

Functional Programming

IO

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Referential transparency and substitutivity

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- Every variable and expression has just one value
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- Every variable can be replaced by its definition
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Enables reasoning

```
-- sequence of function calls does not matter  
f () + g () == g () + f ()  
  
-- number of function calls does not matter  
f () + f ( ) == 2 * f ()
```

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Bad example

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- Expect to read one input and use it twice
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- Expect to read one input and use it twice
- By substitutivity, this expression must behave like

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which reads two inputs!
- VERY WRONG!!!

The dilemma

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A contradiction?

No!

- Instead of performing IO operations directly, there is an abstract type of **IO instructions**, which get executed lazily by the operating system
- Some instructions (e.g., read from a file) return values, so the abstract IO type is parameterized over their type
- Keep in mind: instructions are just values like any other

Haskell IO

The main function

Top-level result of a program is an IO “instruction”.

```
main :: IO ()  
main = undefined
```

- an instruction describes the **effect** of the program
- effect = IO action, imperative state change, ...

Kinds of instructions

Primitive instructions

```
-- defined in the Prelude  
putChar    :: Char -> IO ()  
getChar    :: IO Char  
writeFile  :: FileName -> String -> IO ()  
readFile   :: FileName -> IO String
```

and many more

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and many more

No op instruction

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

The IO instruction `return 42` performs no IO, but yields the value 42.

Combining two instructions

The bind operator $\gg=$

Intuition: next instruction may depend on the output of the previous one

$(\gg=) :: IO\ a \rightarrow (a \rightarrow IO\ b) \rightarrow IO\ b$

The instruction $m \gg= f$

- executes $m :: IO\ a$ first
- gets its result $x :: a$
- applies $f :: a \rightarrow IO\ b$ to the result
- to obtain an instruction $f\ x :: IO\ b$ that returns a b
- and executes this instruction to return a b

Combining two instructions

The bind operator $>>=$

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$(>>=) :: IO\ a \rightarrow (a \rightarrow IO\ b) \rightarrow IO\ b$

The instruction $m >>= f$

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- gets its result $x :: a$
- applies $f :: a \rightarrow IO\ b$ to the result
- to obtain an instruction $f\ x :: IO\ b$ that returns a b
- and executes this instruction to return a b

Example

```
readFiles f1 f2 =  
  readFile f1 >>= \xs1 -> readFile f2
```


More convenient: do notation

```
copyFile source target =  
  undefined
```

```
doTwice io =  
  undefined
```

```
doNot io =  
  undefined
```

Translating do notation into >>= operations

- $\text{do } \textit{lastaction}$
→
 $\textit{lastaction}$
- $\text{do } \{ x \leftarrow \textit{action1}; \textit{instructions} \}$
→
 $\textit{action1} \gg= \backslash x \rightarrow \text{do } \{ \textit{instructions} \}$
- $\text{do } \{ \textit{action1}; \textit{instructions} \}$
→
 $\textit{action1} \gg \text{do } \{ \textit{instructions} \}$
- $\text{do } \{ \text{let } \textit{binding}; \textit{instructions} \}$
→
 $\text{let } \textit{binding} \text{ in } \text{do } \{ \textit{instructions} \}$

Instructions vs functions

Functions

behave the same each time they called

Instructions vs functions

Functions

behave the same each time they called

Instructions

may be interpreted differently each time they are executed, depending on context

Underlying concept: **Monad**

What's a monad?

- abstract datatype for instructions that produce values
- built-in combination $>>=$
- abstracts over different interpretations (computations)

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IO is a special case of a monad

- one very useful application for monad
- built into Haskell
- but there's more to the concept
- many more instances to come!

Hands-on task

Define a function

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

-- sortFile inFile outFile
-- reads inFile, sorts its lines, and writes the result to outFile

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

Utilities

```
sequence :: [IO a] -> IO [a]
```

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


Another hands-on task

Define a function

```
printTable :: [String] -> IO ()  
  
{-  
printTable ["New York", "Rio", "Tokio"]  
outputs  
1: New York  
2: Rio  
3: Tokyo  
-}
```

First meeting with monads

- abstract data type of instructions returning results
- next instruction can depend on previous result
- instructions are just values
- basis for Haskell's standard IO