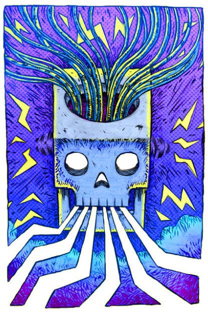


Programming IO

a + b = b + a ?

Think of programming language.

Imagine a program which contains

`f() + g()`

where all you know is that f and g both return integers

Can you safely swap f and g?

`g() + f()`

Or can they be computed in parallel?

When is a function a function?

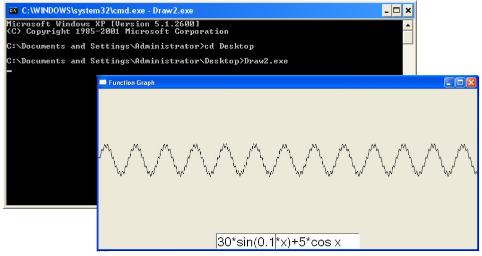
In most programming languages, **no**, because functions are not really functions in the mathematical sense.

e.g., Python: `input() + input()`

Haskell is a **pure** functional language. Functions really are functions.

So how can Haskell be pure and still interact with the outside world?

Let's run a Haskell program…



```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corporation

C:\Documents and Settings\Administrator>cd Desktop

C:\Documents and Settings\Administrator\Desktop>Draw2.exe
_
```

```
30*sin(0.1*x)+5*cos x
```

- What's the type of *that* result???

A Much Simpler Example

```
Prelude> writeFile "foo" "baz"

Prelude>
```

- Writes baz to the file called foo.
- No result displayed—wonder why not?

What's "foo"?

```
Prelude> :t "foo"
"foo" :: [Char]
Prelude> :i String
-- type constructor
type String = [Char]
```

Huh? I thought it was a String

A type synonym

- A String is a *list of characters*
- A character (Char) corresponds more-or-less to a key on the keyboard.
- Examples: 'a', '1', ' '

What's writeFile?

```
Prelude> :i writeFile
writeFile :: FilePath -> String -> IO ()
```

Just a String

INSTRUCTIONS to the operating system to write the file

- When GHCi finds an expression of IO type, it *obeys the instructions* instead of printing them.

An Analogy

- Instructions:

Take this card, go to a Bankomat.
Put in the card.
Enter this code, select 500kr.
Take the money and the card.

- Value:

Which would you rather have?

Instructions with Results

- Instructions can have results:

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

Instructions for computing a String

- readFile "foo" *is not a String*, and no String can be extracted from it

Just as no 500:- can be extracted from a bank card

- But it can be used as *part* of more complex instructions, to compute a String

Combining Instructions

- We combine instructions using **do:**

```
copyFile fromA toB =
   do contents <- readFile fromA
      writeFile toB contents
```

"First follow readFile instructions, call the result contents, then follow writeFile instructions"

- readFile fromA is an IO String
- But contents is just a String
- ~~writeFile toB (readFile fromA)~~

Example: Displaying Instruction Results

```
display io =
   do result <- io
      print result
```

Follow the instructions to get a value, then print it

```
Main> display (readFile "foo")
"baz"
Main> display (writeFile "foo" "bar")
()
```

Repeating Instructions

```
doTwice io =
   do a <- io
      b <- io
      return (a,b)
dont io =
     return ()
```

An instruction to compute the given result

```
Main> display (doTwice (print "hello"))
"hello"
"hello"
((),())
Main> display (dont (print "hello"))
()
```

Writing instructions and *obeying* them are two different things!

Why Distinguish Instructions?

- *Functions* always give the same result for the same arguments
- *Instructions* can behave differently on different occasions
- Confusing them (as in most programming languages) is a major source of bugs
  - This concept a major breakthrough in programming languages in the 1990s
  - How would you write doTwice in C?

Monads = Instructions

- What is the type of doTwice?

```
Main> :i doTwice
doTwice :: Monad a => a b -> a (b,b)
```

Even the *kind of instructions* can vary! Different kinds of instructions, depending on who obeys them.

Whatever kind of result argument produces, we get a pair of them

IO means operating system.

Monads = Instructions

- A new built-in type
  - IO a

Instructions to the Operating System

- Standard functions:
  - putStr   :: String -> IO ()
  - readFile :: FilePath -> IO String
  - writeFile :: FilePath -> String -> IO ()
  - …

() is the "empty tuple" – no interesting contents

Quiz

- Define the following function:

```
sortFile :: FilePath -> FilePath -> IO ()
```

- "sortFile file1 file2" reads the lines of file1, sorts them, and writes the result to file2
- You may use the following standard functions:

```
sort    :: Ord a => [a] -> [a]
lines   :: String -> [String]
unlines :: [String] -> String
```

An example

- Suppose:

```
lastCommand :: [IO a] -> IO a
lastCommand ios = head (reverse io)
```

- What happens:

```
lastCommand [print "apa", print "bepa", print "cepa"]
```

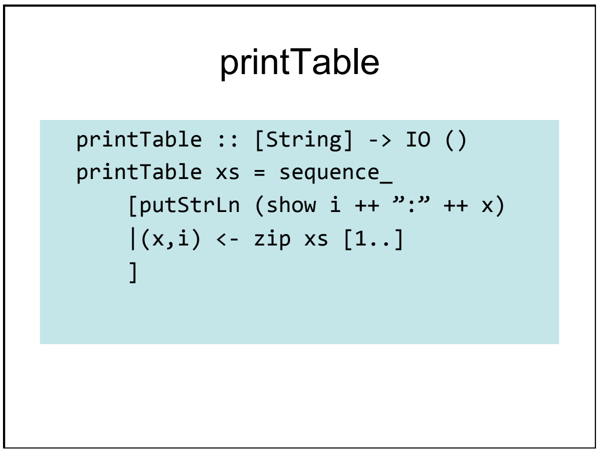
Sequence

- Useful functions:

```
sequence  :: [IO a] -> IO [a]
sequence_ :: [IO a] -> IO ()
```

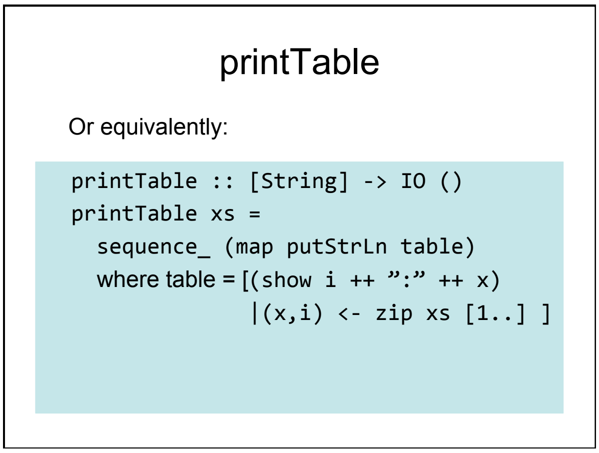
- Example:

```
printTable :: [String] -> IO ()
printTable xs = ?
ghci> printTable ["apa","bepa","cepa"]
  1: apa
  2: bepa
  3: cepa
```



printTable

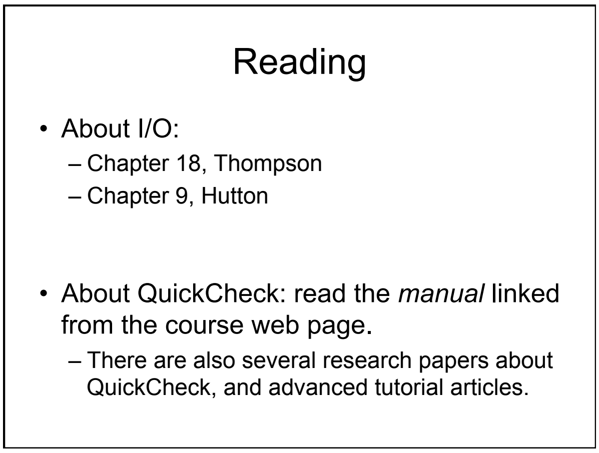
```
printTable :: [String] -> IO ()
printTable xs = sequence_
    [putStrLn (show i ++ ”:” ++ x)
    |(x,i) <- zip xs [1..]
    ]
```



printTable

Or equivalently:

```
printTable :: [String] -> IO ()
printTable xs =
  sequence_ (map putStrLn table)
  where table = [(show i ++ ”:” ++ x)
                |(x,i) <- zip xs [1..] ]
```



Reading

- About I/O:
  - Chapter 18, Thompson
  - Chapter 9, Hutton
- About QuickCheck: read the *manual* linked from the course web page.
  - There are also several research papers about QuickCheck, and advanced tutorial articles.