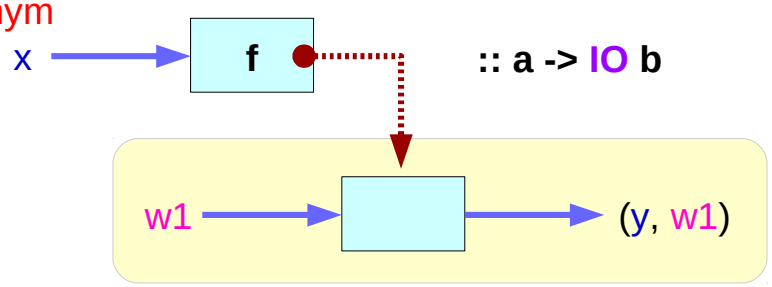
```
f :: a -> IO b
f x :: IO b
f :: a -> World -> (b World)
f x w1 :: (b World)
```

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

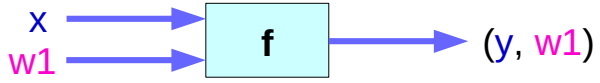
type synonym



ioX w0



f x w1



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Binding variables

ioX >>= f :: IO a -> (a -> IO b) -> IO b

ioX :: IO a
f :: a -> IO b

w0 :: World

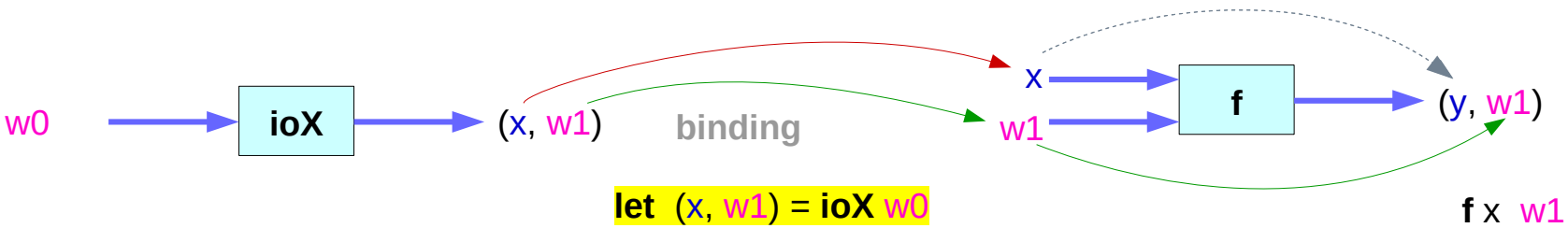
x :: a
w1 :: World

internal variables

ioX w0 **::** (a**,** World) ➡ (x, w1) **::** (a**,** World)
f x :: IO b
f x w1 **::** (b**,** World) ➡ (y, w1) **::** (b**,** World)

ioX – monadic value

f – monad returning function



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Steps of **ioX >>= f** (1. state update, 2. result)

the expression (**ioX >>= f**) has

type **IO a -> (a -> IO b) -> IO b**

first, execute the **action**

execute **ioX**

State updated

w0 → **w1**

result extracted

x is the **result**

then, compute the new **result**

using **f x**

no **State transition**

w1 is remained

result computed **y = (f x)**

(t,World) (t,World) (t,World)

(–,w0) → **(x,w1)** → **(y,w1)**

the implementation of bind

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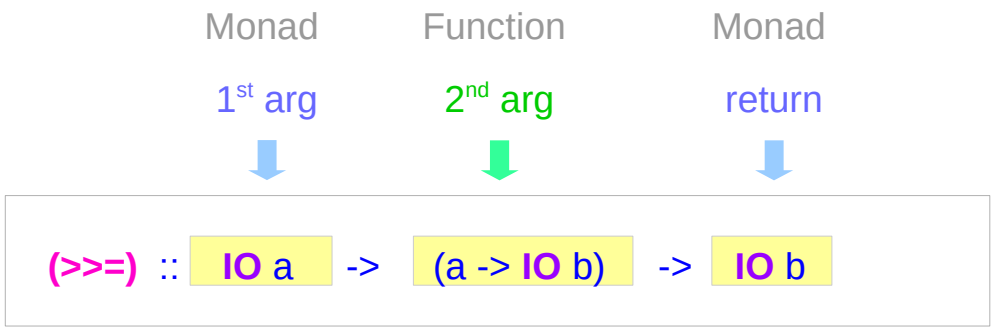
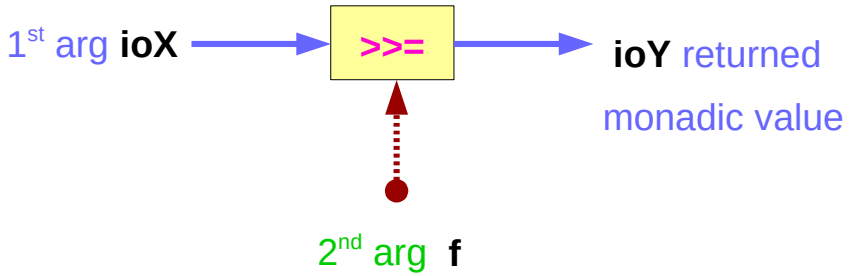
(>>=) operator type signature

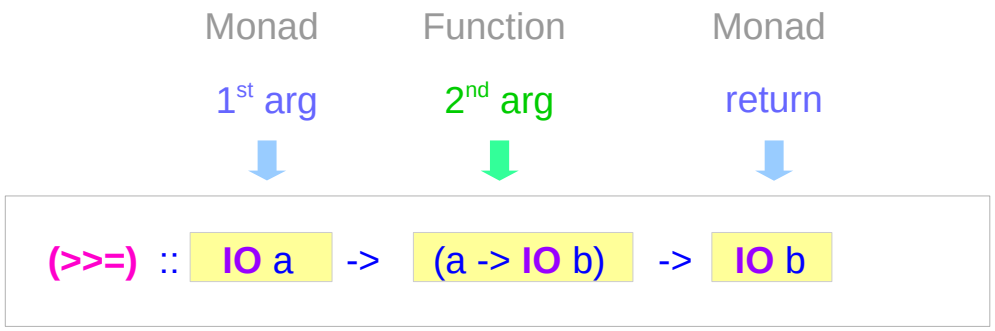


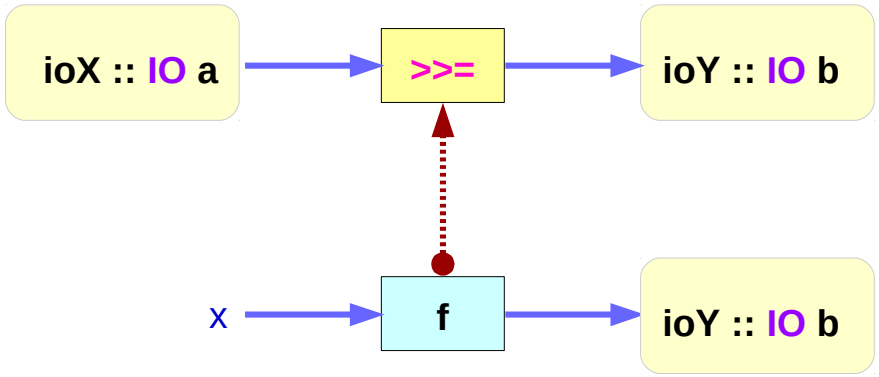


ioX :: IO a

ioY :: IO b

(>>=) operator type diagram

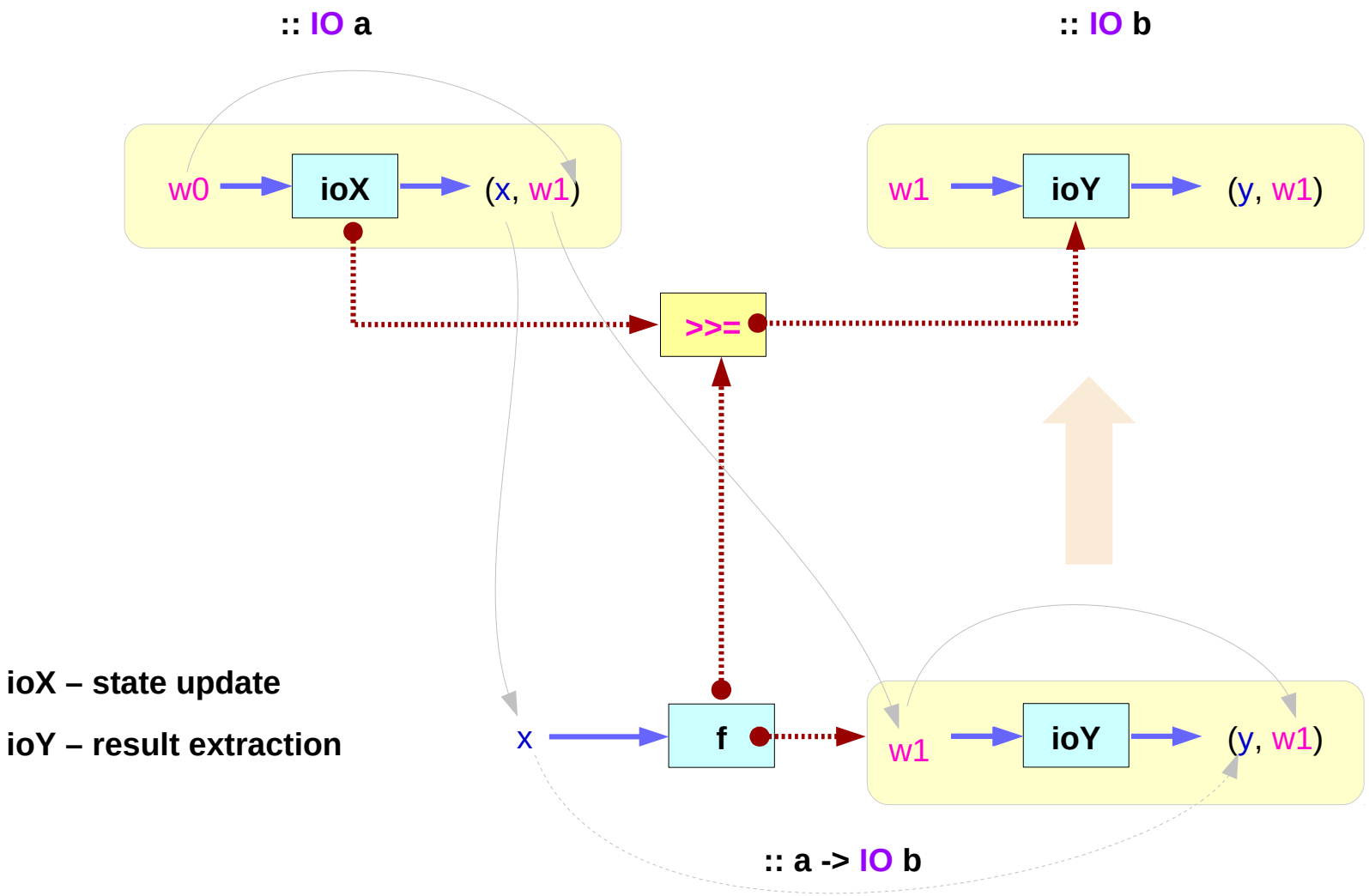




IoX – state update

IoY – result extraction

(>>=) operator threads

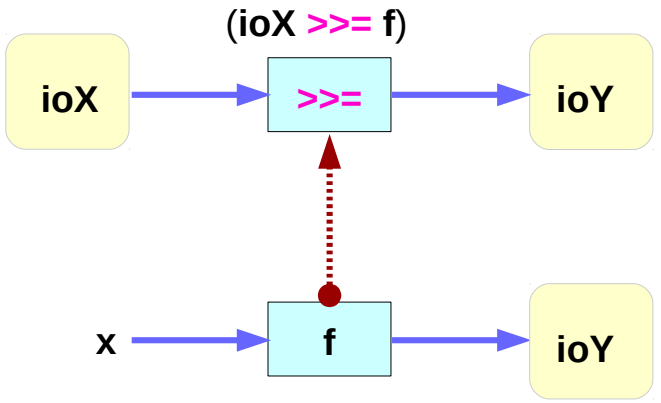


(>>=) operator summary

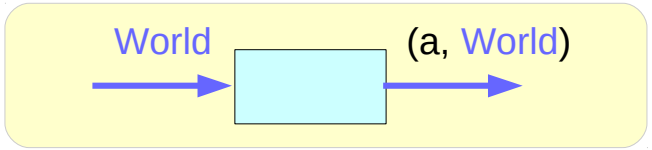
the expression (**ioX >>= f**) has
type **IO a -> (a -> IO b) -> IO b**

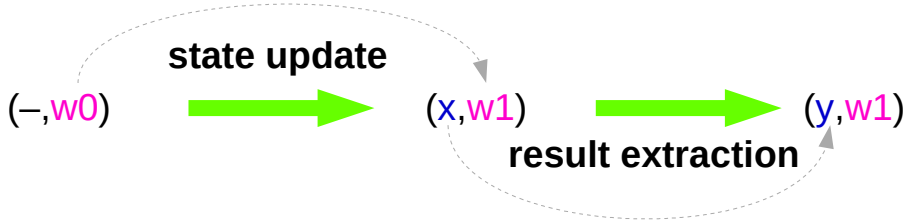
ioX :: **IO a** has a **function** type of **World -> (a, World)**
a **function** that takes **w0 :: World**,
returns **x :: a** and the new, updated **w1 :: World**

x and **w1** get passed to **f**, resulting in another **IO** monad,
which again is a **function** that takes **w1 :: World**
and returns **y** computed from **x** and the same **w1 :: World**



ioX :: IO a **f :: a -> IO a** **ioY :: IO b**





ioX :: IO a

ioY :: IO b

ioX – state update

ioY – result extraction

https://www.cs.hmc.edu/~adavidso/monads.pdf

(>>=) operator binding

We give the **IOx** the **w0** — **w0 :: World**

we got back the updated **w1** — **w1 :: World**

and **x** out of its monad — **x :: a**

the **f** is given with

the **x** with — **x :: a**

the updated **w1** — **w1 :: World**

.

The final **IO** Monad

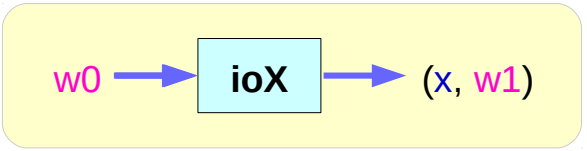
takes **w1** — **w1 :: World**

returns **w1** — **w1 :: World**

and **y** out of its monad — **y :: a**

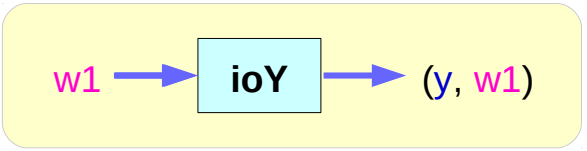
the expression (**ioX >>= f**) has

type **IO a -> (a -> IO b) -> IO b**



let (x, w1) = ioX w0

bind variables



let (y, w1) = ioY w0

bind variables

https://www.cs.hmc.edu/~adavidso/monads.pdf

GHCI

Every time a new **command** is given to **GHCI**,

GHCI passes the current World to **IO**,

GHCI gets the *result* of the command back,

GHCI request to display the *result* (**executing actions**)

(which updates the World by modifying

- the contents of the screen or
- the list of defined variables or
- the list of loaded modules or whatever),

GHCI saves the new World to process the next command.

the implementation of bind

https://www.cs.hmc.edu/~adavidso/monads.pdf

IO Monad

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

newtype IO a = IO (State# RealWorld -> (# State# RealWorld, a #))

newtype State s a = State { runState :: s -> (a, s) }
```

http://blog.ezyang.com/2011/05/unraveling-the-mystery-of-the-io-monad/

Threading the state

```
newtype State s a = State { runState :: s -> (a, s) }


do x <- doSomething
   y <- doSomethingElse
   return (x + y)

\s ->
let (x, s')  = doSomething s
   (y, s'') = doSomethingElse s' in
(x + y, s'')
```

creating data dependecies

s → s' → s''

http://blog.ezyang.com/2011/05/unraveling-the-mystery-of-the-io-monad/

References

[1] ftp://ftp.geoinfo.tuwien.ac.at/navratil/HaskellTutorial.pdf

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