

# C/CPS 506

**Comparative Programming Languages**

**Prof. Alex Ufkes**

**Topic 8:** Side effects and actions in Haskell

# Notice!









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# Course Administration

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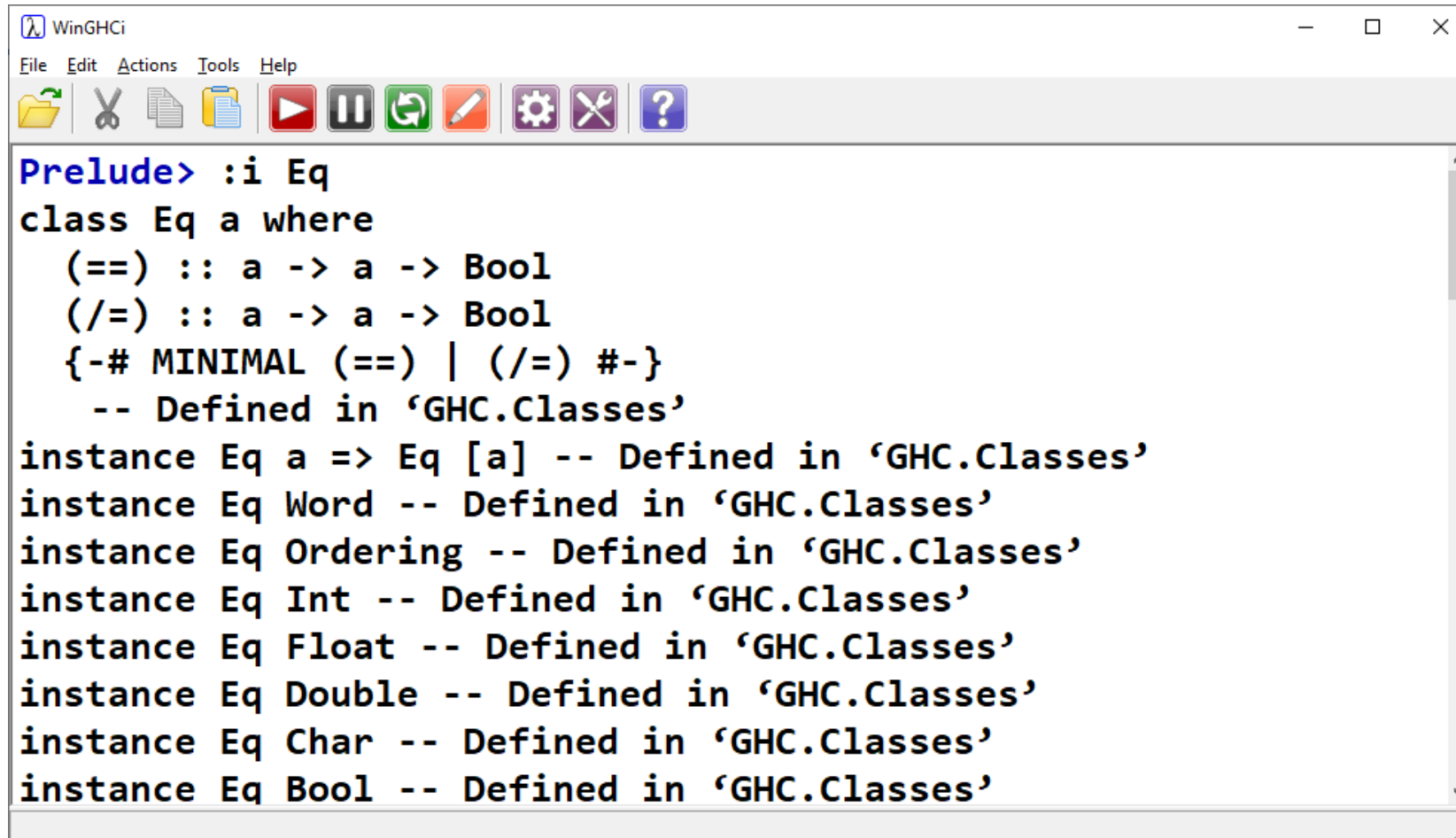
Content Grades Assessment ▾ Communication ▾ Resources ▾ Classlist Course Admin

- Don't forget about the assignments!



# Let's Get Started!

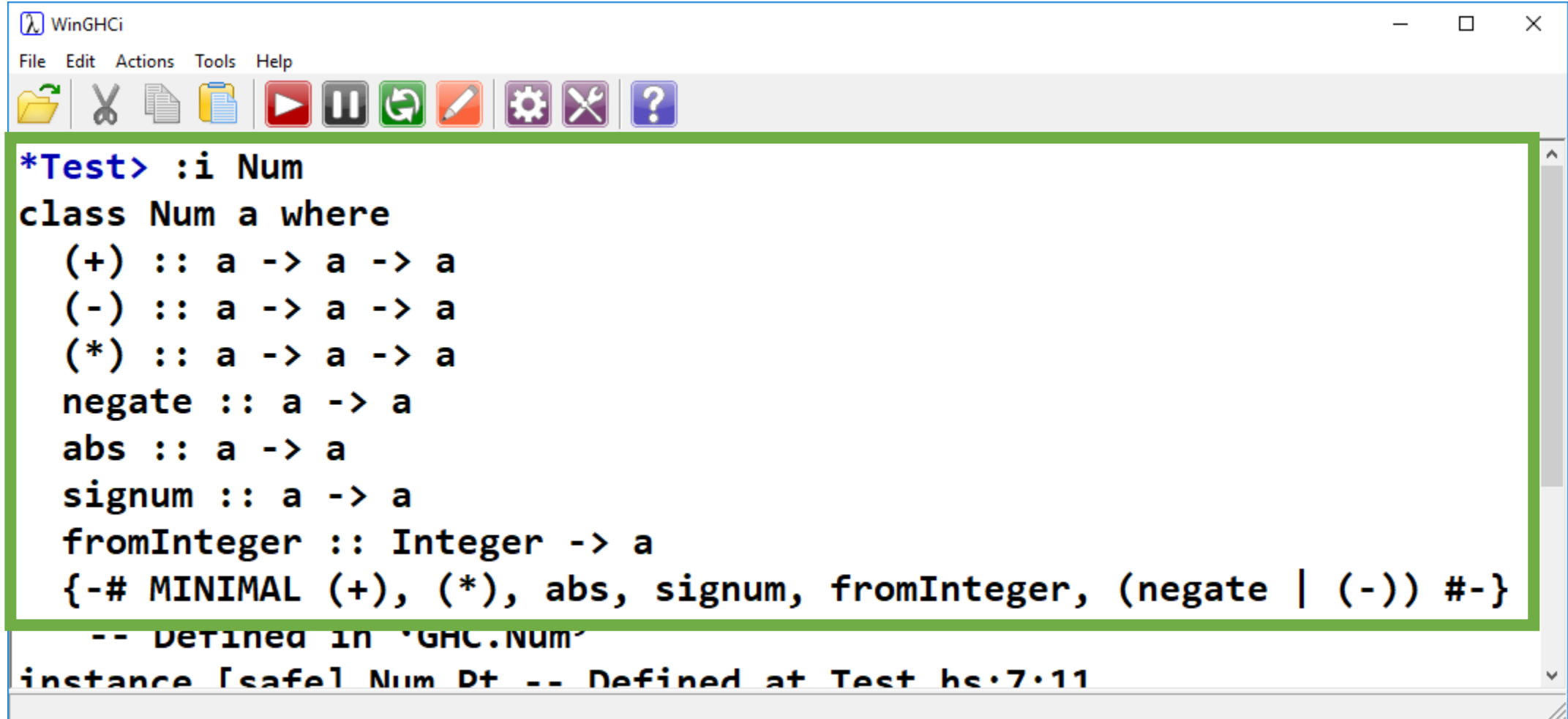
# Previously



```
WinGHCi
File Edit Actions Tools Help
[Icons: Folder, Scissors, Document, Document with Arrow, Play, Pause, Refresh, Pencil, Gear, Wrench, Question Mark]

Prelude> :i Eq
class Eq a where
  (==) :: a -> a -> Bool
  (/=) :: a -> a -> Bool
  {-# MINIMAL (==) | (/=) #-}
  -- Defined in 'GHC.Classes'
instance Eq a => Eq [a] -- Defined in 'GHC.Classes'
instance Eq Word -- Defined in 'GHC.Classes'
instance Eq Ordering -- Defined in 'GHC.Classes'
instance Eq Int -- Defined in 'GHC.Classes'
instance Eq Float -- Defined in 'GHC.Classes'
instance Eq Double -- Defined in 'GHC.Classes'
instance Eq Char -- Defined in 'GHC.Classes'
instance Eq Bool -- Defined in 'GHC.Classes'
```

# Previously



```
WinGHCi
File Edit Actions Tools Help
[Icons: Folder, Scissors, Document, Clipboard, Play, Pause, Refresh, Eraser, Gear, Wrench, Question Mark]

*Test> :i Num
class Num a where
  (+) :: a -> a -> a
  (-) :: a -> a -> a
  (*) :: a -> a -> a
  negate :: a -> a
  abs :: a -> a
  signum :: a -> a
  fromInteger :: Integer -> a
  {-# MINIMAL (+), (*), abs, signum, fromInteger, (negate | (-)) #-}
  -- Defined in <GHC.Num>
instance [safe] Num DInt -- Defined at Test.hs:7:11
```

# Ord:

```
WinGHCi
File Edit Actions Tools Help
instance Ord Ordering -- Defined in 'GHC.Classes'
instance Ord Int -- Defined in 'GHC.Classes'
instance Ord Float -- Defined in 'GHC.Classes'
instance Ord Double -- Defined in 'GHC.Classes'
instance Ord Char -- Defined in 'GHC.Classes'
instance Ord Bool -- Defined in 'GHC.Classes'
instance (Ord a, Ord b, Ord c, Ord d, Ord e, Ord f, Ord
```

# Num:

```
WinGHCi
File Edit Actions Tools Help
-- Defined in 'GHC.Num'
instance Num Word -- Defined in 'GHC.Num'
instance Num Integer -- Defined in 'GHC.Num'
instance Num Int -- Defined in 'GHC.Num'
instance Num Float -- Defined in 'GHC.Float'
instance Num Double -- Defined in 'GHC.Float'
*Test>
```



# Pure Code, Monads, Actions



*Every function is pure*



**Pure Functions:** Functions that have no side effects.



A function can be said to have a side effect if it has an observable interaction with the outside world aside from returning a value.

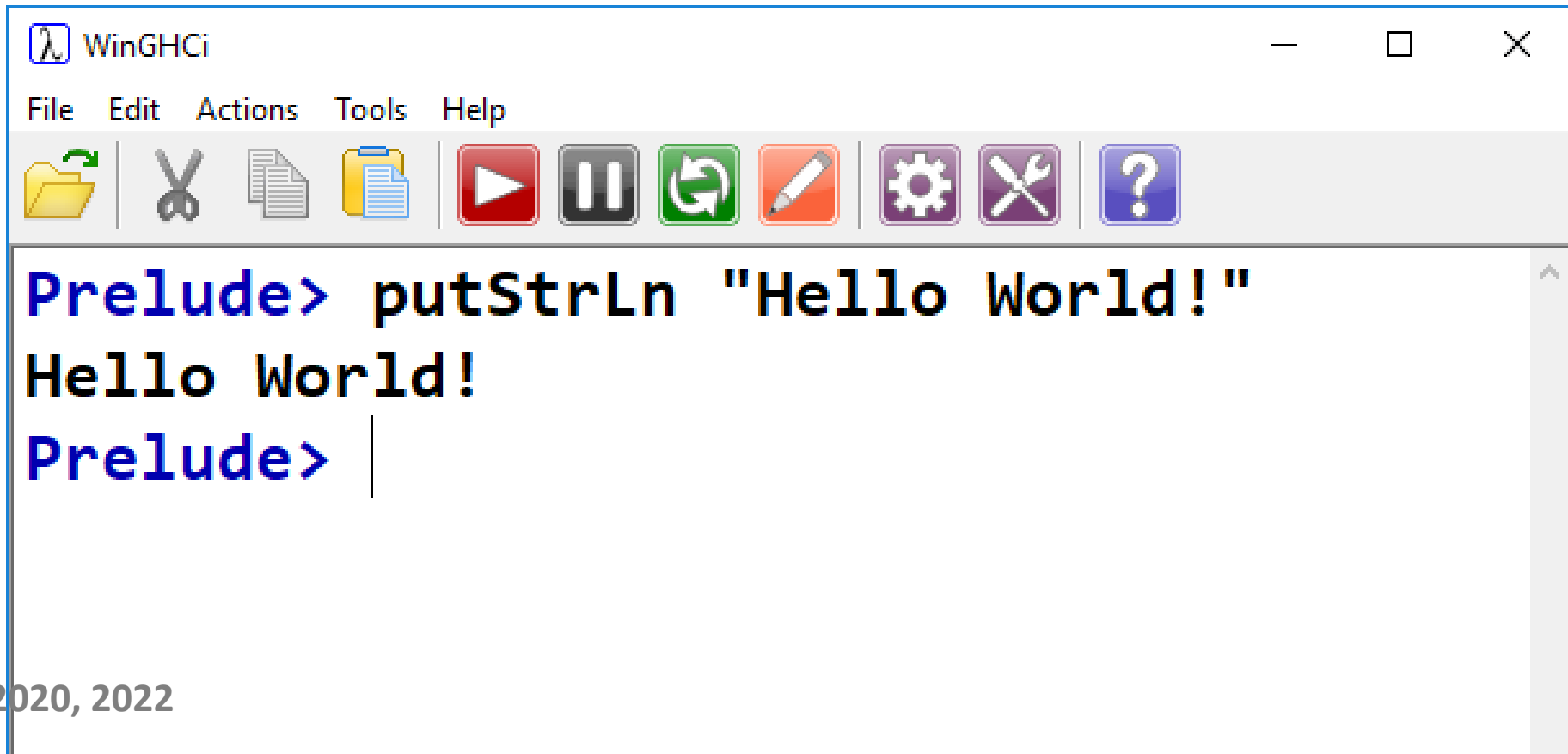


- Modify global variable
- Raise an exception
- **Write data to display** or file

# Write to Display

---

This was the very first thing we saw!



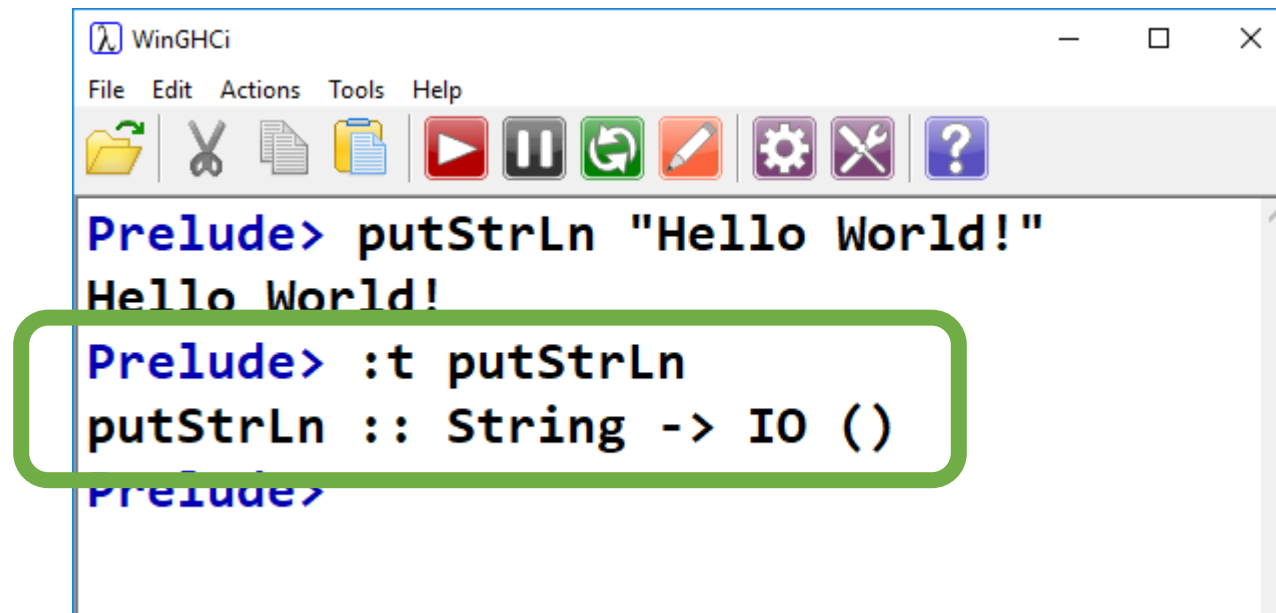
The screenshot shows a window titled "WinGHCi" with a menu bar (File, Edit, Actions, Tools, Help) and a toolbar containing icons for file operations, execution, and settings. The main text area displays the following interaction:

```
Prelude> putStrLn "Hello World!"  
Hello World!  
Prelude> |
```

# Haskell and I/O

---

- Haskell separates pure functions from computations where side effects must be considered
- Encodes side effect-producing functions with a specific type.
- We've already seen an example of this:

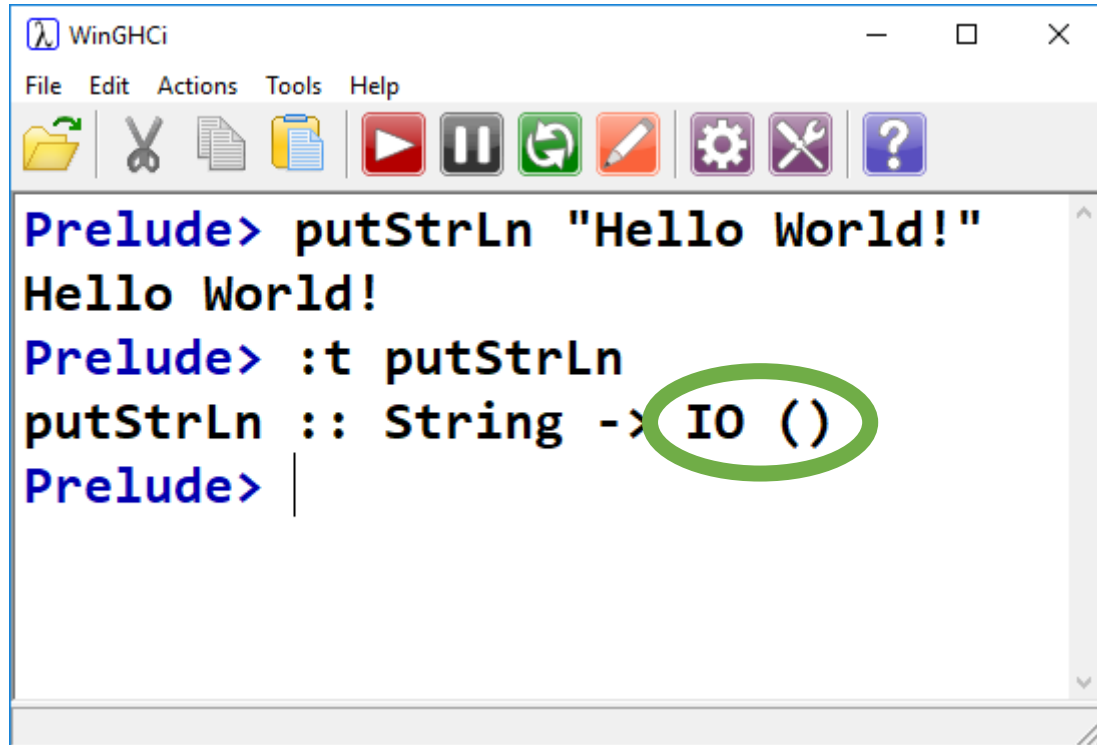
A screenshot of the WinGHCi Haskell interpreter window. The window has a title bar 'WinGHCi' and a menu bar with 'File', 'Edit', 'Actions', 'Tools', and 'Help'. Below the menu bar is a toolbar with icons for file operations (folder, scissors, copy, paste), execution (play, pause, refresh), editing (eraser, pencil), settings (gear, wrench), and help (question mark). The main text area shows the following interaction:

```
Prelude> putStrLn "Hello World!"  
Hello World!  
Prelude> :t putStrLn  
putStrLn :: String -> IO ()  
Prelude>
```

The line `putStrLn :: String -> IO ()` is highlighted with a green rounded rectangle.

# Haskell and I/O

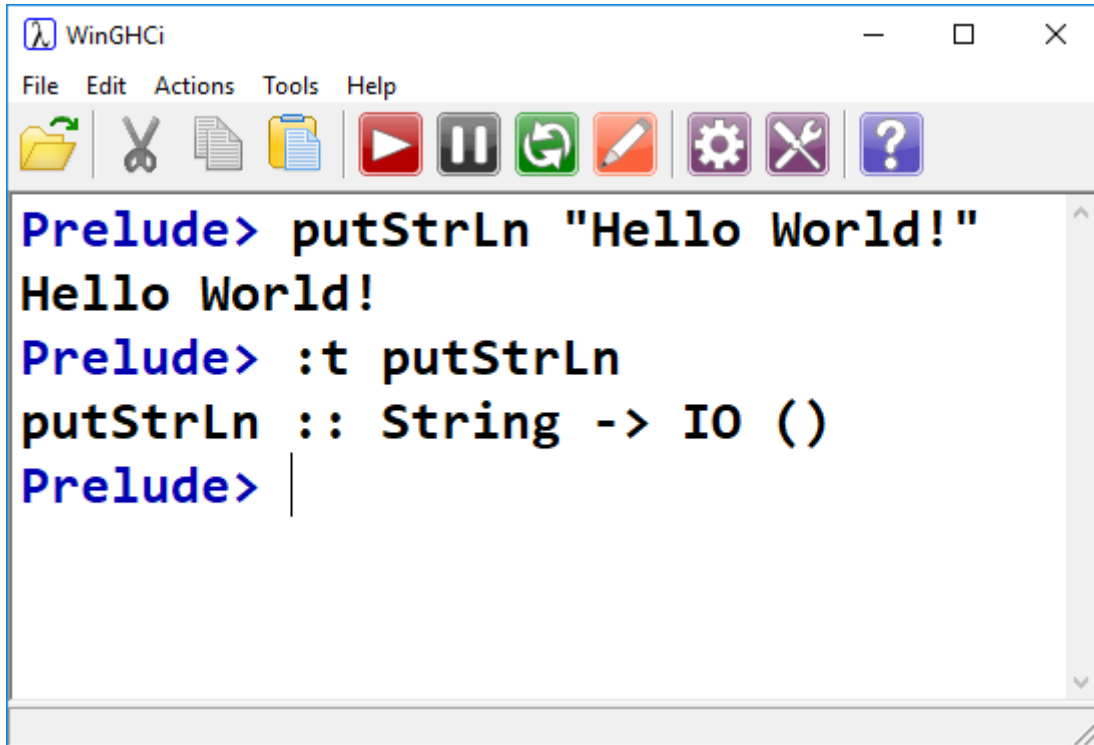
---



```
Prelude> putStrLn "Hello World!"
Hello World!
Prelude> :t putStrLn
putStrLn :: String -> IO ()
Prelude> |
```

- The actual ***act*** of printing to the screen does not occur as a result of a function call.
- Printing to the screen is an ***action***.
- Actions are **values**, they have a type!
- **putStrLn** accepts a **String** argument.
- What it returns is an action of type **IO()**

# Haskell and I/O

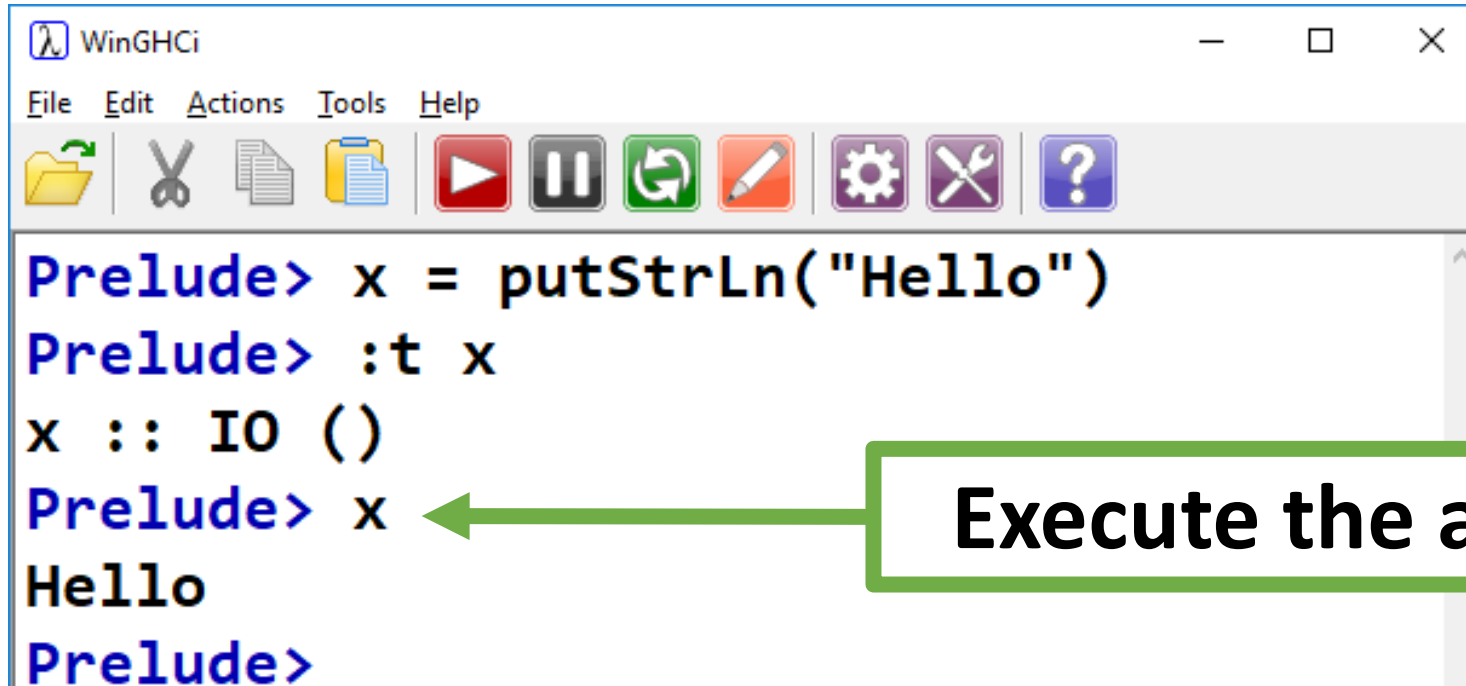


```
WinGHCi
File Edit Actions Tools Help
[Icons]
Prelude> putStrLn "Hello World!"
Hello World!
Prelude> :t putStrLn
putStrLn :: String -> IO ()
Prelude> |
```

## Speaking precisely:

- **putStrLn** is a *function* (no side effects!)
  - Takes a String as an input argument
  - Returns an action, whose type is `IO()`
- When the `IO()` action is executed, it returns `()`.
- This can be read as an empty tuple.
- The action, when executed, produces a side effect.
- The **putStrLn** function, strictly speaking, does **not**.

# Haskell and I/O

A screenshot of the WinGHCi Haskell interpreter window. The window has a title bar with the WinGHCi logo and standard window controls. Below the title bar is a menu bar with 'File', 'Edit', 'Actions', 'Tools', and 'Help'. Underneath the menu bar is a toolbar with icons for file operations (folder, copy, paste, save), execution (play, pause, refresh), editing (eraser), settings (gear), and help (question mark). The main text area shows the following interaction:

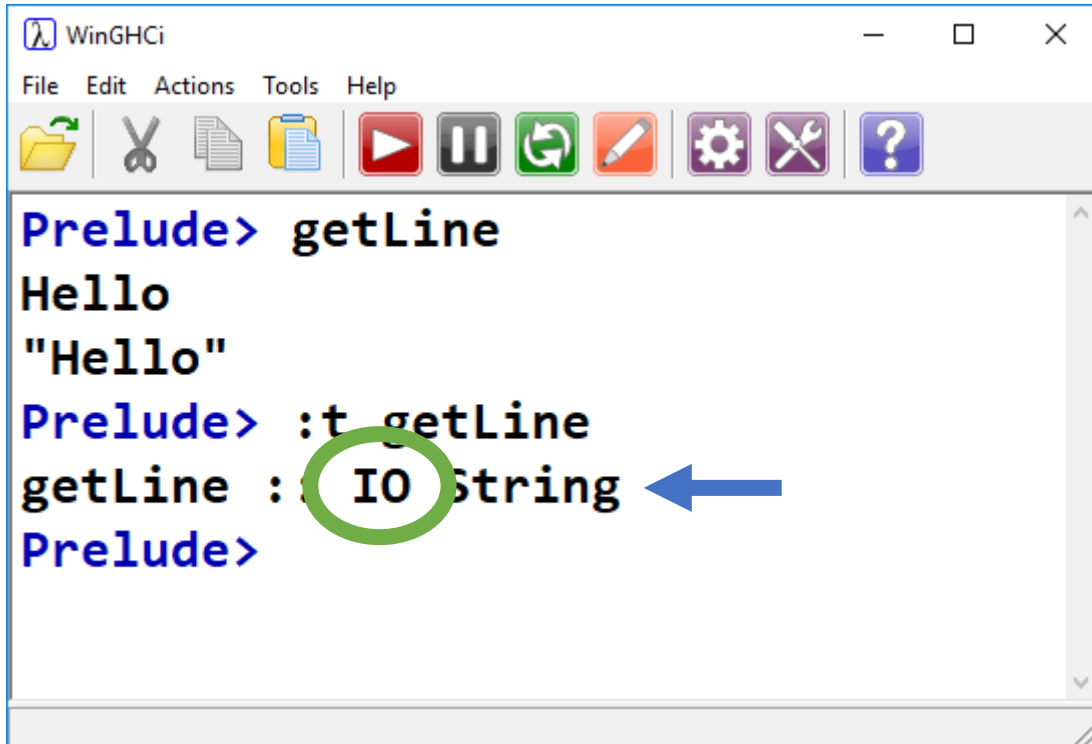
```
Prelude> x = putStrLn("Hello")
Prelude> :t x
x :: IO ()
Prelude> x
Hello
Prelude>
```

A green arrow points from the text 'Execute the action' to the 'x' in the 'Prelude> x' line.

**Execute the action**

- Actions are values, just like strings and numbers.
- They are completely inert – they do not affect the real world until executed.

# Haskell and I/O



```
Prelude> getLine
Hello
"Hello"
Prelude> :t getLine
getLine :: IO String
Prelude>
```

- We can also look at `getLine`
- `getLine` returns an IO action also
- It returns a `String` (`IO String` vs `IO ()`)
- Ordinary Haskell *evaluation* doesn't cause actions to be executed.
- GHCi will execute actions for us, as seen previously.



**Just remember:** actions are not functions.

Functions are pure. Actions (specifically IO actions),  
when executed are not.

Functions are *evaluated*, actions are *executed* or *run*

Actions are values. Actions can be returned by functions  
or passed as arguments.

Actions have a type. We've seen one so far, **IO**

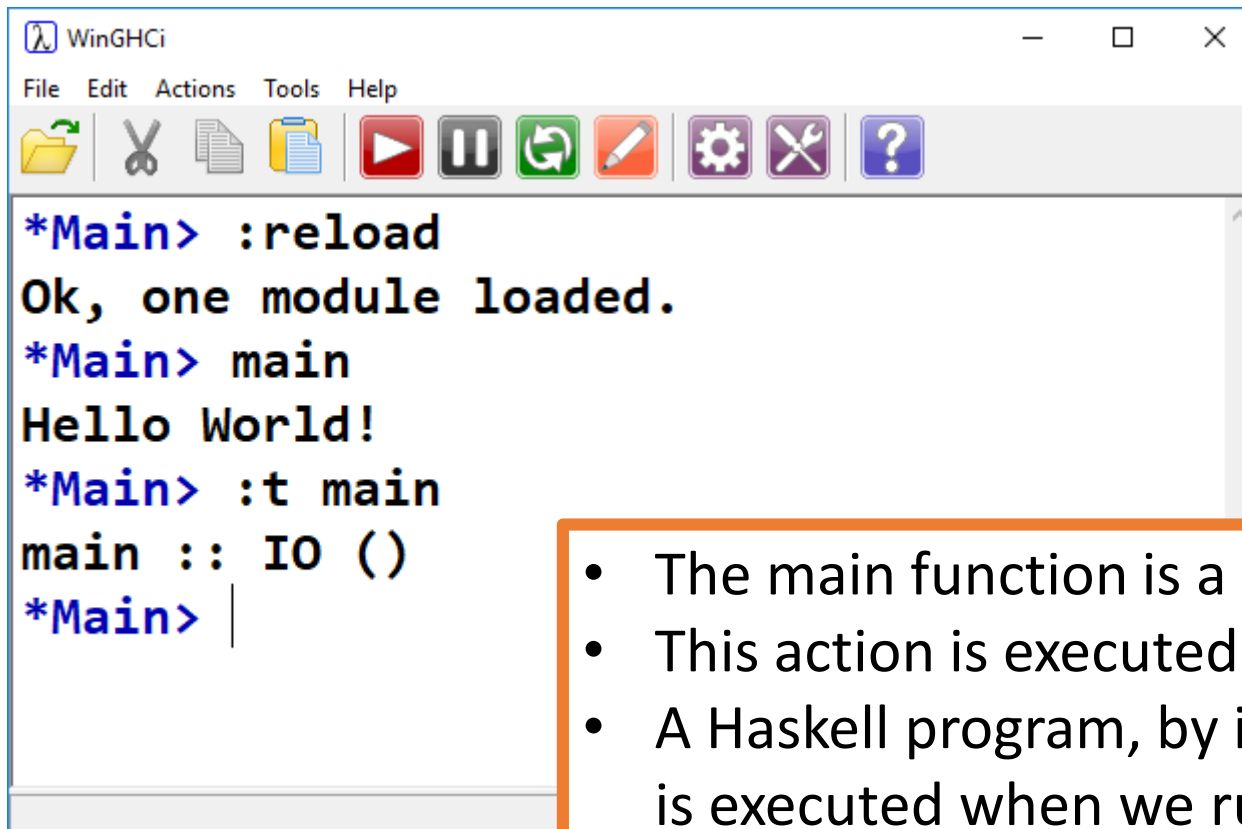
Actions can only be executed from within other actions.

A compiled Haskell program begins by executing a  
single action – **`main :: IO()`**

[https://wiki.haskell.org/Introduction\\_to\\_Haskell\\_IO/Actions](https://wiki.haskell.org/Introduction_to_Haskell_IO/Actions)

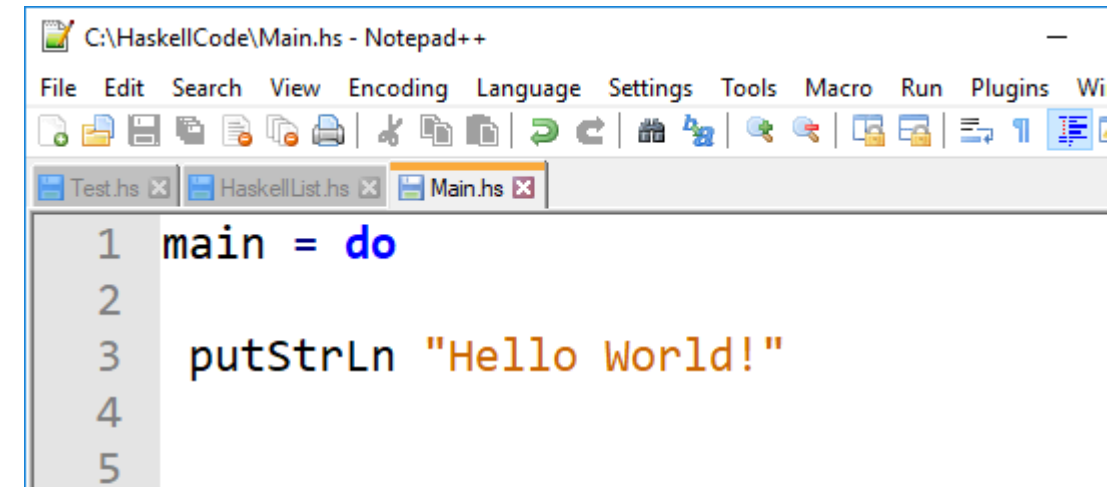
# main :: IO()

**Recall:** Every compiled Haskell program must have a main function:



A screenshot of the WinGHCi terminal window. The window has a menu bar with 'File', 'Edit', 'Actions', 'Tools', and 'Help'. Below the menu is a toolbar with icons for file operations and execution. The terminal text shows the following sequence of commands and output:

```
*Main> :reload
Ok, one module loaded.
*Main> main
Hello World!
*Main> :t main
main :: IO ()
*Main> |
```



A screenshot of a Notepad++ editor window titled 'C:\HaskellCode\Main.hs - Notepad++'. The window has a menu bar with 'File', 'Edit', 'Search', 'View', 'Encoding', 'Language', 'Settings', 'Tools', 'Macro', 'Run', 'Plugins', and 'Window'. The editor shows the following Haskell code:

```
1 main = do
2
3   putStrLn "Hello World!"
4
5
```

- The main function is a single action
- This action is executed when the program is run.
- A Haskell program, by itself, is a single action that is executed when we run the program.

# Staying Grounded

---

- A Haskell program begins with the execution of a single action (`main :: IO()`)
  - Functions that *return* actions are often incorrectly referred to as actions.
- From within this action, any number of additional actions can be executed
- Pure functions can also be called/evaluated from within actions!
- However – actions cannot be executed from within pure functions.
- If we try, Haskell will infer the type of the function as an action.

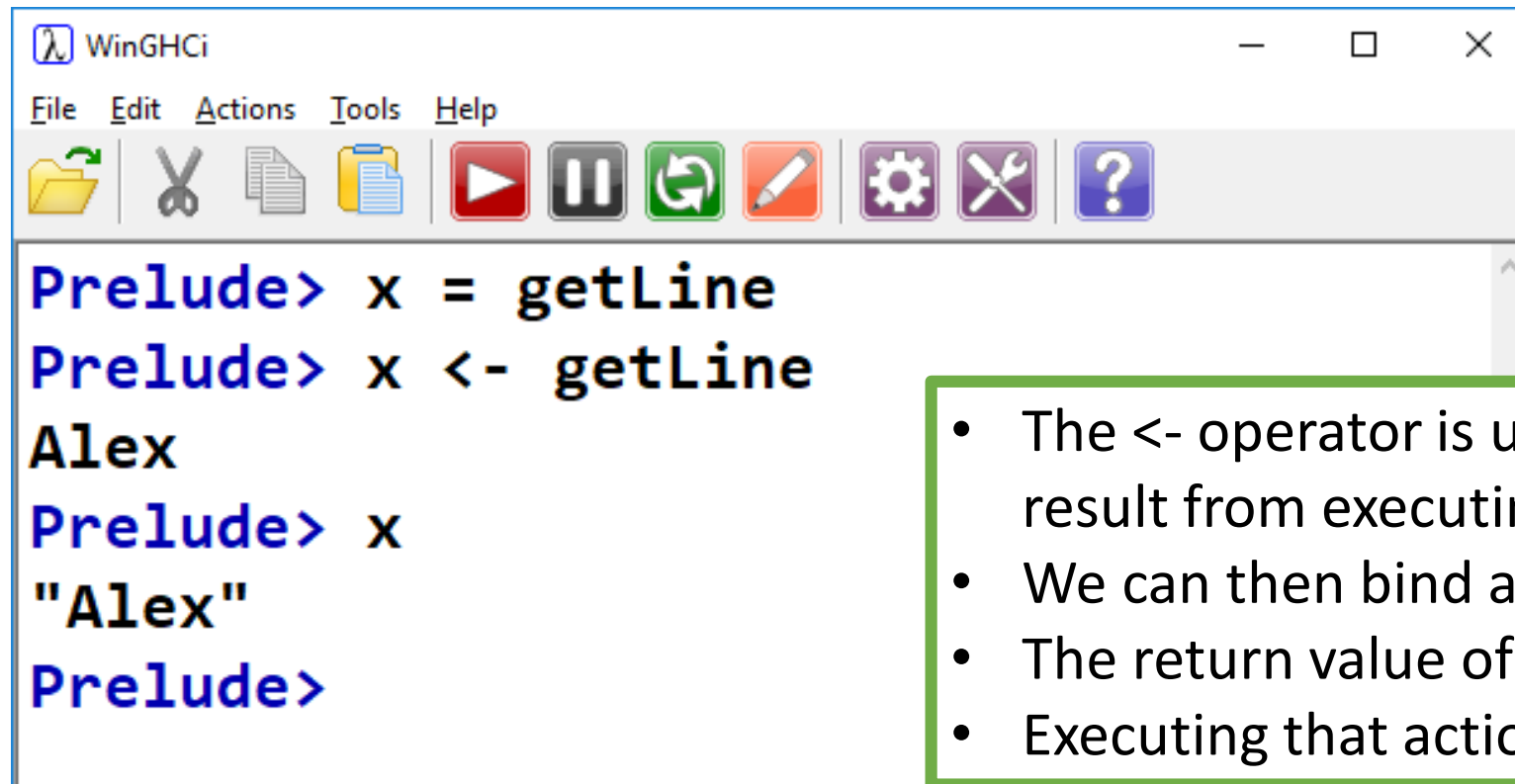
# Staying Grounded

---

- An action can be thought of as a *recipe*
- This recipe (in the case of IO) is a list of instructions that affect the world outside our program.
- *The act of creating this recipe does not have side effects.*
- The recipe can be the output of a pure function.
- Same inputs to the function, same recipe.

# IO Actions

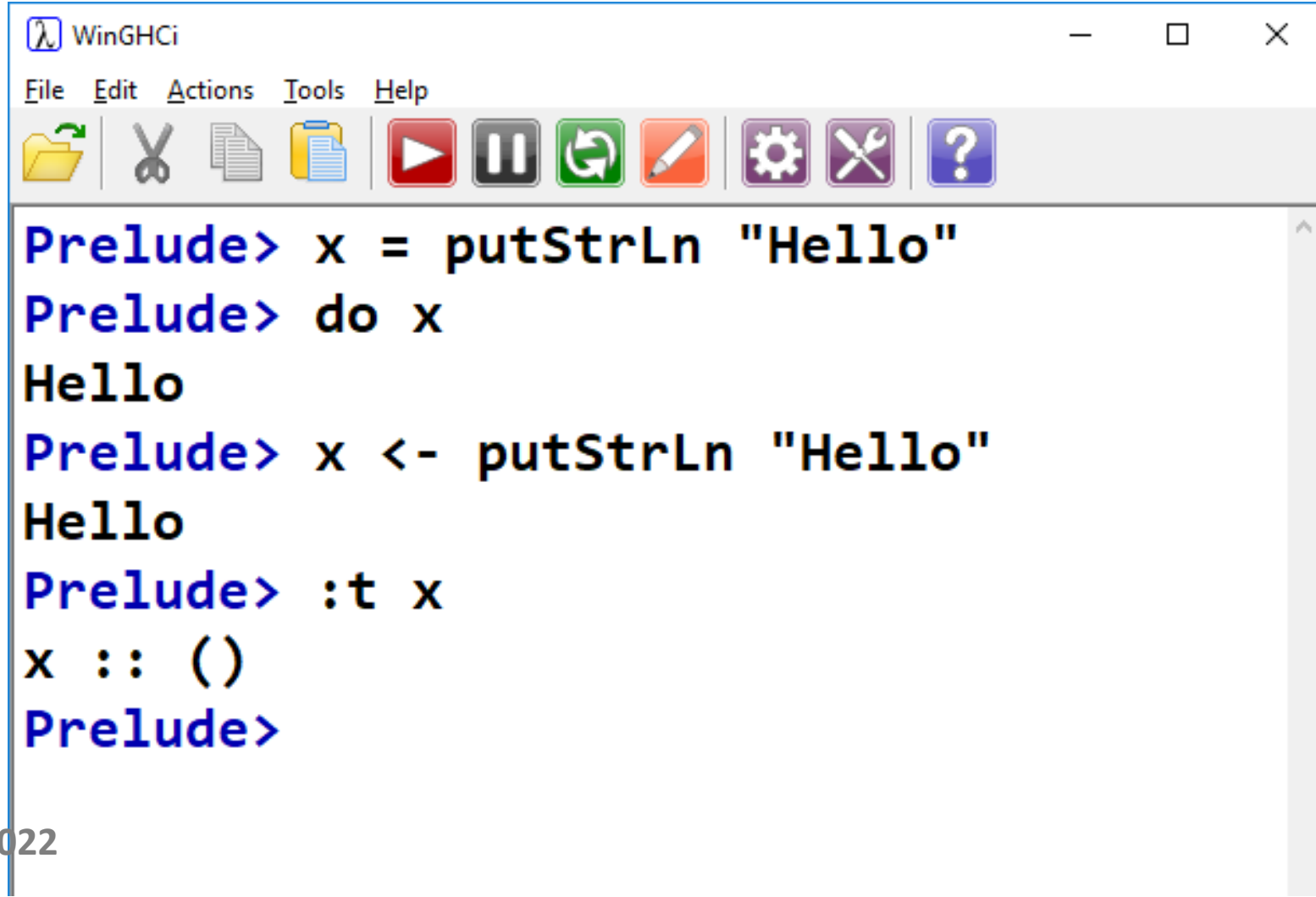
We can use the `<-` operator to execute:

A screenshot of the WinGHCi window. The title bar says 'WinGHCi'. The menu bar has 'File', 'Edit', 'Actions', 'Tools', and 'Help'. The toolbar contains icons for file operations (folder, scissors, document, clipboard), execution (play, pause, refresh), editing (pencil), settings (gear, wrench), and help (question mark). The main text area shows the following interaction:

```
Prelude> x = getLine
Prelude> x <- getLine
Alex
Prelude> x
"Alex"
Prelude>
```

- The `<-` operator is used to pull out the result from executing an IO action.
- We can then bind a name to it.
- The return value of `getLine` is an action.
- Executing that action returns a String.

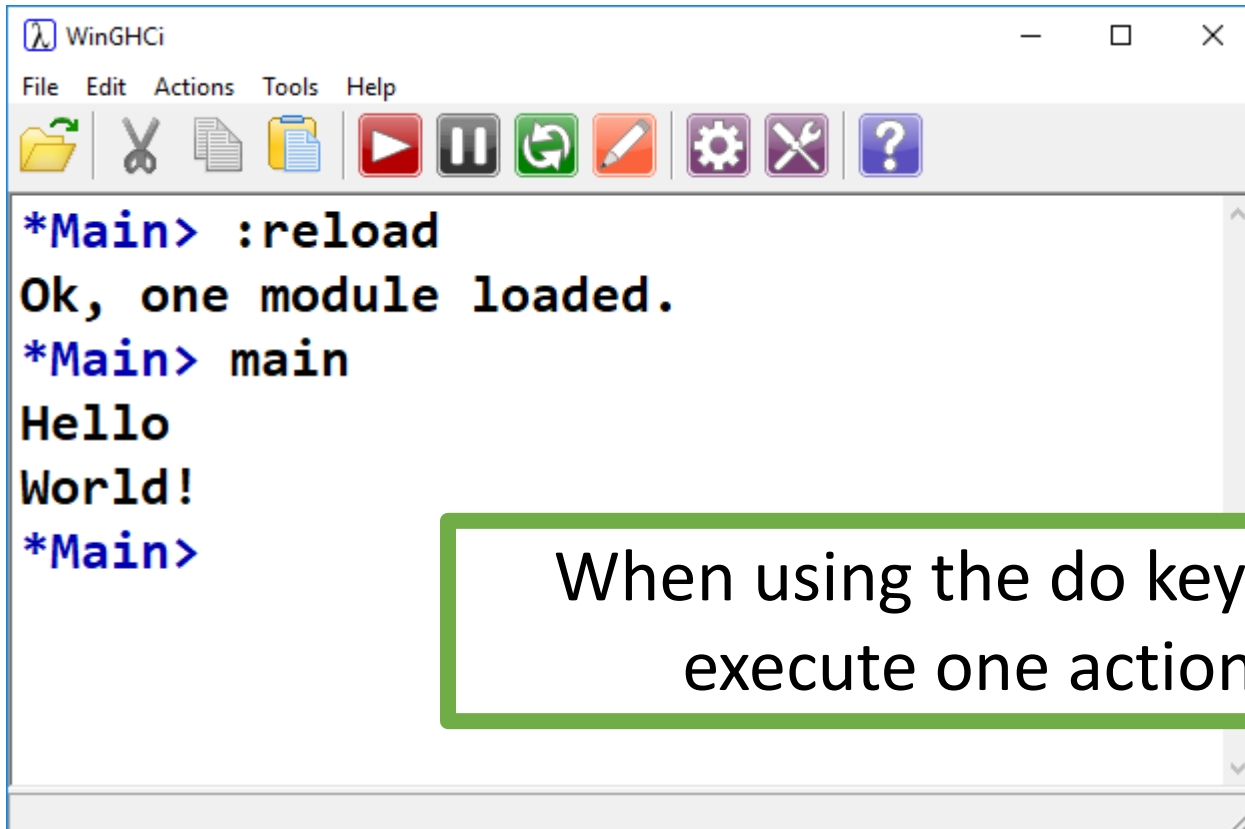
# IO Actions

A screenshot of the WinGHCi window. The window has a title bar with the WinGHCi logo and standard window controls. Below the title bar is a menu bar with 'File', 'Edit', 'Actions', 'Tools', and 'Help'. Under the 'Actions' menu, there is a toolbar with icons for file operations (folder, copy, paste), execution (play, pause, refresh), editing (pencil), settings (gear), and help (question mark). The main text area contains the following Haskell code:

```
Prelude> x = putStrLn "Hello"
Prelude> do x
Hello
Prelude> x <- putStrLn "Hello"
Hello
Prelude> :t x
x :: ()
Prelude>
```

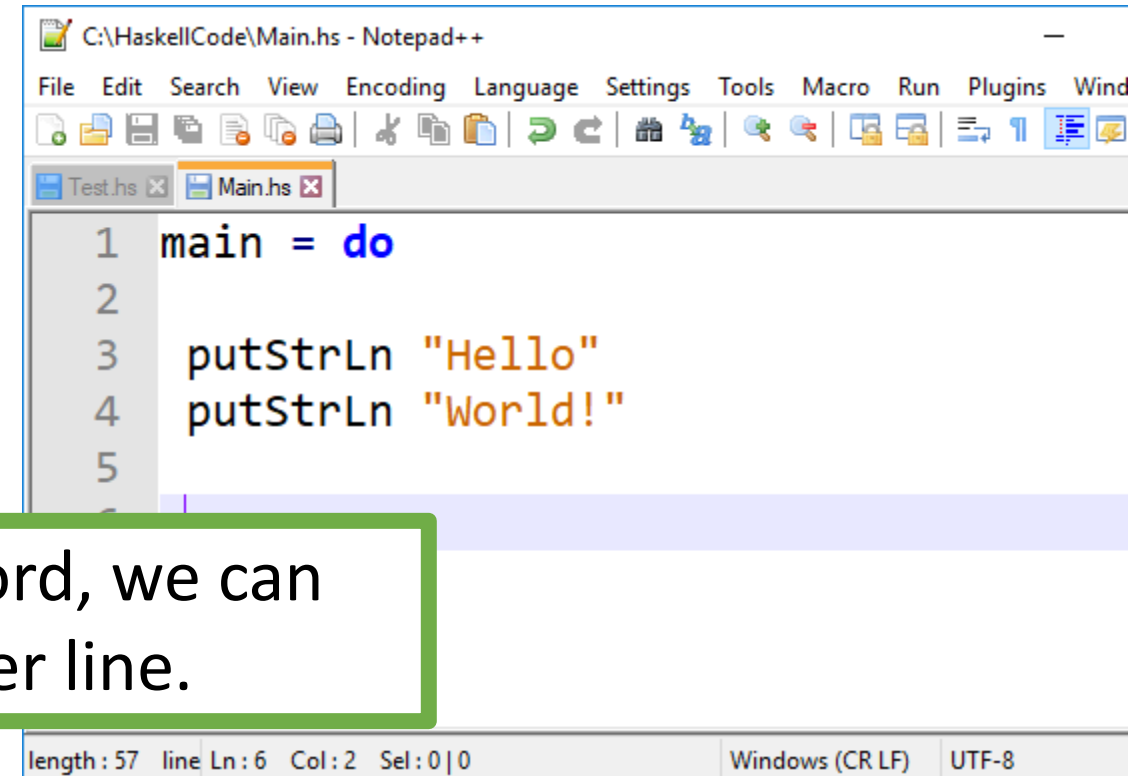
# Combining Actions

We can do this using the **do** keyword:



A screenshot of the WinGHCi terminal window. The window has a menu bar with 'File', 'Edit', 'Actions', 'Tools', and 'Help'. Below the menu bar is a toolbar with icons for file operations and execution. The terminal text shows the following sequence of actions and output:

```
*Main> :reload
Ok, one module loaded.
*Main> main
Hello
World!
*Main>
```



A screenshot of a Notepad++ editor window titled 'C:\HaskellCode\Main.hs - Notepad++'. The window has a menu bar with 'File', 'Edit', 'Search', 'View', 'Encoding', 'Language', 'Settings', 'Tools', 'Macro', 'Run', 'Plugins', and 'Window'. The editor shows the following Haskell code:

```
1 main = do
2
3   putStrLn "Hello"
4   putStrLn "World!"
5
```

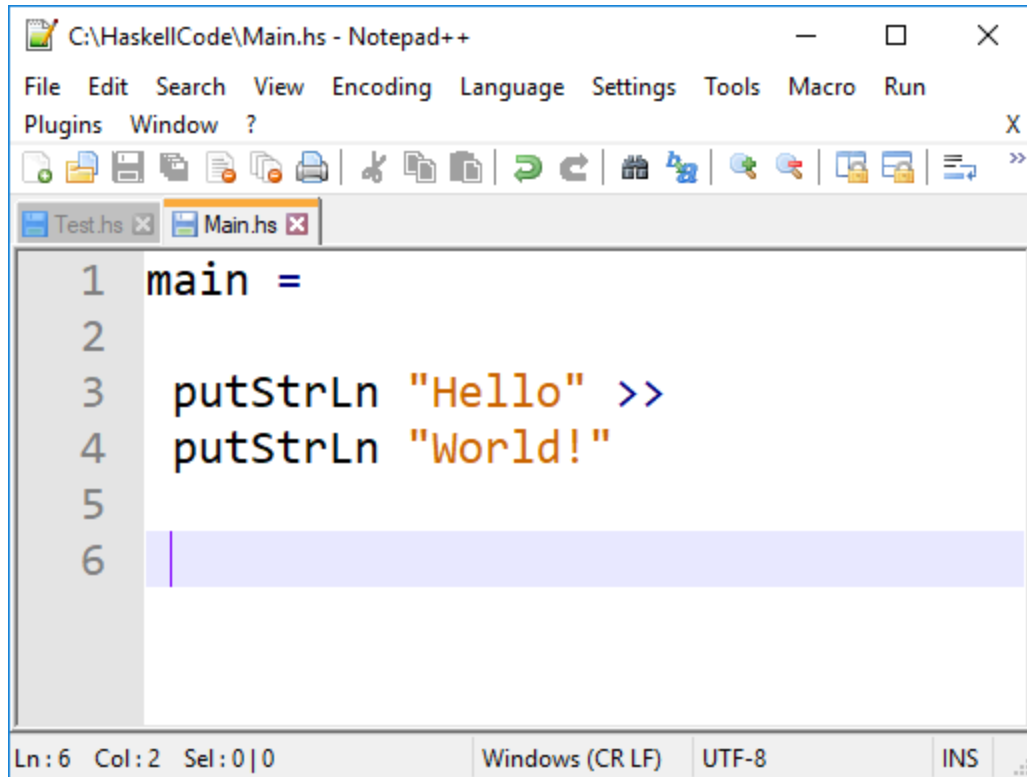
The status bar at the bottom indicates 'length: 57 line Ln: 6 Col: 2 Sel: 0|0', 'Windows (CR LF)', and 'UTF-8'.

When using the **do** keyword, we can execute one action per line.



# Combining Actions

**do** is syntactic sugar for **>>**

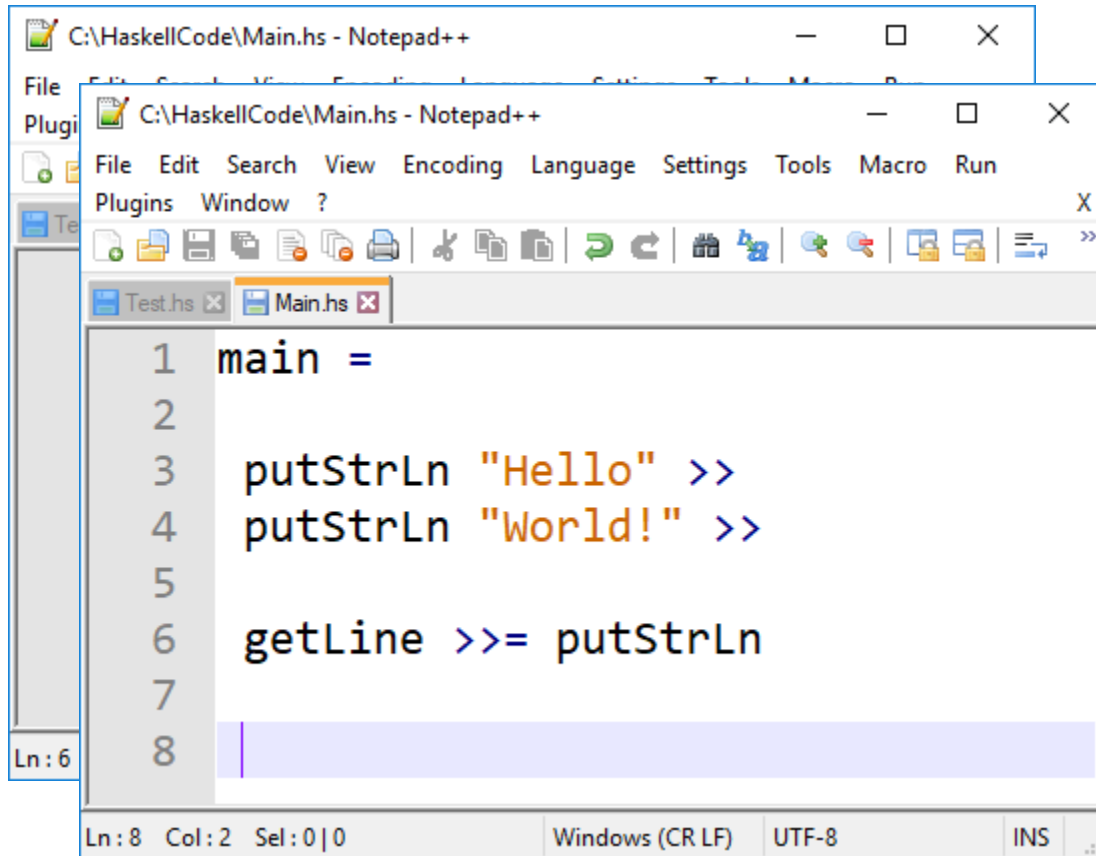


```
1 main =
2
3   putStrLn "Hello" >>
4   putStrLn "World!"
5
6
```

- **>>** says execute this, then this.
- If the first action produces a result, it is discarded.
- What if we want to use the result?
- Use the **>>=** operator to pipe the result into the next action.

# Combining Actions

**do** is syntactic sugar for **>>**



```
1 main =  
2  
3   putStrLn "Hello" >>  
4   putStrLn "World!" >>  
5  
6   getLine >>= putStrLn  
7  
8
```

- **>>** says execute this, then this.
- If the first action produces a result, it is discarded.
- What if we want to use the result?
- Use the **>>=** operator to pipe the result into the next action.
- Here, we grab a string using **getLine**, and display it using **putStrLn**
- **getLine** returns an action that produces a string
- **putStrLn** takes string as an argument.

C:\HaskellCode\Main.hs - Notepad++

File Edit Search View Encoding Language Settings Tools Macro Run  
Plugins Window ?

Test.hs x Main.hs x

```
1 main =  
2  
3   putStrLn "Hello" >>  
4   putStrLn "World!" >>  
5  
6   getLine >>= putStrLn  
7  
8
```

Ln: 8 Col: 2 Sel: 0 | 0 Windows (CR LF) UTF-8

WinGHCi

File Edit Actions Tools Help

```
*Main> :reload  
[1 of 1] Compiling Main  
  ( Main.hs, interpreted )  
Ok, one module loaded.  
*Main> main  
Hello  
World!  
Alex  
Alex  
*Main> |
```

# More Complicated

```
C:\HaskellCode\Main.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?
Test.hs Main.hs
1 main =
2   putStrLn "What is your name?"
3   >> getLine
4   >>= \name -> putStrLn ("Hello, " ++ name ++ "!")
5
6
```

- Lambda function accepting 1 arg, name
- Received directly from the getLine above

```
WinGHCi
File Edit Actions Tools Help
*Main> :reload
Ok, one module loaded.
*Main> main
What is your name?
Alex
Hello, Alex!
*Main>
```

Up until now, we've only really seen how to evaluate expressions (and execute actions, though we didn't know that's what we were doing) in GHCi.

Now we're seeing how to write, compile, and execute a complete Haskell program containing *actions*.

C:\HaskellCode\Main.hs - Notepad++

File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?

Test.hs x Main.hs x

```
1 main =
2   putStrLn "What is your name?"
3   >> getLine
4   >>= \name -> putStrLn ("Hello, " ++ name ++ "!")
5
6
```

Haskell length : 110 lines : 6

Command Prompt

```
C:\HaskellCode>ghc -o a Main.hs
[1 of 1] Compiling Main                ( Main.hs, Main.o )
Linking a.exe ...

C:\HaskellCode>a
What is your name?
Alex
Hello, Alex!

C:\HaskellCode>
```

# Actions & Functions

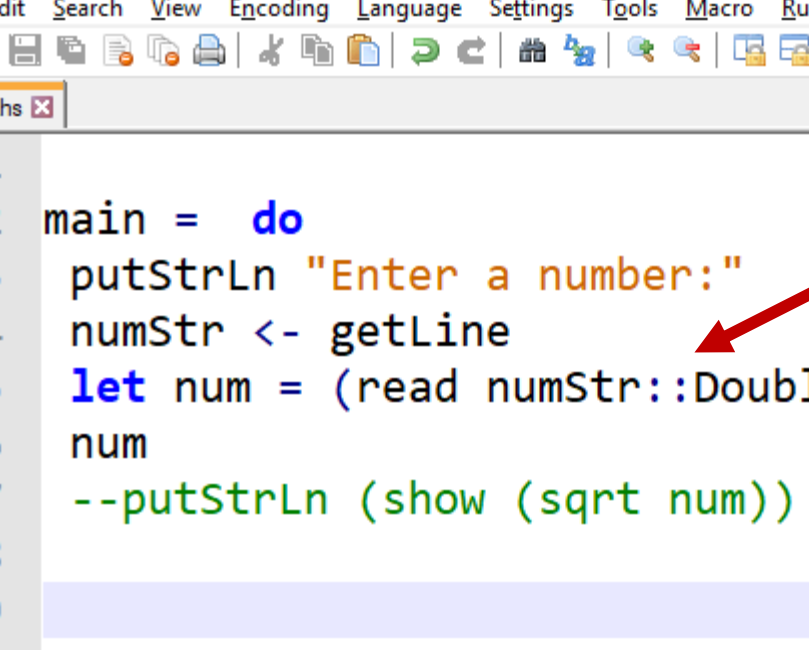
```
C:\HaskellCode\Main.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins
Test.hs Main.hs
1
2 main = do
3   putStrLn "Enter a number:"
4   numStr <- getLine
5   let num = (read numStr::Double)
6   putStrLn (show (sqrt num))
7
8
9
length: 132 lines: 9
```

```
Command Prompt
C:\HaskellCode>ghc -o a Main.hs
C:\HaskellCode>a
Enter a number:
100
10.0
C:\HaskellCode>
```

- Use `<-` when binding the result of executing an action
- Use `let` and `=` when binding the result of an expression

# Problem?


- We are executing actions in **main**
- Its return type must be an action.
- The value of a “do” block is the value of the last expression evaluated



The screenshot shows a code editor window with the title bar "D:\GoogleDrive\Teaching - Ryerson\(\CPS 506\Resources\Code\Haskell\main.hs - ...". The menu bar includes "File", "Edit", "Search", "View", "Encoding", "Language", "Settings", "Tools", "Macro", "Run", and "Plugins". The toolbar contains icons for file operations (new, open, save, print, copy, paste, delete), navigation (back, forward), and development (run, debug, search, etc.). The editor window has a tab titled "main.hs". The code is as follows:

```
1  
2 main = do  
3   putStrLn "Enter a number:"  
4   numStr <- getLine  
5   let num = (read numStr::Double)  
6   num  
7   --putStrLn (show (sqrt num))  
8  
9
```

A red arrow points to the `getLine` function on line 4. The status bar at the bottom shows "length: 138", "lin: 9", "col: 2", "sel: 0 | 0", "Windows (CR LF)", and "UTF-8".



The screenshot shows the WinGHCi window with the following content:

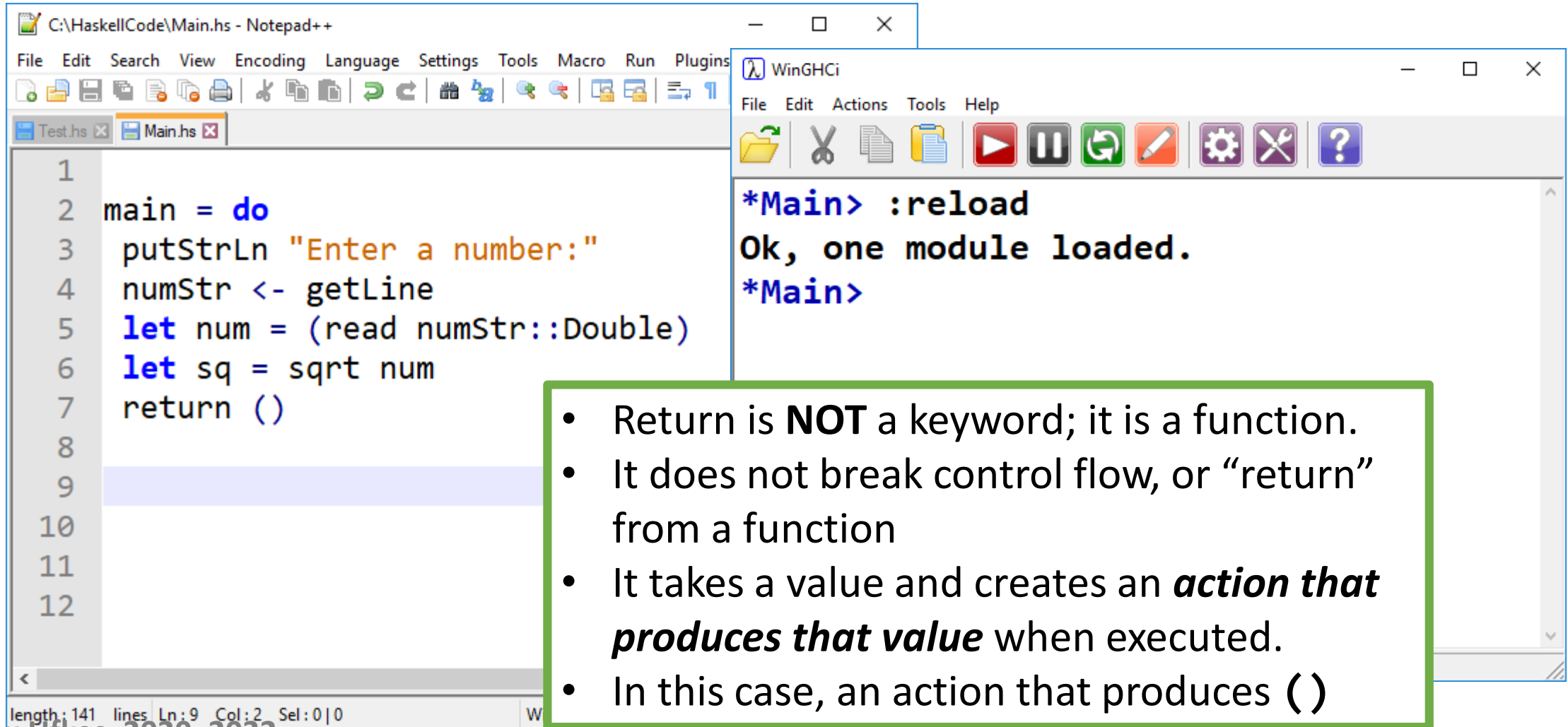
```
Prelude> :reload

main.hs:6:2: error:
  • Couldn't match expected type 'IO b'
    with actual type 'Double'
  • In a stmt of a 'do' block: num
    In the expression:
      do putStrLn "Enter a number:"
```

The error message is displayed in red text. The number 32 is visible in the bottom right corner of the image.



# return ()



The screenshot shows a Haskell development environment. On the left is a Notepad++ window titled 'C:\HaskellCode\Main.hs - Notepad++' containing the following Haskell code:

```
1  
2 main = do  
3   putStrLn "Enter a number:"  
4   numStr <- getLine  
5   let num = (read numStr::Double)  
6   let sq = sqrt num  
7   return ()  
8  
9  
10  
11  
12
```

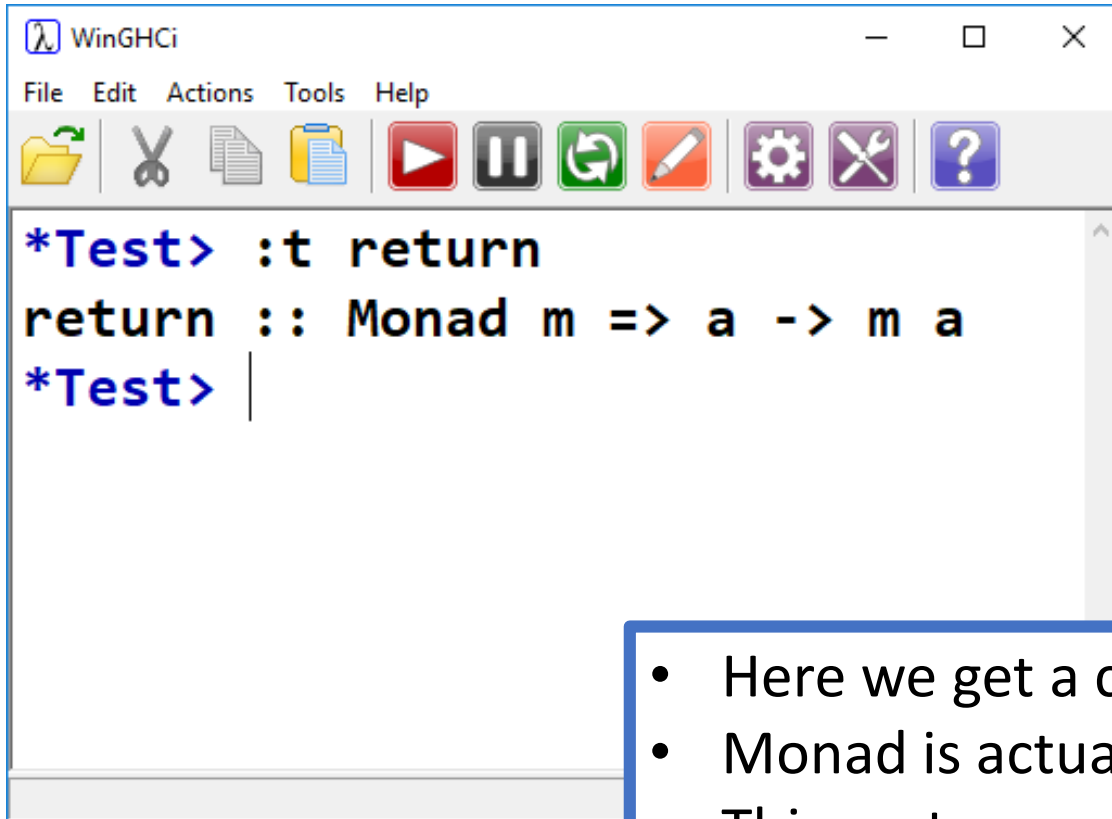
On the right is a WinGHCi window titled 'WinGHCi' showing the following interaction:

```
*Main> :reload  
Ok, one module loaded.  
*Main>
```

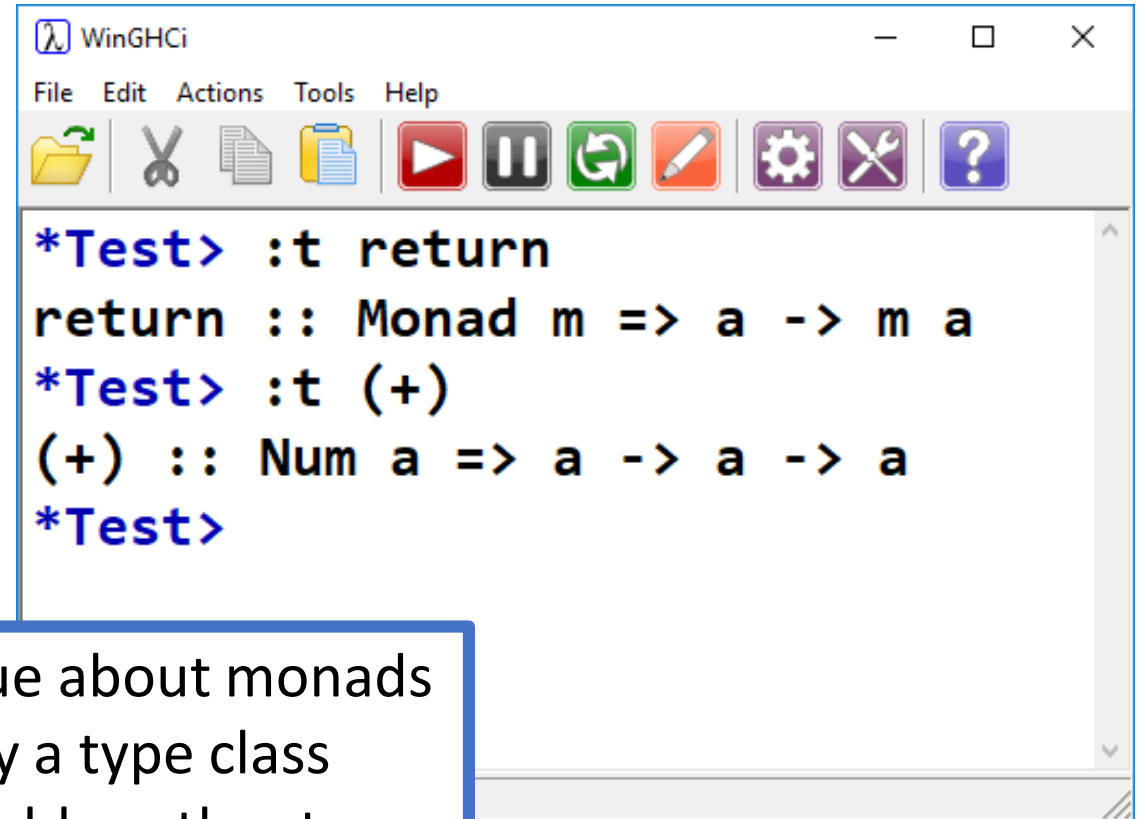
A green-bordered box highlights the following list of points:

- Return is **NOT** a keyword; it is a function.
- It does not break control flow, or “return” from a function
- It takes a value and creates an ***action that produces that value*** when executed.
- In this case, an action that produces ()

# Monads & return ( )

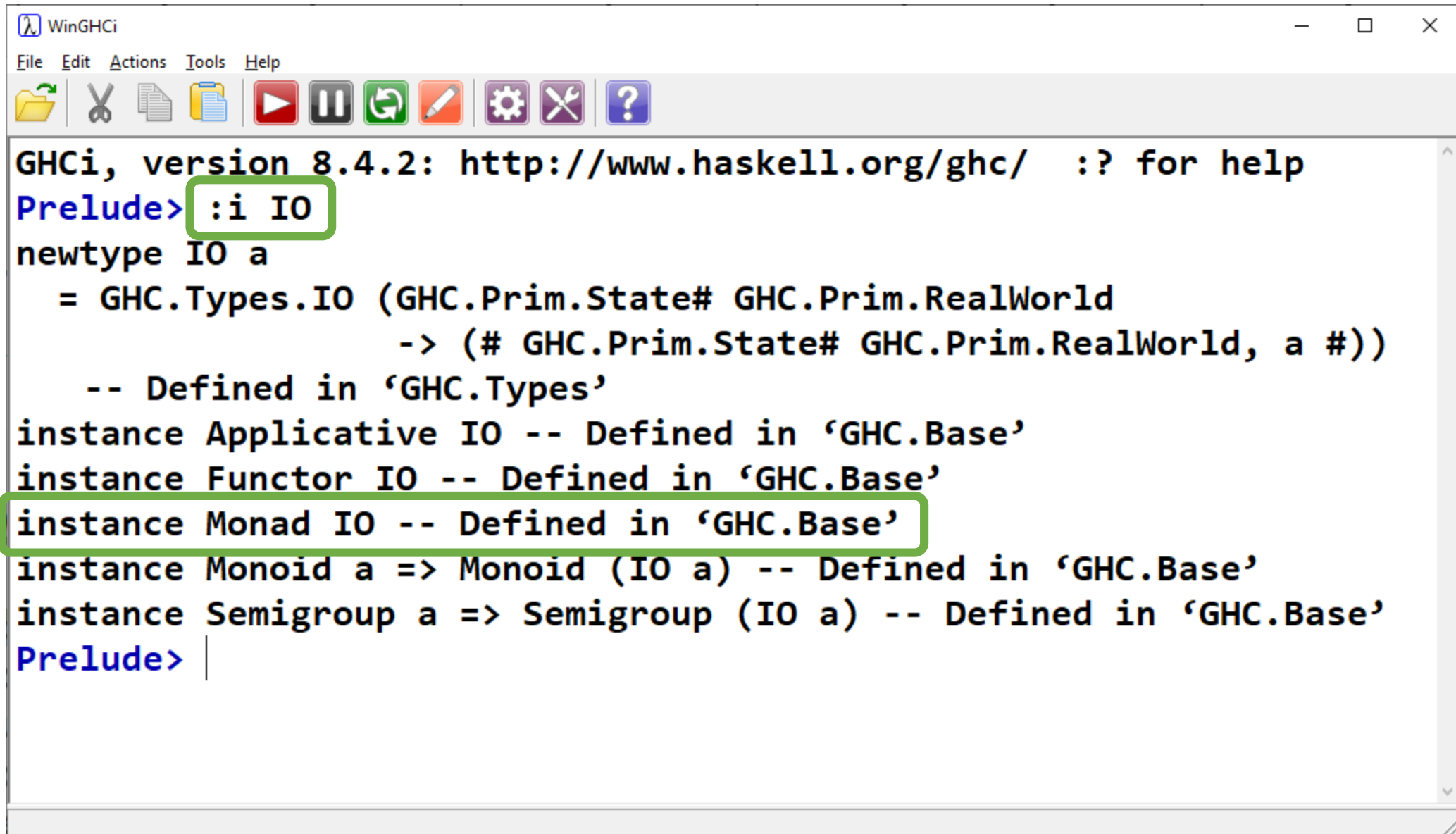


```
WinGHCi
File Edit Actions Tools Help
[Icons]
*Test> :t return
return :: Monad m => a -> m a
*Test> |
```



```
WinGHCi
File Edit Actions Tools Help
[Icons]
*Test> :t return
return :: Monad m => a -> m a
*Test> :t (+)
(+) :: Num a => a -> a -> a
*Test>
```

- Here we get a clue about monads
- Monad is actually a type class
- This syntax resembles other type classes we've seen.

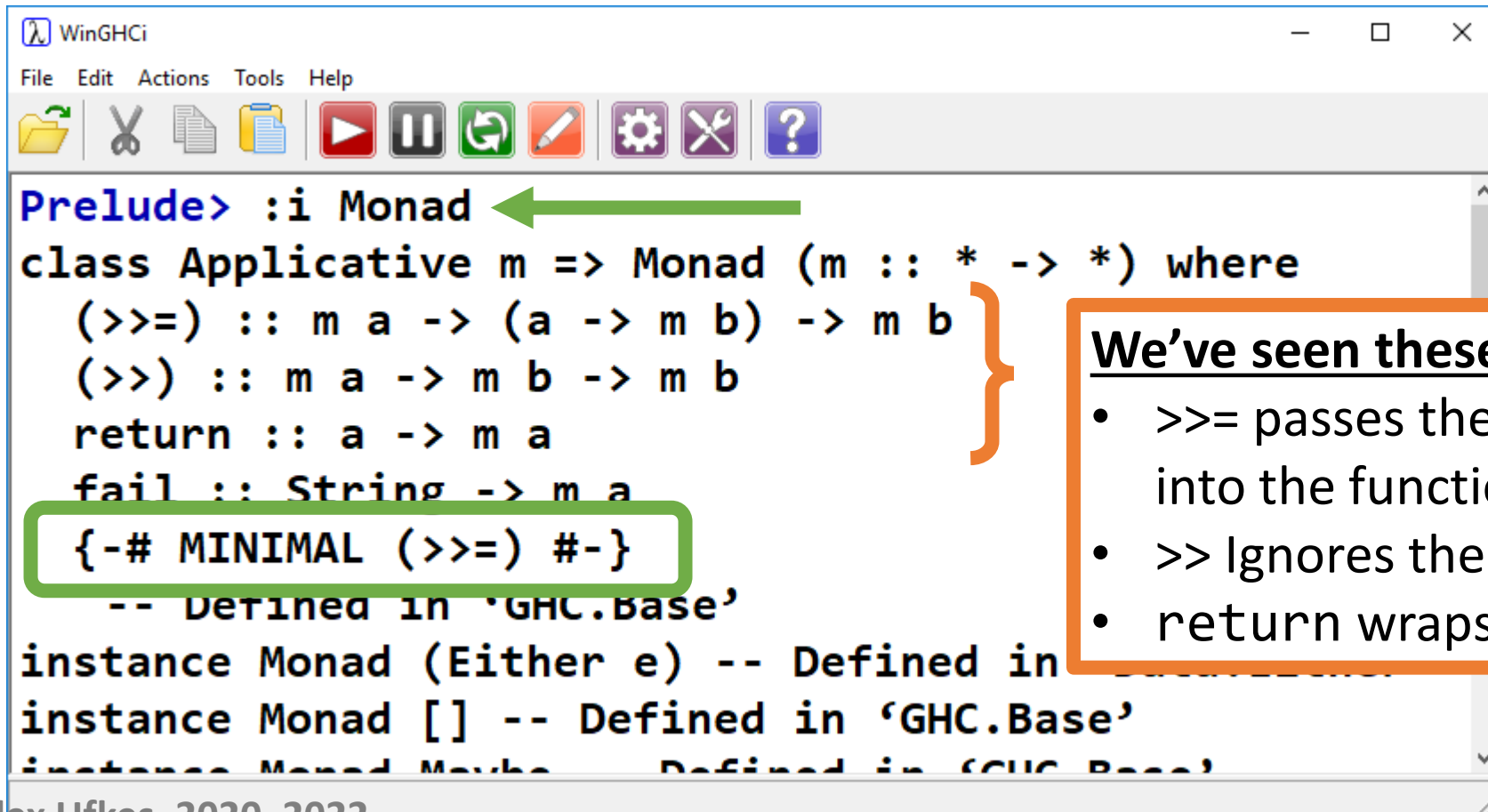
A screenshot of a WinGHCi window. The window has a title bar with the icon and text 'WinGHCi'. Below the title bar is a menu bar with 'File', 'Edit', 'Actions', 'Tools', and 'Help'. Under 'Actions' is a toolbar with icons for file operations (copy, paste, save, etc.) and execution (run, step through, etc.). The main text area contains the following Haskell code:

```
GHCi, version 8.4.2: http://www.haskell.org/ghc/  :? for help
Prelude> :i IO
newtype IO a
  = GHC.Types.IO (GHC.Prim.State# GHC.Prim.RealWorld
                  -> (# GHC.Prim.State# GHC.Prim.RealWorld, a #))
  -- Defined in 'GHC.Types'
instance Applicative IO -- Defined in 'GHC.Base'
instance Functor IO -- Defined in 'GHC.Base'
instance Monad IO -- Defined in 'GHC.Base'
instance Monoid a => Monoid (IO a) -- Defined in 'GHC.Base'
instance Semigroup a => Semigroup (IO a) -- Defined in 'GHC.Base'
Prelude> |
```

The code is displayed in a monospaced font. The prompt 'Prelude>' is in blue. The command ':i IO' is highlighted with a green box. The definition of 'newtype IO a' and the 'instance Monad IO' line are also highlighted with green boxes. The window has a standard macOS-style title bar with minimize, maximize, and close buttons.

# Monads

Monad is a typeclass:



```
WinGHCi
File Edit Actions Tools Help
[Icons]

Prelude> :i Monad
class Applicative m => Monad (m :: * -> *) where
  (>>=) :: m a -> (a -> m b) -> m b
  (>>)  :: m a -> m b -> m b
  return :: a -> m a
  fail   :: String -> m a
  {-# MINIMAL (>>=) #-}
  -- Defined in 'GHC.Base'
instance Monad (Either e) -- Defined in 'GHC.Base'
instance Monad [] -- Defined in 'GHC.Base'
instance Monad Maybe -- Defined in 'GHC.Base'
```

## We've seen these:

- `>>=` passes the result on the left into the function on the right.
- `>>` ignores the result on the left
- `return` wraps data in a monad

# Monad Jargon

---

**“Monadic”**      Pertaining to monads. A monadic type is an instance of type class `Monad` (`IO`, for example)

**“type `xxx` is a `Monad`”**      `xxx` is an instance of type class `Monad`. `xxx` implements `>>`, `>>=`, and **`return`**

**“action”**      Another name for a monadic value

## **By the way:**

- It turns out that Monads are good for things other than side effect-producing `IO`.
- We’ll see an example coming up.

# >>= VS >>

---

Where the  
magic happens

**>>=**

Chains actions together. Result of left side is given as input to the right side.

**>>**

Chains actions together. Ignore result of left side.

a >> b **VS** a >>= \\_ -> b

>> can be defined in terms of >>=

# Non-main Example

```
C:\HaskellCode\Test.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ? X
Test.hs Main.hs
1 module Test where
2
3 positive = do
4   putStr "Enter a number: "
5   num <- getLine
6   (read num :: Double) < 0
7
```

- Function that reads in a number
- Returns true if < zero, false otherwise
- **Problem:** We're creating IO actions
- The return type cannot be Boolean
- It must be IO *something*

```
WinGHCi
File Edit Actions Tools Help
1 1 1 1
Test.hs:7:3: error:
• Couldn't match expected type 'IO b' with actual type 'Bool'
• In a stmt of a 'do' block: (read num :: Double) < 0
In the expression:
do putStr "Enter a number: "
```

# Non-main Example

What if we still want to get a Boolean back?

```
C:\HaskellCode\Test.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins
Test.hs Main.hs
1 module Test where
2
3 positive = do
4   putStr "Enter a number: "
5   num <- getLine
6   return ((read num::Double) < 0)
7
8
9
10
11
Length: 133 Line: 11 Col: 10 Windows (CR LF) UTF-8
```

```
WinGHCi
File Edit Actions Tools Help
*Test> :t positive
positive :: IO Bool
*Test> x <- positive
Enter a number: 8
*Test> x
False
*Test> :t x
x :: Bool
*Test> |
```

Extract the value from the action using <-

- The return type of positive is an IO action.
- When executed, that action produces a Bool



# Calling Pure Code

We can still call pure functions from actions:

```
C:\HaskellCode\Main.hs - Notepad+
File Edit Search View Encoding
Test.hs x Main.hs x
1 findBigger x y = if x > y then x else y
2
3 main = do
4   putStrLn "Enter first number:"
5   nStr <- getLine
6   let num1 = (read nStr::Double)
7   putStrLn "Enter second number:"
8   nStr <- getLine
9   let num2 = (read nStr::Double)
10  let big = findBigger num1 num2
11  putStrLn ("Larger: " ++ (show big))
12
13
length: 304 lines Lm: 13 Col: 3 Sel: 0 | 0
Windows (CR LF) UTF-8 INS
```

```
Command Prompt
C:\HaskellCode>ghc -o a Main.hs
[1 of 1] Compiling Main           ( Main.
Linking a.exe ...

C:\HaskellCode>a
Enter first number:
4.5
Enter second number:
7.9
Larger: 7.9

C:\HaskellCode>
```

# Best Practice

Separate pure code into its own functions:

The image shows two windows side-by-side. The left window is Notepad++ editing a file named 'Test.hs'. The code is as follows:

```
1 module Test where
2
3 testPos numString = do
4   let x = read numString::Double
5   if x < 0 then False else True
6
7 positive = do
8   putStr "Enter a number: "
9   num <- getLine
10  return (testPos num)
```

The code is annotated with two boxes: a green box around lines 3-5 labeled 'Pure!' and a red box around lines 7-10 labeled 'Action'.

The right window is WinGHCi, showing the following interactive session:

```
*Test> x <- positive
Enter a number: -8
*Test> x
False
*Test> :t positive
positive :: IO Bool
*Test> :t testPos
testPos  :: String -> Bool
*Test> |
```

*When looking at `main`, Haskell looks rather imperative...*

Even at this point, however, Haskell sets itself apart from imperative languages.

It creates a separate type of programming construct for operations that produce side effects

We can always be sure of which parts of the code will alter the state of the world, and which parts won't.

Imperative languages do no such thing, and make no guarantees whatsoever regarding function purity

# Monads

---

*“The essence of monad is thus separation of composition timeline from the composed computation's execution timeline, as well as the ability of computation to implicitly carry extra data”*

*“This lends monads to supplementing pure calculations with features like I/O, common environment, updatable state, etc.”*

**Not just for I/O! Not just for side effects!**

# Maybe Monad

---

Monads were originally introduced for IO operations

It turns out, as a construct, they are useful for modelling other things as well!

**For example:** exception handling, non-determinism, etc.

# Maybe Monad

---

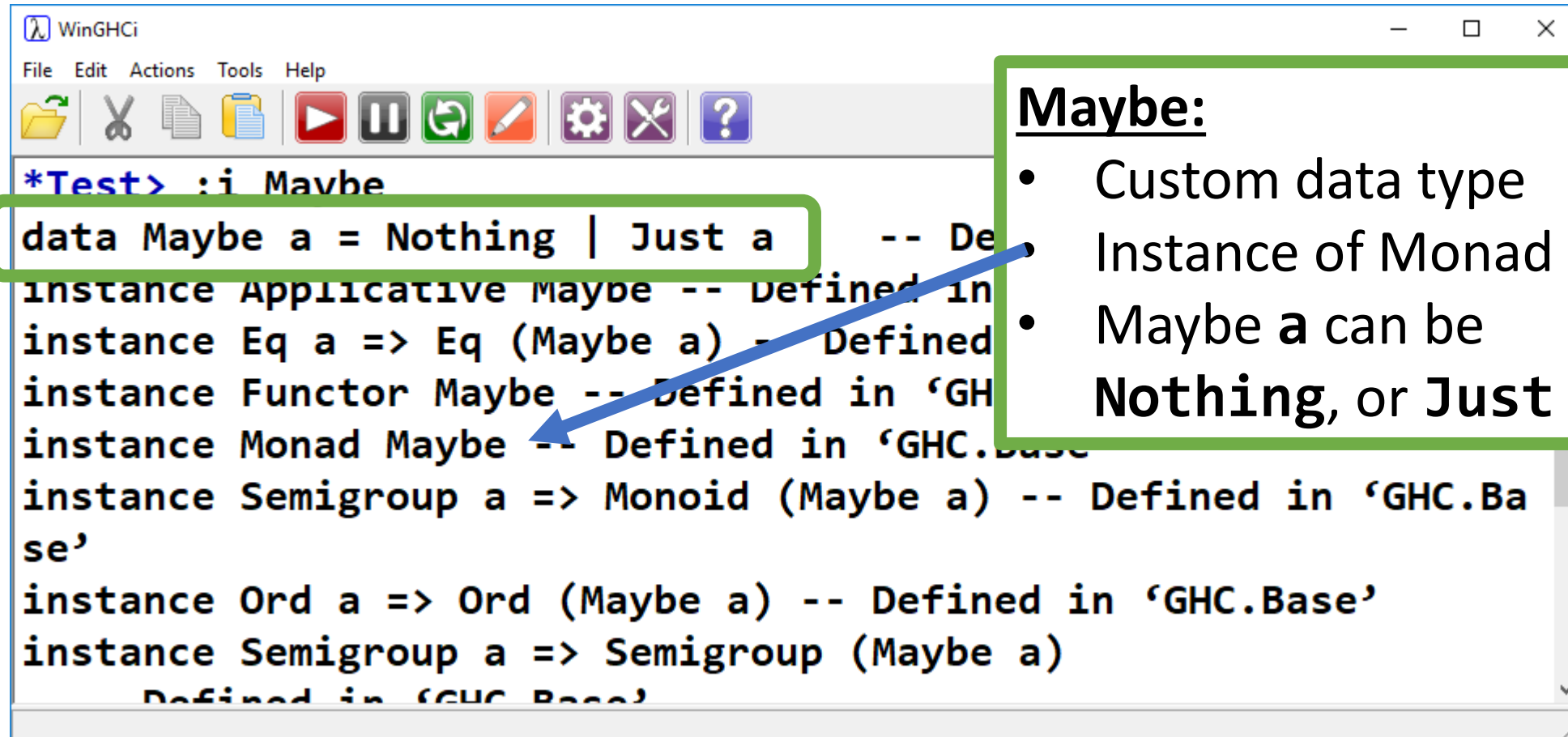
Represents a computation that might not produce a result

Computations that might “go wrong”

For example – calling tail with a list that might be empty

We can use Maybe to create a safety wrapper for functions that might fail, depending on input.

# Maybe Monad



```
WinGHCi
File Edit Actions Tools Help
[Icons]

*Test> :i Maybe
data Maybe a = Nothing | Just a -- Defined in 'GHC.Base'
instance Applicative Maybe -- Defined in 'GHC.Base'
instance Eq a => Eq (Maybe a) -- Defined in 'GHC.Base'
instance Functor Maybe -- Defined in 'GHC.Base'
instance Monad Maybe -- Defined in 'GHC.Base'
instance Semigroup a => Monoid (Maybe a) -- Defined in 'GHC.Base'
instance Ord a => Ord (Maybe a) -- Defined in 'GHC.Base'
instance Semigroup a => Semigroup (Maybe a) -- Defined in 'GHC.Base'
```

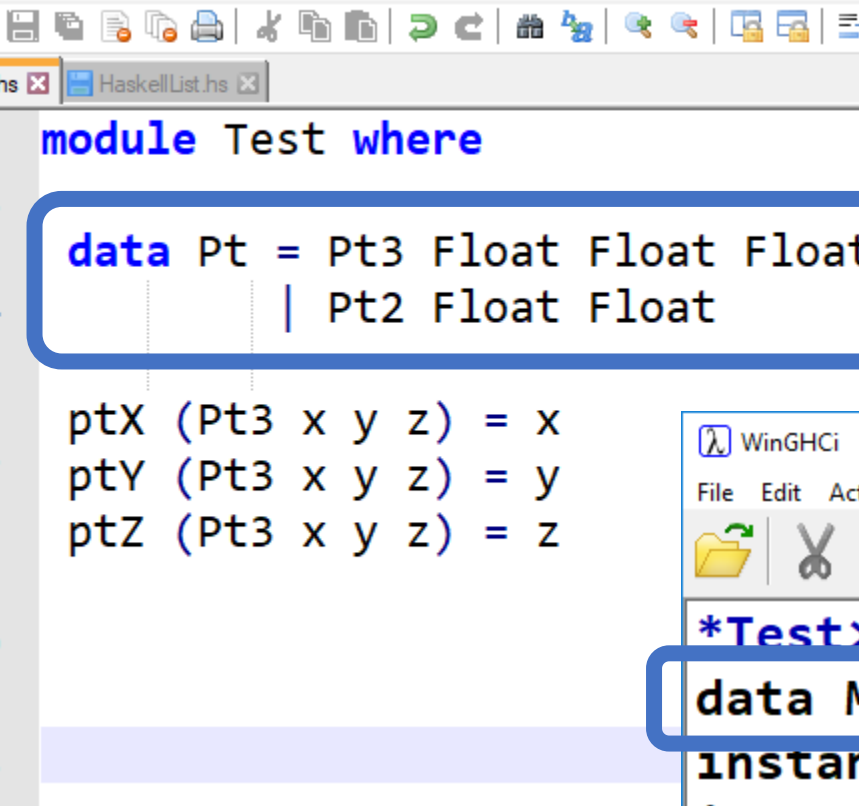
## Maybe:

- Custom data type
- Instance of Monad
- Maybe **a** can be **Nothing**, or **Just a**

# We've seen this before...

Pt can take the value Pt3 Float  
Float Float, or Pt2 Float Float

Maybe can take the value  
Nothing or Just a



```
1 module Test where
2
3 data Pt = Pt3 Float Float Float
4         | Pt2 Float Float
5
6 ptX (Pt3 x y z) = x
7 ptY (Pt3 x y z) = y
8 ptZ (Pt3 x y z) = z
9
10
11
12
13
```

length: 1,358 lines: 78 Ln: 12 Col: 2 Sel: 0 | 0

WinGHCi

File Edit Actions Tool

\*Test> :i

data Maybe

instance

instance

instance

```
*Test> :i Maybe
```

```
data Maybe a = Nothing | Just a      -- Defined in 'GHC.Base'
```

```
instance Applicative Maybe -- Defined in 'GHC.Base'
```

```
instance Eq a => Eq (Maybe a) -- Defined in 'GHC.Base'
```

```
instance Functor Maybe -- Defined in 'GHC.Base'
```

```
instance Monad Maybe -- Defined in 'GHC.Base'
```

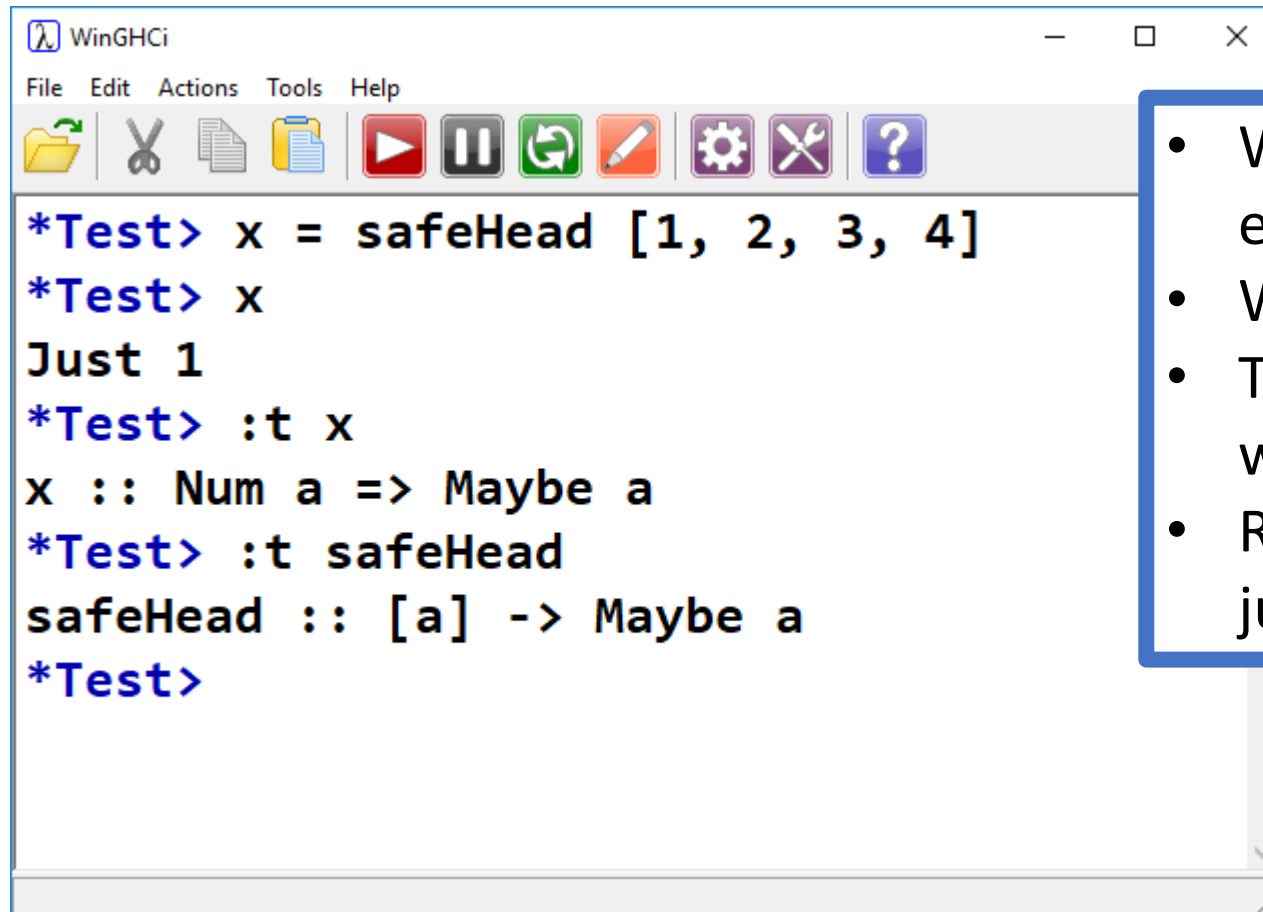


# Maybe Monad

```
C:\HaskellCode\Test.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ? X
Main.hs Test.hs
1 module Test where
2
3 safeTail x
4   | (length x > 0) = Just (tail x)
5   | otherwise = Nothing
6
7 safeHead x
8   | (length x > 0) = Just (head x)
9   | otherwise = Nothing
10
11
12
13
length: 2,585 |Ln: 11 |Col: 2 |Sel: 0 |0 Windows (CR LF) UTF-8 INS
```

- Define safe functions for head and tail.
  - Using guards - |
- Instead of failing on empty lists, evaluate to Nothing.
- If a tail or head can be found, evaluate to Just head x, or Just tail x
- Just head? Just tail?

# Maybe Monad

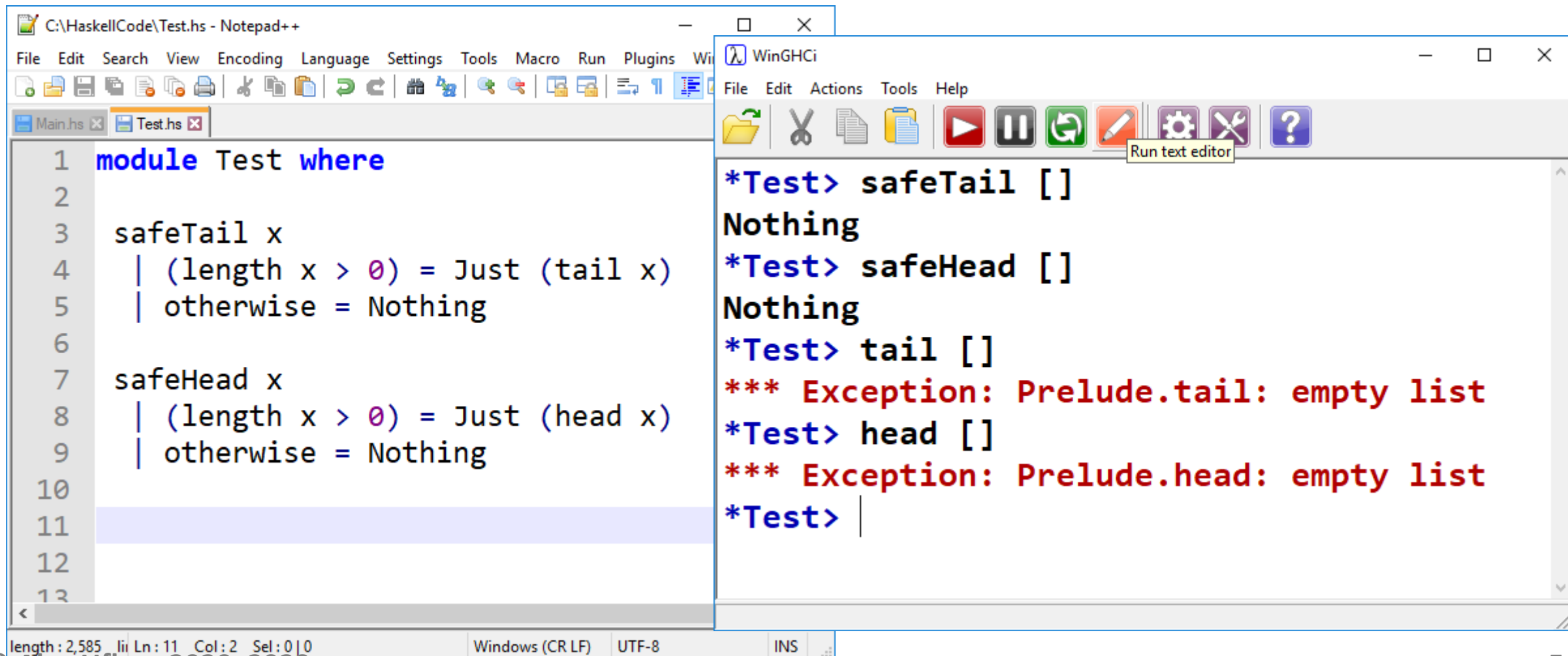


```
WinGHCi
File Edit Actions Tools Help
[Icons]

*Test> x = safeHead [1, 2, 3, 4]
*Test> x
Just 1
*Test> :t x
x :: Num a => Maybe a
*Test> :t safeHead
safeHead :: [a] -> Maybe a
*Test>
```

- When we call `safeHead` on a non-empty list, we don't get the head.
- We get *Just head*
- This is the head of the list wrapped in a Maybe monad.
- Remember that Maybe is a type, just like our custom Pt type

# Maybe Monad



The image shows a screenshot of a Haskell development environment. On the left, a Notepad++ window titled 'C:\HaskellCode\Test.hs - Notepad++' displays the following Haskell code:

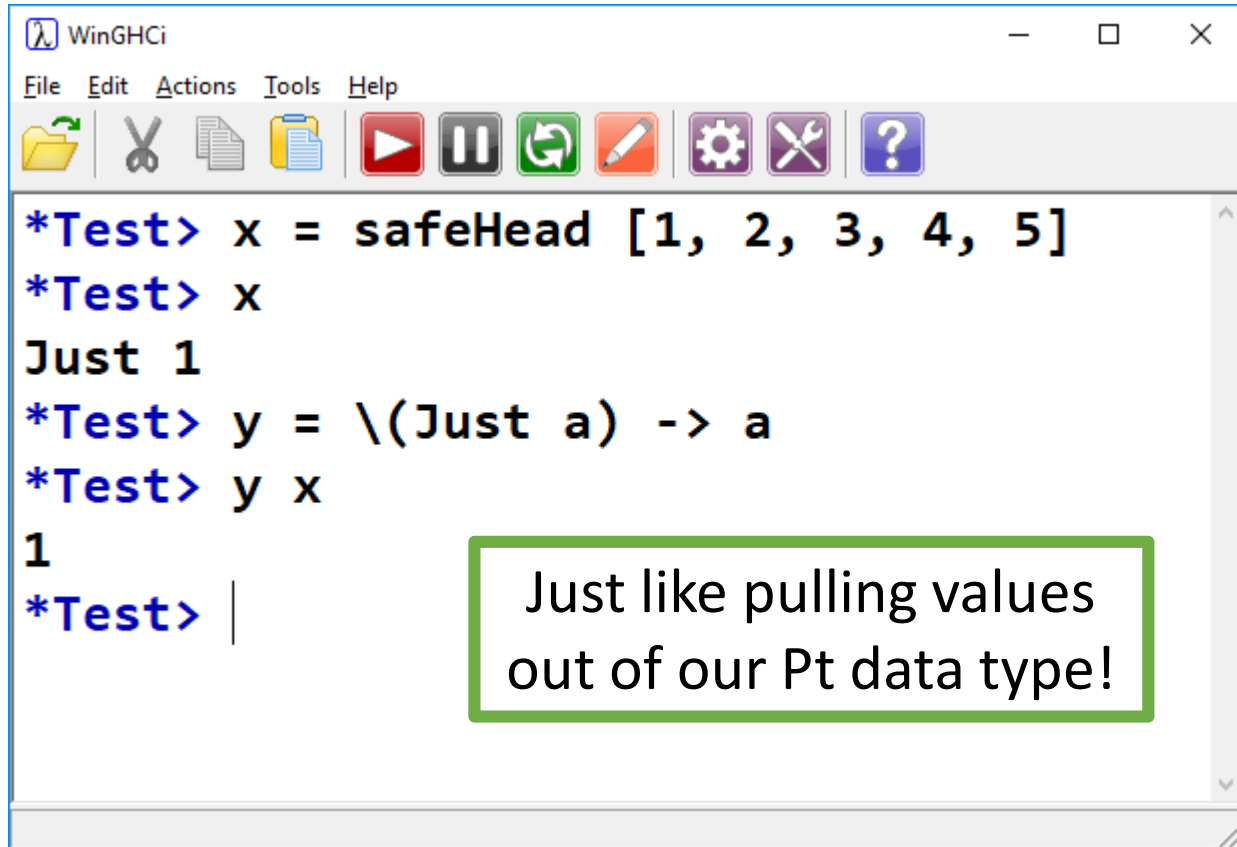
```
1 module Test where
2
3 safeTail x
4   | (length x > 0) = Just (tail x)
5   | otherwise = Nothing
6
7 safeHead x
8   | (length x > 0) = Just (head x)
9   | otherwise = Nothing
10
11
12
13
```

On the right, a WinGHCi window titled 'WinGHCi' shows the execution of the code. The prompt is `*Test>`. The results are:

```
*Test> safeTail []
Nothing
*Test> safeHead []
Nothing
*Test> tail []
*** Exception: Prelude.tail: empty list
*Test> head []
*** Exception: Prelude.head: empty list
*Test> |
```

The status bar at the bottom of the Notepad++ window indicates 'length: 2,585', 'Ln: 11', 'Col: 2', 'Sel: 0|0', 'Windows (CR LF)', 'UTF-8', and 'INS'.

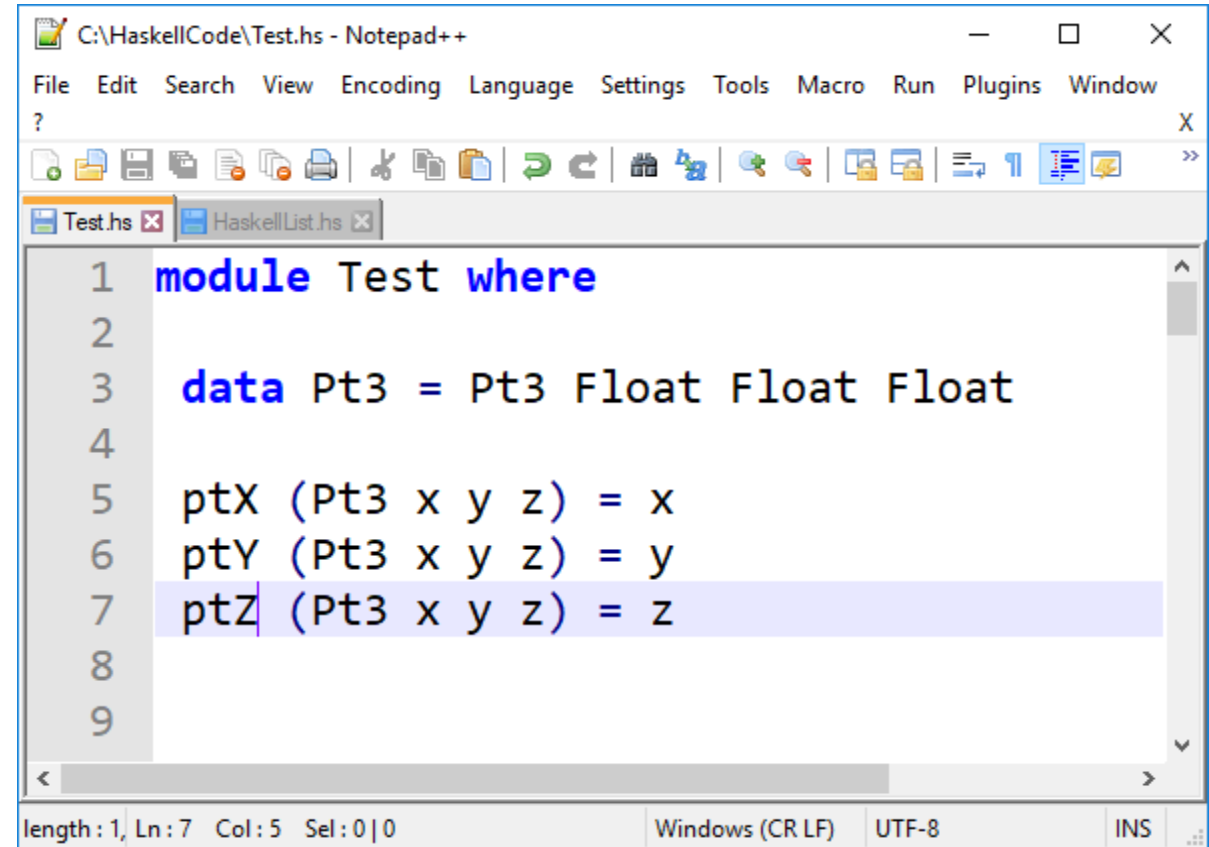
# Unwrap Just a?



WinGHCi

```
*Test> x = safeHead [1, 2, 3, 4, 5]
*Test> x
Just 1
*Test> y = \(Just a) -> a
*Test> y x
1
*Test> |
```

Just like pulling values out of our Pt data type!



C:\HaskellCode\Test.hs - Notepad++

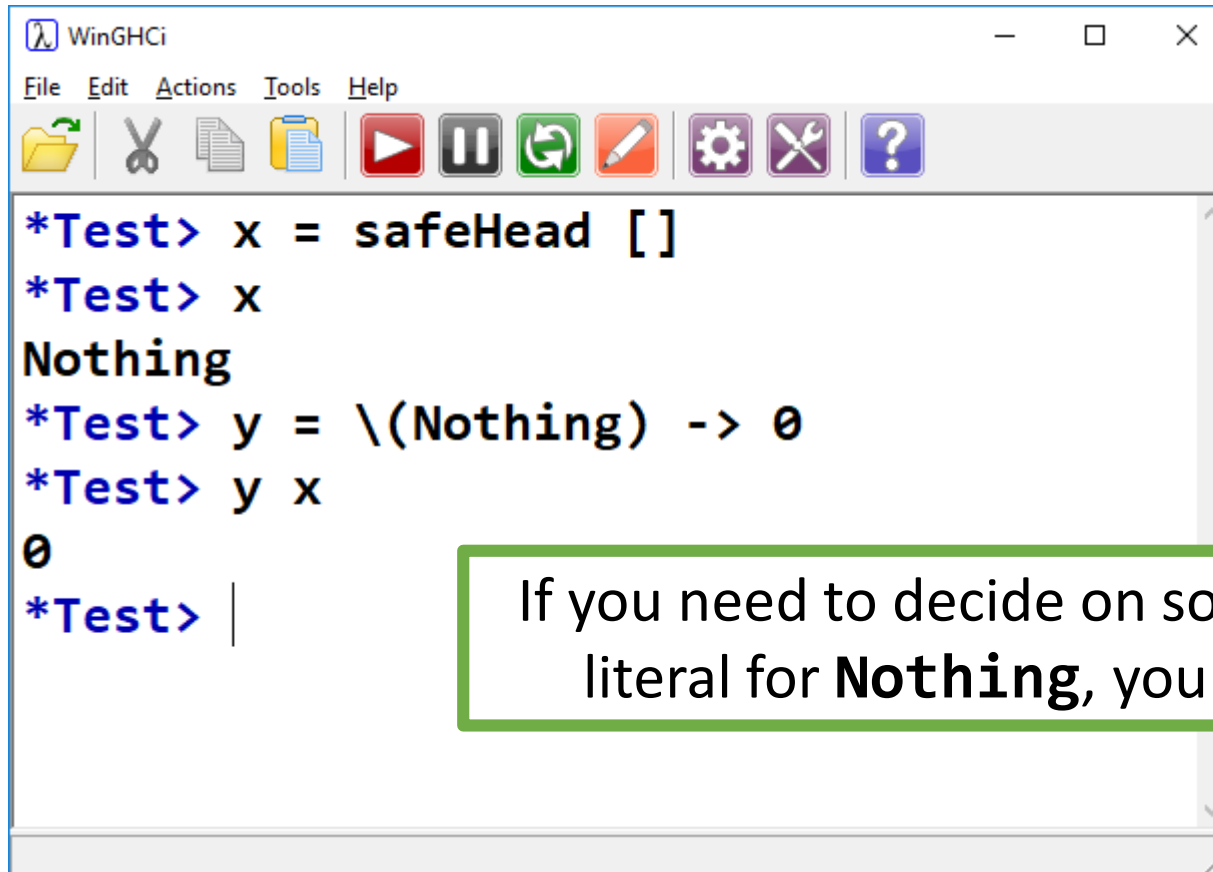
```
1 module Test where
2
3 data Pt3 = Pt3 Float Float Float
4
5 ptX (Pt3 x y z) = x
6 ptY (Pt3 x y z) = y
7 ptZ (Pt3 x y z) = z
8
9
```

length: 1, Ln: 7 Col: 5 Sel: 0 | 0 Windows (CR LF) UTF-8 INS

```
*C:\cps506\haskell\Test.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Win
Test.hs cond1.c
1 module Test where
2
3 safeTail x
4   | (length x > 0) = Just (tail x)
5   | otherwise = Nothing
6
7 safeHead x
8   | (length x > 0) = Just (head x)
9   | otherwise = Nothing
10
11 getMaybeVal (Just a) = a
12
13
14
15
```

```
WinGHCi
File Edit Actions Tools Help
*Test> x = safeHead [8, 6, 4]
*Test> y = safeTail [8, 6, 4]
*Test> getMaybeVal x
8
*Test> getMaybeVal y
[6,4]
*Test> :t getMaybeVal
getMaybeVal :: Maybe a -> a
*Test> |
```

# Unwrap *Nothing*?



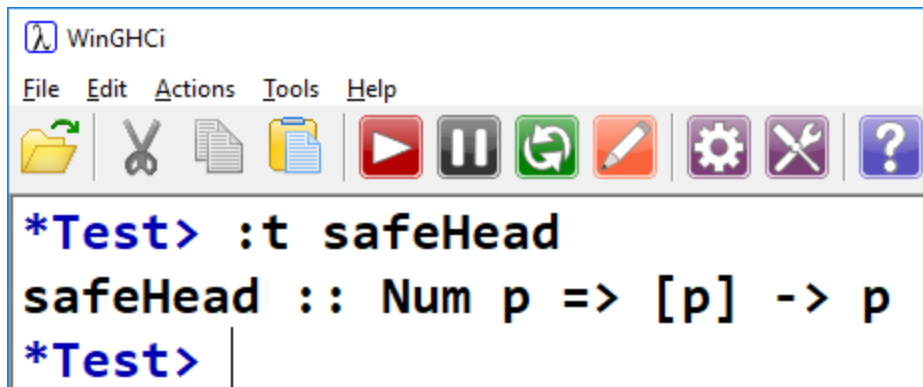
A screenshot of the WinGHCi window. The title bar says 'WinGHCi'. The menu bar includes 'File', 'Edit', 'Actions', 'Tools', and 'Help'. The toolbar contains icons for file operations (folder, scissors, copy, paste), execution (play, pause, refresh), editing (eraser), settings (gear, wrench), and help (question mark). The main text area shows the following interaction:

```
*Test> x = safeHead []
*Test> x
Nothing
*Test> y = \(Nothing) -> 0
*Test> y x
0
*Test> |
```

If you need to decide on some numeric literal for **Nothing**, you can do so

# Why Not This?

```
safeHead x
| (length x > 0) = head x
| otherwise = 0
```



A screenshot of the WinGHCi window. The title bar says 'WinGHCi'. The menu bar includes 'File', 'Edit', 'Actions', 'Tools', and 'Help'. The toolbar contains icons for file operations (folder, copy, paste, save), execution (play, pause, refresh), and settings (gear, wrench, question mark). The main text area shows the following code:

```
*Test> :t safeHead
safeHead :: Num p => [p] -> p
*Test> |
```

## Zero as error code

- What if head of list is *actually* 0?
- Static typing means list passed to safeHead can only be instance of Num!
- **Just** can contain anything
- **Nothing** is useful as an “error” value

# Using Maybe

---

Maybe can make code safer by gracefully dealing with failure.

Should we use Maybe for everything?

**No.** Not everything has a chance to fail. Wrapping the return type of  $(x > y)$  in Maybe only serves to obfuscate your code.



# Consider a Lookup Table

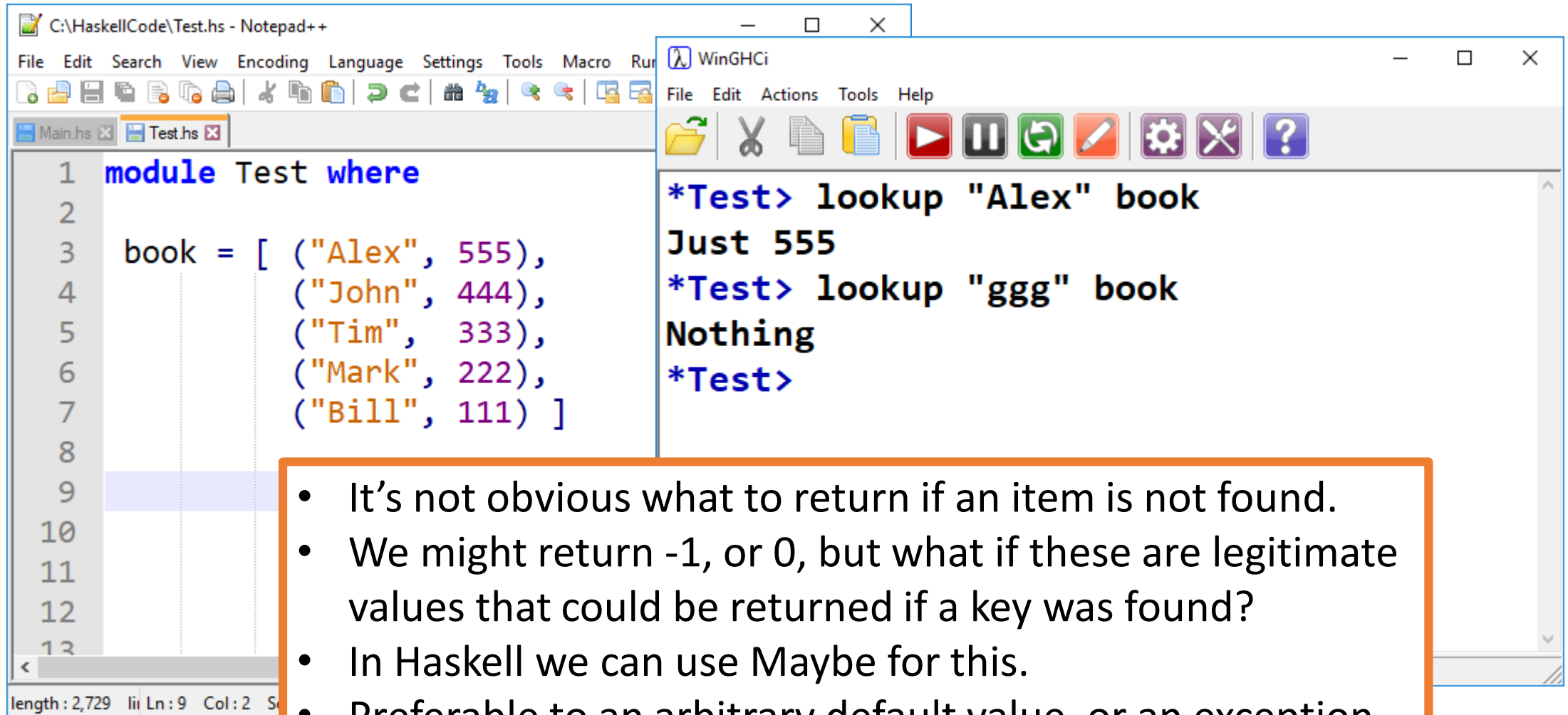
---

We have a list of tuple pairs:

```
book = [ ("Alex", 555),  
          ("John", 444),  
          ("Tim", 333),  
          ("Mark", 222),  
          ("Bill", 111) ]
```

- We want to search the table for a name
- If found, return its number
- If not found, return.... ?

# Use lookup



The image shows two windows. The left window is Notepad++ editing a file named `C:\HaskellCode\Test.hs`. It contains the following Haskell code:

```
1 module Test where
2
3 book = [ ("Alex", 555),
4          ("John", 444),
5          ("Tim", 333),
6          ("Mark", 222),
7          ("Bill", 111) ]
8
9
10
11
12
13
```

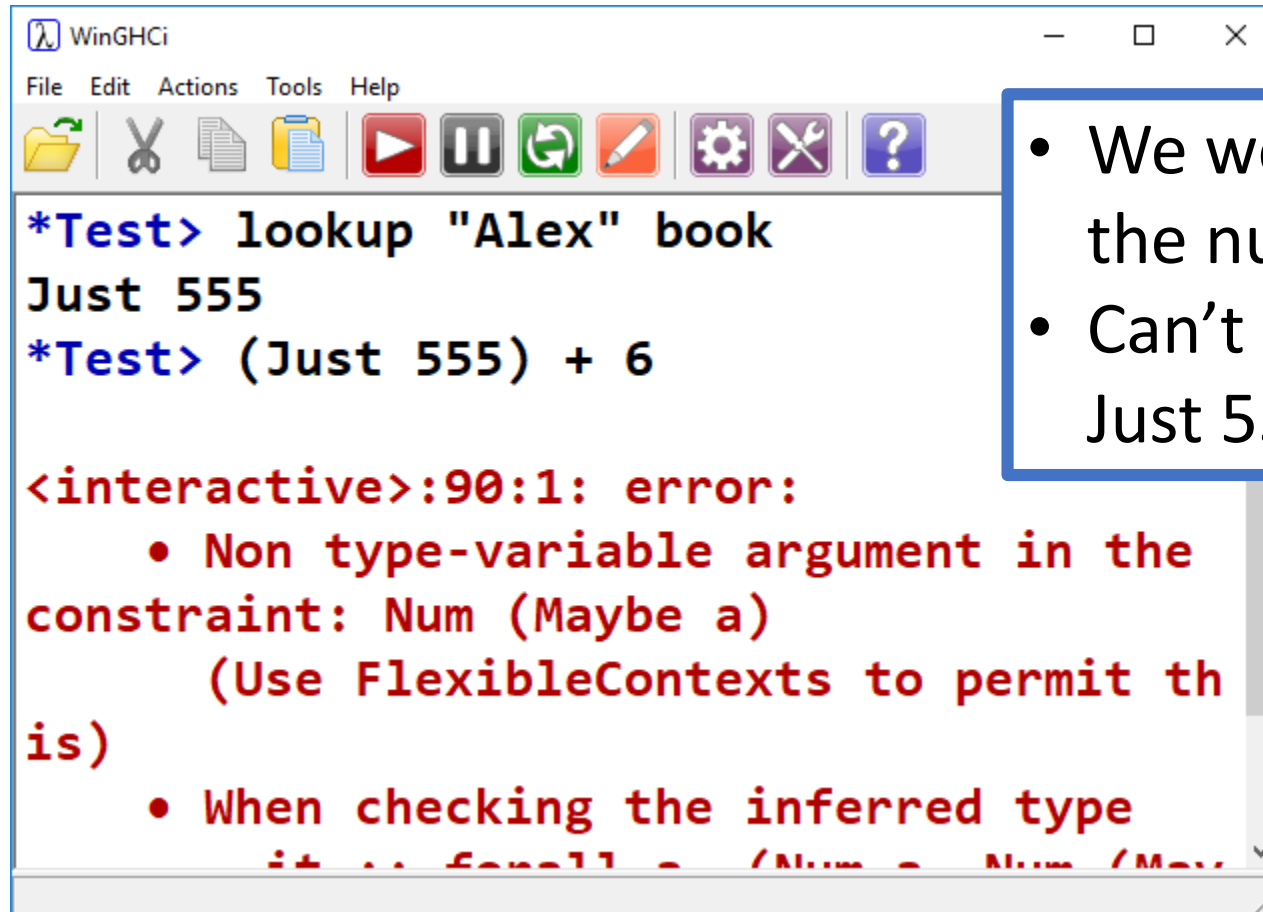
The right window is WinGHCi, showing the execution of the code:

```
*Test> lookup "Alex" book
Just 555
*Test> lookup "ggg" book
Nothing
*Test>
```

An orange-bordered box contains a list of bullet points discussing the result of a lookup operation.

- It's not obvious what to return if an item is not found.
- We might return -1, or 0, but what if these are legitimate values that could be returned if a key was found?
- In Haskell we can use Maybe for this.
- Preferable to an arbitrary default value, or an exception.

# Just 555 VS 555



The screenshot shows the WinGHCi window with the following content:

```
WinGHCi
File Edit Actions Tools Help
[Icons: Folder, Scissors, Document, Clipboard, Play, Pause, Refresh, Pencil, Gear, Wrench, Question Mark]

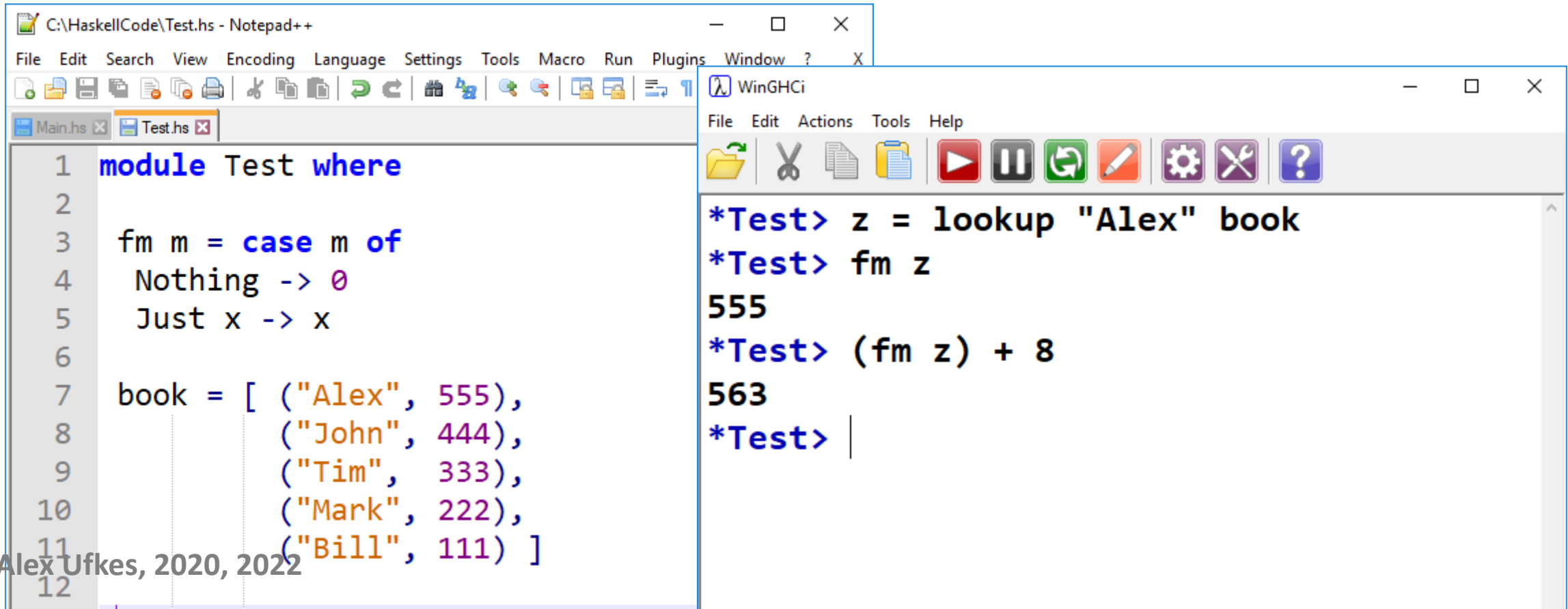
*Test> lookup "Alex" book
Just 555
*Test> (Just 555) + 6

<interactive>:90:1: error:
  • Non type-variable argument in the
  constraint: Num (Maybe a)
    (Use FlexibleContexts to permit th
  is)
  • When checking the inferred type
    it is forall a. (Num a, Num (May
```

- We would like to extract the numeric value 555
- Can't do arithmetic on Just 555, for example.

# Just 555 VS 555

If we have a **Just** value, we can see its contents and extract through pattern matching



The image shows a Haskell code editor (Notepad++) and a WinGHCi terminal window. The code defines a function `fm` that uses pattern matching on a `case` expression to extract values from a `Just` value. The terminal shows the execution of these functions, demonstrating how to extract the contents of a `Just` value and perform operations on them.

```
1 module Test where
2
3 fm m = case m of
4   Nothing -> 0
5   Just x -> x
6
7 book = [ ("Alex", 555),
8           ("John", 444),
9           ("Tim", 333),
10          ("Mark", 222),
11          ("Bill", 111) ]
12
```

```
*Test> z = lookup "Alex" book
*Test> fm z
555
*Test> (fm z) + 8
563
*Test> |
```

# Use lookup

```
C:\HaskellCode\Test.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Windows
Test.hs Main.hs
10 Nothing -> 0
11 Just x -> x
12
13 book1 = [ ("Alex", 555), ("John", 444),
14           ("Tim", 333), ("Mark", 222) ]
15
16 book2 = [ (555, 1), (444, 2),
17           (333, 3), (111, 4) ]
18
19 book3 = [ (1, "First"), (2, "Second"),
20           (5, "Third"), (4, "Fourth") ]
21
22
23
```

- Value from book1 is the key to book2
- Value of book2 is the key to book3
- We want the value from book3

- Not every value in book1 corresponds to a key in book2.
- Not every value in book2 corresponds to a key in book3
- There are several ways a lookup could fail

```

1 module Test where
2
3 getPlace :: String -> Maybe String
4 getPlace name = do
5     code <- lookup name book1
6     num <- lookup code book2
7     lookup num book3
8
9 fm m = case m of
10     Nothing -> ""
11     Just x -> x
12
13 book1 = [ ("Alex", 555), ("John", 444),
14           ("Tim", 333), ("Mark", 222) ]
15
16 book2 = [ (555, 1), (444, 2),
17           (333, 3), (111, 4) ]
18
19 book3 = [ (1, "First"), (2, "Second"),
20           (5, "Third"), (4, "Fourth") ]
21

```

- What happens if lookup fails to find a match?
- We saw that it returns **Nothing**
- What happens if we try to lookup **Nothing**?

```

*Test> :t getPlace
getPlace :: String -> Maybe String
*Test> getPlace "Alex"
Just "First"
*Test> getPlace "Tim"
Nothing
*Test> getPlace "Mark"
Nothing
*Test> fm (getPlace "Alex")
"First"
*Test>

```

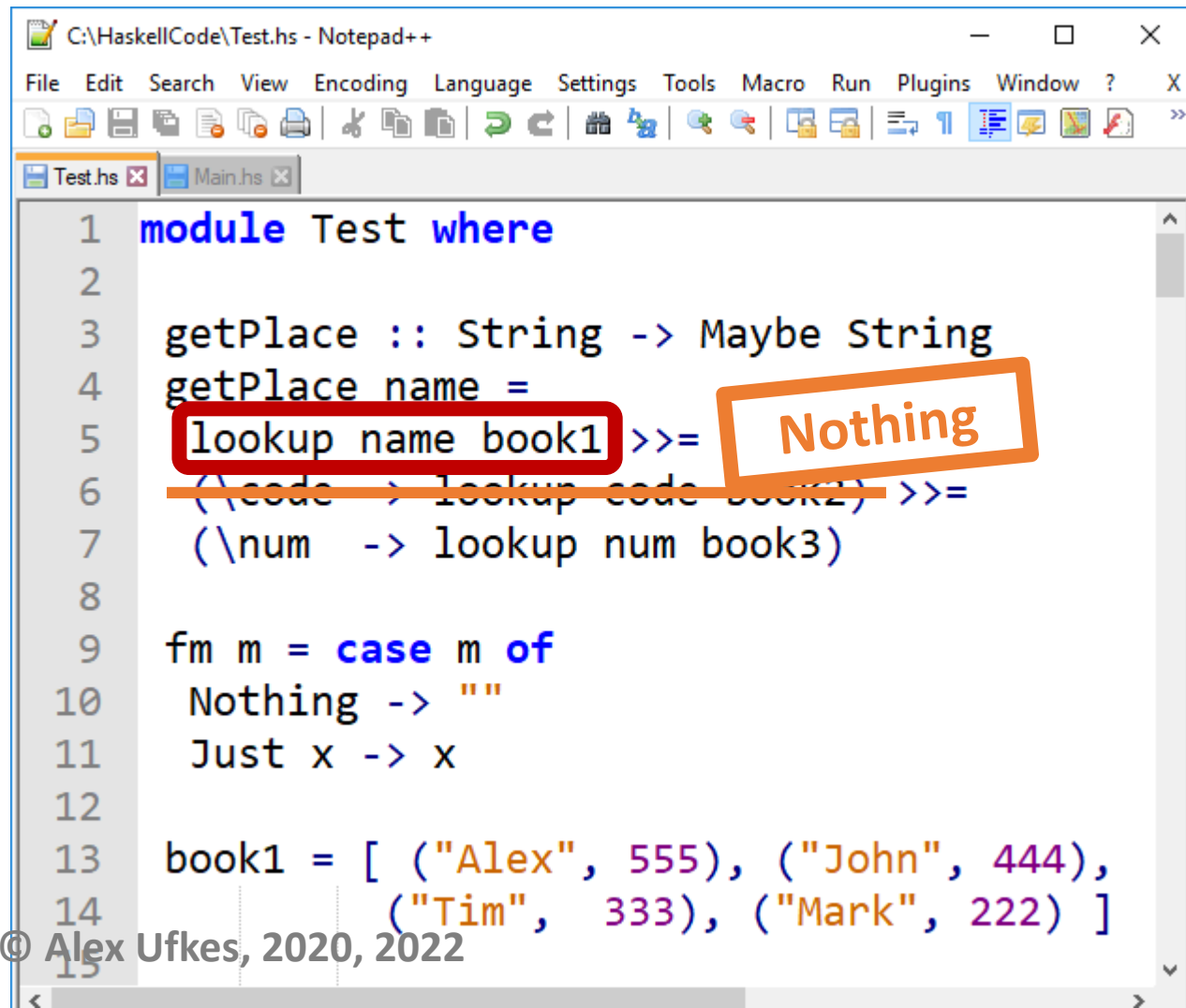
# Cascading Failure

```
C:\HaskellCode\Test.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ? X
Test.hs Main.hs
1 module Test where
2
3 getPlace :: String -> Maybe String
4 getPlace name = do
5   code <- lookup name book1
6   num <- lookup code book2
7   lookup num book3
8
9 fm m = case m of
10   Nothing -> ""
11   Just x -> x
12
13 book1 = [ ("Alex", 555), ("John", 444),
14           ("Tim", 333), ("Mark", 222) ]
15
16 © Alex Ufkes, 2020, 2022
```

Is the  
same as:

```
C:\HaskellCode\Test.hs - Notepad++
File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ? X
Test.hs Main.hs
1 module Test where
2
3 getPlace :: String -> Maybe String
4 getPlace name =
5   lookup name book1 >=>
6   (\code -> lookup code book2) >=>
7   (\num -> lookup num book3)
8
9 fm m = case m of
10   Nothing -> ""
11   Just x -> x
12
13 book1 = [ ("Alex", 555), ("John", 444),
14           ("Tim", 333), ("Mark", 222) ]
15
16 63
```

# Cascading Failure

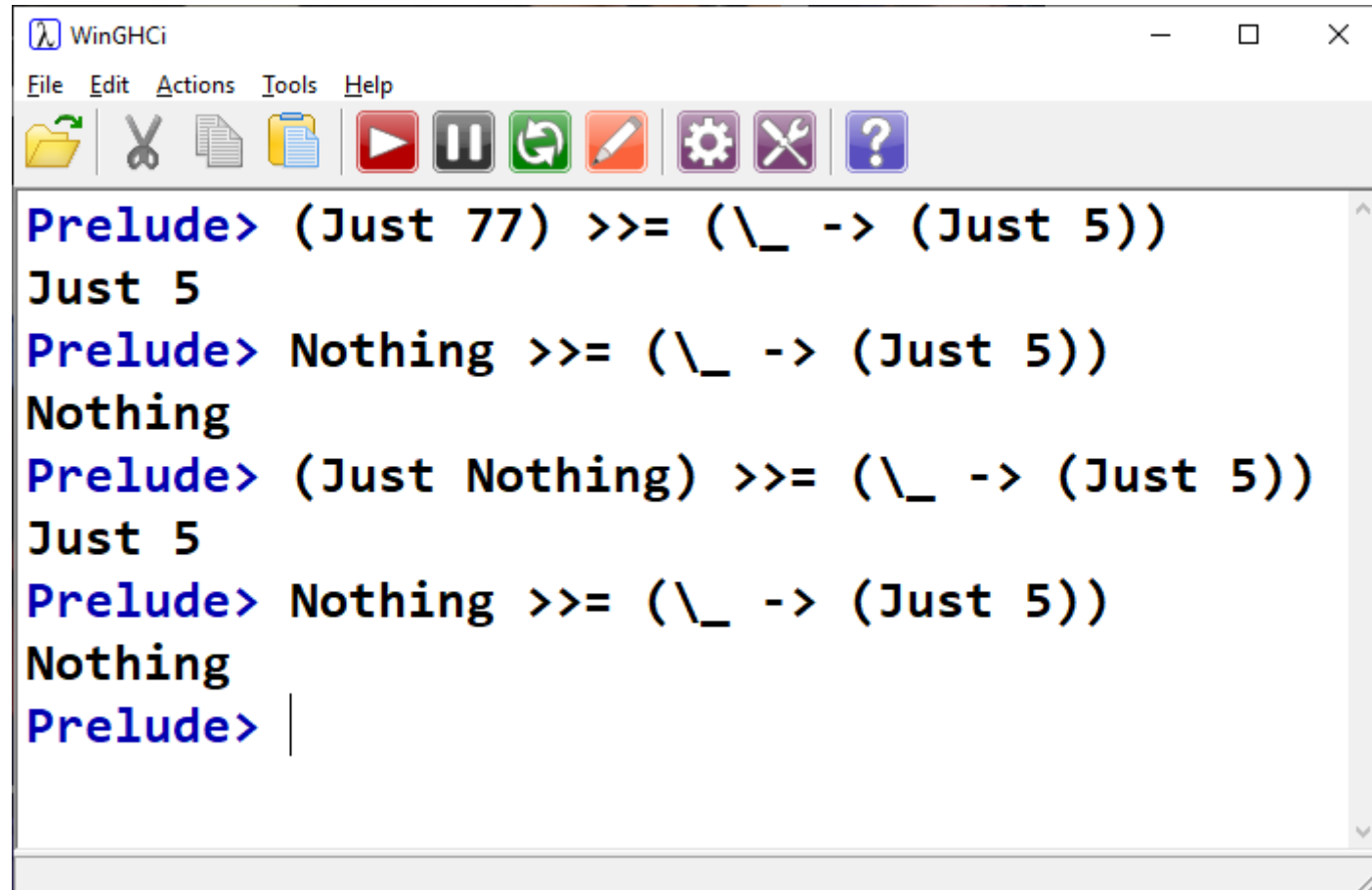


```
1 module Test where
2
3 getPlace :: String -> Maybe String
4 getPlace name =
5   lookup name book1 >=>
6   (\code -> lookup code book2) >=>
7   (\num -> lookup num book3)
8
9 fm m = case m of
10   Nothing -> ""
11   Just x -> x
12
13 book1 = [ ("Alex", 555), ("John", 444),
14           ("Tim", 333), ("Mark", 222) ]
15
```

- When the first argument to ( $>=>$ ) is **Nothing**, it just returns **Nothing** while ignoring the given function
- This causes failure to cascade
- If the first lookup fails, **Nothing** is passed into the second  $>=>$ .
- The failure then cascades into the third  $>=>$ , and is returned.
- After the first **Nothing**, subsequent  $>=>$  pass **Nothing** to each other



*When the first argument to ( $\gg=$ ) is **Nothing**, it just returns **Nothing** while ignoring the given function*

A screenshot of the WinGHCi window. The window has a title bar with the WinGHCi logo and standard window controls. Below the title bar is a menu bar with 'File', 'Edit', 'Actions', 'Tools', and 'Help'. Under the 'Actions' menu, there is a toolbar with icons for file operations (folder, copy, paste, save), execution (play, pause, step over, step into), and settings (gear, wrench, question mark). The main text area contains the following Haskell code and its output:

```
Prelude> (Just 77) >>= (\_ -> (Just 5))
Just 5
Prelude> Nothing >>= (\_ -> (Just 5))
Nothing
Prelude> (Just Nothing) >>= (\_ -> (Just 5))
Just 5
Prelude> Nothing >>= (\_ -> (Just 5))
Nothing
Prelude> |
```

# Moving on...

## ...to imperative.

Rust is an imperative language. However, we'll see many cool features that remind us of the functional languages we've seen.







