Side Effects (3A)

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1/5/18

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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

Variables

Imperative programming:

- **variables** as changeable locations in a computer's memory
- imperative programs explicitly commands

  the computer what to do

functional programming

- a way to think in higher-level mathematical terms
- defining how **variables** **relate** to one another
- leaving the **compiler** to **translate** these

  to the step-by-step **instructions**

  that the computer can process.

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

Haskell Language Features

Haskell Functional Programming

- **Immutability**
- **Recursive Definition**
- **No Data Dependency**

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

Redefinition : not allowed

imperative programming:

after setting **r = 5** and then changing it to **r = 2**.

r = 5

r = 2

Hakell programming:

an error: "multiple declarations of **r**".

Within a given scope, a **variable** in Haskell

gets defined only once and cannot change,

like variables in mathematics.

r = 5

~~**r = 2**~~

No mutation

In Haskell

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

Variables in a file

Immutable:

they can change only based on

the data we enter to run the program.

We cannot define **r** two ways in the same code,

but we could change the value by changing the file

Vars.hs

```
a = 100
r = 5
pi = 3.14159
e = 2.7818
```

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

Loading a variable definition file

```
$ ghci
GHCi, version 7.10.3: http://www.haskell.org/ghc/  :? for help
Prelude> :load Var1.hs
[1 of 1] Compiling Main             ( var.hs, interpreted )
Ok, modules loaded: Main.
*Main> r
5
*Main> :t r
r :: Integer
*Main>


*Main> :load Var2.hs
[1 of 1] Compiling Main             ( var2.hs, interpreted )
Ok, modules loaded: Main.
*Main> r
55
```

:load Var1.hs

:load Var1.hs

definition with initialization

Var1.hs file

```
r = 5
x = 1
y = 3.14
…
```

Var2.hs file

```
r = 55
x = 1
y = 3.14
…
```

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

No Mutation

```
*Main> r = 33
<interactive>:12:3: parse error on input ‘=’



$ ghci
GHCi, version 7.10.3: http://www.haskell.org/ghc/  :? for help
Prelude> r = 333
<interactive>:2:3: parse error on input ‘=’
Prelude>
```

No mutation, Immutable

let r = 33

let r = 33

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

Recursive Definition

imperative programming: **r = r + 1**

incrementing the variable r

(**updating** the value in memory)

Hakell programming:

a **recursive definition** of **r**

(defining it in terms of itself)

Side effect, Stateful computation

if **r** had been defined with any value beforehand,

then **r = r + 1** in Haskell would bring an error message.

Use a function **addOne x = x + 1**

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

Simulating imperative codes

The most primitive way of **x = v**
is to use a function taking **x** as argument, and pass **v** to that function.

```
// sum 0..100
i = s = 0;
while (i <= 100) {
   s = s+i;
   i++;
}
return s;
```

```
sum = f 0 0  -- the initial values
  where
  f i s | i <=100   = f (i+1) (s+i)  // increment i, augment s
        | otherwise = s              // return s at the end
```

The above code is not pretty FP code,
but it is simulating imperative code

https://stackoverflow.com/questions/43525193/how-can-i-re-assign-a-variable-in-a-function-in-haskell

No Data Depndence

```
y = x * 2
x = 3
```

```
x = 3
y = x * 3
```

Hakell programming:

because the values of variables do not change

variables can be defined in any order

no mandatory : "**x** being declared before **y**"

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

Evaluation

```
   area 5
=>    { replace the LHS  area r = ...  by the RHS  ... = pi * r^2 }
   pi * 5 ^ 2
=>    { replace  pi  by its numerical value }
   3.141592653589793 * 5 ^ 2
=>    { apply exponentiation (^) }
   3.141592653589793 * 25
=>    { apply multiplication (*) }
   78.53981633974483
```

area r = pi * r^2

pi = 3.141592653589793

5^2 = 25

3.141592653589793 * 25 =
78.53981633974483

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

Translation to instructions

functional programming

- leaving the **compiler** to **translate** these

  to the step-by-step **instructions**

  that the computer can process.

replace each **function** and **variable** with its **definition**

repeatedly replace the results until a single value remains.

to apply or call a function means

to **replace** the LHS of its **definition** by its RHS.

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

Side Effects Definition

a **function** or **expression** is said to have a **side effect**
if it modifies some state outside its scope or
has an observable interaction
with its calling functions or the outside world
besides **returning a value**.

a particular function might

- modify a **global** variable or **static** variable,
- modify one of its **arguments**,
- raise an **exception**,
- write data to a **display** or **file**,
- read data from a **keyboard** or **file**, or
- call *other side-effecting functions*.

https://en.wikipedia.org/wiki/Side_effect_(computer_science)

History, Order, and Context

In the presence of **side effects**,
a program's behaviour may depend on **history**;

the **order** of **evaluation** matters.
the **context** and **histories**

Imperative programming : frequent utilization of **side effects**.
functional programming : **side effects** are rarely used.

The lack of side effects makes it easier
to do **formal verifications** of a program

https://en.wikipedia.org/wiki/Side_effect_(computer_science)

Side Effects Examples in C

```
int i, j;
i = j = 3;

i = (j = 3);          // j = 3 returns 3, which then gets assigned to i
```

```
// The assignment function returns 10
// which automatically casts to "true"
// so the loop conditional always evaluates to true

while (b = 10) { }
```

https://en.wikipedia.org/wiki/Side_effect_(computer_science)

Pure Languages

Haskell is a **pure** language

programs are made of **functions**

that can't change

any global state or variables,

they can only do

some computations and return them results.

every variable's value does not change in time

However, some problems are inherently stateful

in that they rely on some state that changes over time.

st1 = 10

s -> (x,s)

st1 (v,10)

a bit tedious to model

Haskell has the **state monad** features

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

Side Effects in Haskell

The functional language Haskell expresses **side effects**

such as **I/O** and

other **stateful computations**

using **monadic actions**

state monad

https://en.wikipedia.org/wiki/Side_effect_(computer_science)

Stateful Computation

a **stateful computation** is a **function** that

takes some **state** and

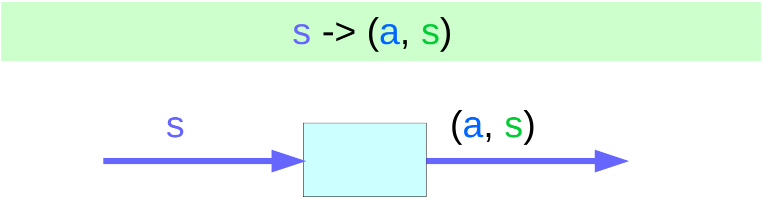
returns a **value** along with some **new state**.

That function would have the following type:

```
s -> (a,s)
```

s is the type of the **state** and

a the **result** of the **stateful computation**.



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

Assignment

Assignment in an imperative language :

will assign the value **5** to the variable **x**

will have the value **5** *as an expression*

Assignment in a functional language

as a **function** that

takes a **state** and

returns a **result** and a **new state**

x = 5

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

Assignment as a stateful computation

Assignment in a functional language

as a **function** that

takes a **state** and

returns a **result** and a **new state**

x = 5

an input **state** :

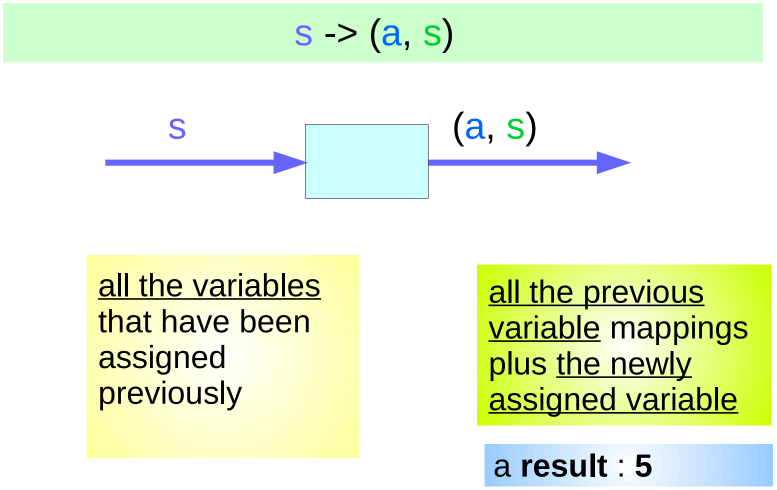
all the variables that have been assigned previously

a **result** : **5**

a **new state** :

all the previous variable mappings plus

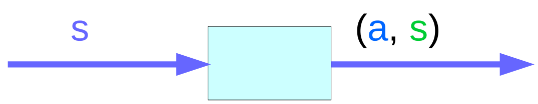
the newly assigned variable.



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

Type Synonym Notation

s -> (a, s)



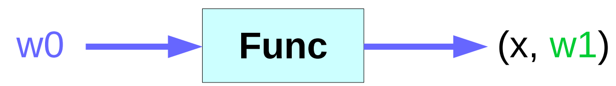
all the variables that have been assigned previously

all the previous variable mappings plus the newly assigned variable

a **result** : **5**

x :: a

IO a



a = 1
b = 2

w0 :: s

a = 1
b = 2
x = 5

w1 :: s

type **IO** a = s -> (a, s)
type **IO** Int = s -> (Int, s)
type **IO** Char = s -> (Char, s)

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

Func :: IO Int

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

Type Synonym Notation

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

put :: s -> (State s) ( )

putStr :: String -> IO ( )

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

an **initial state**

Func :: IO Int

Func w0 **:: IO** Int Int

an **initial state type**

x **::** Int

w0 **::** Int

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

A value with a **context**

The **stateful computation**:

- a **function** that
  - takes a **state** and
  - returns a **result** and a **new state**
- can be considered as a **value** with a **context**

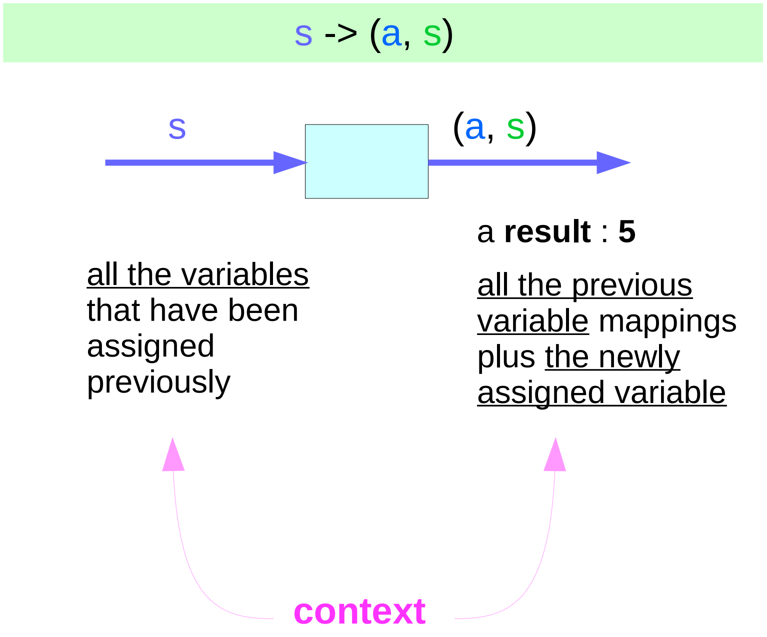
the actual **value** is

the **result**

the **context** is

that we have to provide an **initial state** to get the **result** and

that apart from getting the **result**, we also get a **new state**.



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

Monadic Effect

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

https://en.wikibooks.org/wiki/Haskell/Understanding_monads/IO
https://stackoverflow.com/questions/2488646/why-are-side-effects-modeled-as-monads-in-haskell
https://stackoverflow.com/questions/7840126/why-monads-how-does-it-resolve-side-effects
https://stackoverflow.com/questions/2488646/why-are-side-effects-modeled-as-monads-in-haskell

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

Side Effects of IO Monad

Generally, a monad cannot perform **side effects** in Haskell.
there is one exception: **IO monad**

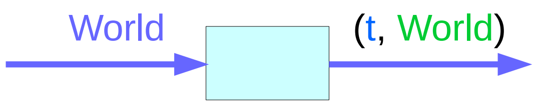
Suppose there is a type called World,
which contains all the state of the external universe

A way of thinking what **IO monad** does

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

type synonym

World -> (t, World)



No variable changes

State changes via a function
A collection of variables
New collection of variables

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

Type Synonym IO t

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

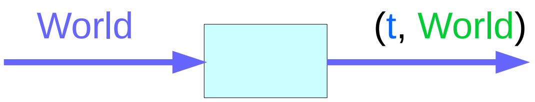
input : a World

output: a value of the type t and a new updated World
obtained by modifying the given World
in the process of computing the value of the type t.

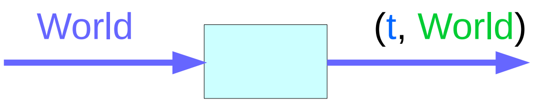
```
type IO t = World -> (t, World)
```

type synonym

World -> (t, World)



IO t



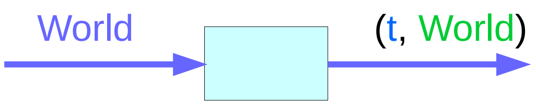
https://www.cs.hmc.edu/~adavidso/monads.pdf

A Parameterized Function of IO Monad (1)

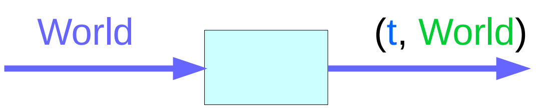
```
type   IO t   =   World   ->   (t, World)
```

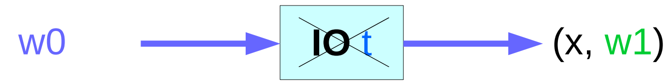
type synonym

World -> (t, World)



IO t





x :: t

w1 :: World

(x, w1) :: IO t World

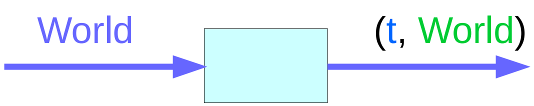
https://www.cs.hmc.edu/~adavidso/monads.pdf

A Parameterized Function of IO Monad (2)

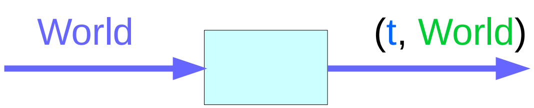
type **IO** t = World -> (t, World)

type synonym

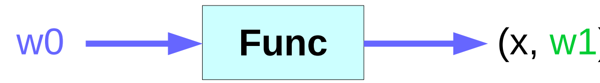
World -> (t, World)



IO t



x :: t
w0 :: World
w1 :: World
(x, w1) :: **IO** t World



Func :: IO t

Func w0 → (x, w1)

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

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

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

Monadic Operation

Monadic operations tend to have types which look like

val-in-type-1 -> ... -> val-in-type-n -> **effect-monad** val-out-type

where the **return type** is a type application:
effect-monad val-out-type

the function tells you
which **effects** are possible

the argument tells you (val-out-type)
what sort of value is produced by the operation

put :: s -> (State s) ( )

putStr :: String -> IO ( )

IO ( )

function: effect-monad
arument: val-out-type

https://stackoverflow.com/questions/16892570/what-is-in-haskell-exactly

Monadic Operation – put, putStr

put :: s -> State s ( )

put :: s -> (State s) ( )

one value input type	**s**
the **effect-monad**	**State s**
the value output type	**( )**

the operation is used *only for its effect*;
the *value* delivered is *uninteresting*

putStr :: String -> IO ( )

delivers a string to stdout but does not return anything exciting.

https://stackoverflow.com/questions/16892570/what-is-in-haskell-exactly

IO Monad

We give **IO** the World — world0 :: World

we got back the World — world1 :: World

from getting x out of its monad, — x :: t

and the thing **IO** gives back to us is

the y with — y :: t

a final version of the World — world1 :: World

.

(t,World)	→	(t,World)	→	(t,World)
(x,world0)		(x,world1)		(y,world1)

the implementation of bind

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

IO Monad in GHC

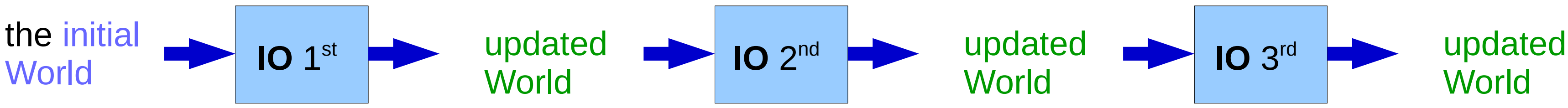
Which World was given initially?
Which World was updated?

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



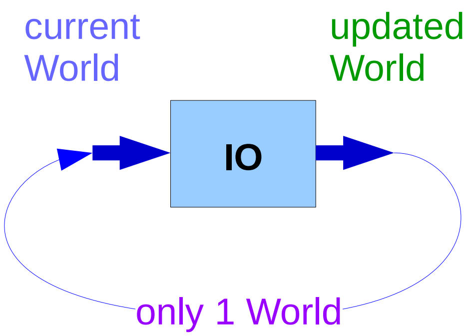
https://www.cs.hmc.edu/~adavidso/monads.pdf

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

the implementation of bind



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*

(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

Monad Definition

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

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

IO Monad Implementation

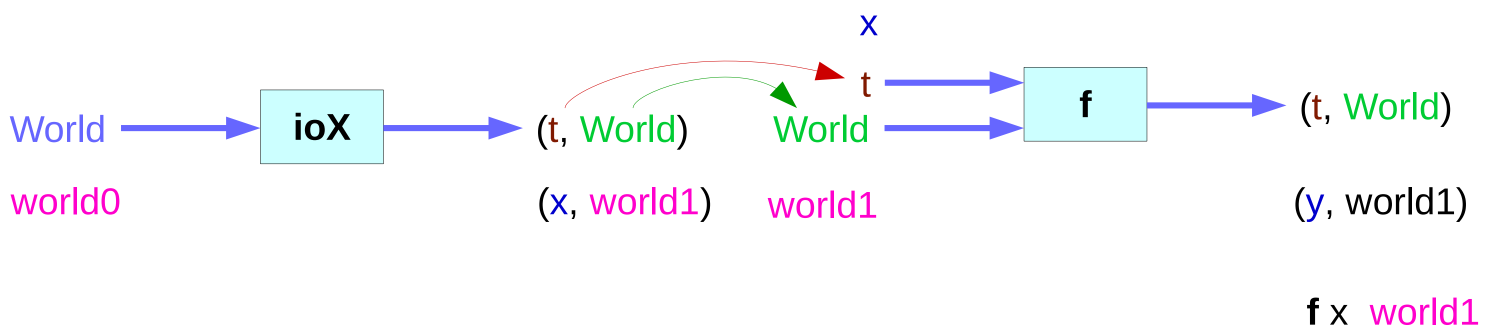
```
instance Monad IO where
    return x world = (x, world)

    (ioX >>= f) world0  =
        let    (x, world1) = ioX world0
        in     f x world1            -- has type (t, World)
```

(x,s) → (x,s') → (y,s')

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

type synonym



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

Monad IO and Monad ST

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

    (ioX >>= f) world0  =
        let    (x, world1) = ioX world0
        in     f x world1          -- has type (t, World)
```

```
instance Monad ST where
    -- return :: a -> ST a
    return x  =  \s -> (x,s)

    -- (>>=)  :: ST a -> (a -> ST b) -> ST b
    st >>= f  =  \s -> let (x,s') = st s
                        in f x s'
```

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

type synonym

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

State Transformers ST

```
instance Monad ST where
  -- return :: a -> ST a
  return x  =  \s -> (x,s)

  -- (>>=)  :: ST a -> (a -> ST b) -> ST b
  st >>= f  =  \s -> let (x,s') = st s in f x s'
```

>>= provides a means of sequencing state transformers:
st >>= f applies the state transformer **st** to an initial state s,
then applies the function **f** to the resulting value x
to give a second state transformer (**f** x),
which is then applied to the modified state s' to give the final result:

```
st >>= f  =  \s -> f x s'
        where (x,s') = st s

st >>= f  =  \s -> (y,s')
        where (x,s') = st s
              (y,s') = f x s'
```

(x,s') = **st** s

f x s'

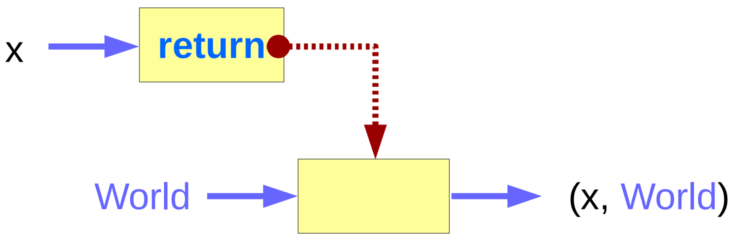
https://cseweb.ucsd.edu/classes/wi13/cse230-a/lectures/monads2.html

Monad IO - return

The **return** function takes x
and gives back a function
that takes a World
and returns x along with the new, updated World (=World)
formed by not modifying the World it was given

.

return x world = (x, world)



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

Monad IO - >>=

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

type World -> (t, World)

a function **ioX** that takes world0 of the type World,

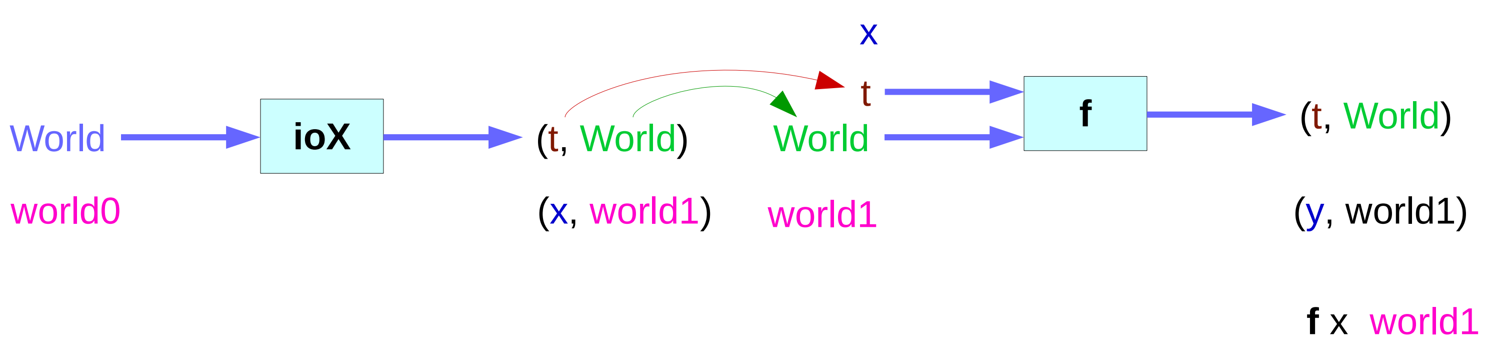
which is used to extract x from its **IO** monad.

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

which again is a function that takes world1 of the type World

and returns a y and a new, updated World.

the implementation of bind



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

References

[1] ftp://ftp.geoinfo.tuwien.ac.at/navratil/HaskellTutorial.pdf
[2] https://www.umiacs.umd.edu/~hal/docs/daume02yaht.pdf