I/O

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CODE WRITTEN IN HASKELL IS GUARANTEED TO HAVE NO SIDE EFFECTS.

...because no one will ever run it?
At Long Last: Hello World

```haskell
-- hello.hs
main = putStrLn "Hello, World!"
```

To run it directly:

```
$ stack runhaskell hello
Hello, World!
```

To compile it into an executable:

```
$ stack ghc -- --make hello
[1 of 1] Compiling Main          ( hello.hs, hello.o )
Linking hello ...   
$ ./hello
Hello, World!
```
Every IO action (e.g., printing, reading), produces an IO object

Output-only actions (e.g., printing), return IO ()

Input actions (e.g., reading a line), return something like IO String
Sequencing is Fundamental to I/O: do Blocks

-- hello2.hs
main :: IO ()
main = do
    putStrLn "Hello. What is your name?" -- Print the string
    name <- getLine -- Read a line; bind result to name
    putStrLn $ "Hello, " ++ name

$ stack runhaskell hello2
Hello. What is your name?
Stephen
Hello, Stephen

*Main> :t getLine
getLine :: IO String

Indentation rules for do blocks same as those for where, let, and do.
I/O Actions Are Expressions That Produce an IO \( t \)

Effectively an implicit \( _ \leftarrow \) if you don’t write your own (except the last line)

```haskell
-- putstrln1.hs
main = do
    result <- putStrLn "Hello World"  -- Not that you’d want to...
    print result                      -- putStrLn . show
```

```
*Main> :l putstrln1
[1 of 1] Compiling Main         ( putstrln1.hs, interpreted )
Ok, one module loaded.
*Main> main
Hello World
()
*Main> :t print
print :: Show a => a -> IO ()
```
Let Blocks: The Third Type of do Block Statement Syntax

```haskell
-- let1.hs
import Data.Char(toUpper)

main = do
    putStrLn "First Name? "             -- 1/3: expr
    fname <- getLine               -- 2/3: name <- expr
    putStrLn "Last Name? "
    lname <- getLine
    let fshout = map toUpper fname                -- 3/3: let decls
        lshout = map toUpper lname
    putStrLn $ "WELCOME " ++ fshout ++ " " ++ lshout
```

$ stack runhaskell let1
First Name? Stephen
Last Name? Edwards
WELCOME STEPHEN EDWARDS
Let is for pure Haskell; <- takes a result from an I/O action

I/O actions are just normal Haskell expressions until connected to `main`

```haskell
-- let2.hs
printTwo = putStrLn "Two"

main = do
  putStrLn "One"
  let printFour = putStrLn "Four"
  getMyLine = getLine
  putStrLn "Three"
  printTwo
  printThree
  putStrLn "Type something "
  myLine <- getMyLine
  printFour
  putStrLn $ "You typed " ++ myLine ++ ""
```
--- reverser.hs

reverseWords :: String -> String
reverseWords = unwords . map reverse . words

main = do
  line <- getLine
  if null line then -- if-then-else is an expression, so both
                   return () -- branches must return the same thing but
    else do -- return doesn’t do quite what you think
      putStrLn $ reverseWords line
  main

$ stack runhaskell reverser
able elba stressed diaper looter debut deeps devil peels
elba able desserts repaid retool tubed speed lived sleep
tacocat deified civic radar rotor kayak aibohphobia
tacocat deified civic radar rotor kayak aibohphobia

Aibohphobia: Fear of palindromes
**Return Encapsulates a Value in a do Block**

```hs
readFromUser :: IO String
readFromUser = getLine

justReturn :: IO String
justReturn = do
  putStrLn "justReturn invoked"
  return "this string"

main :: IO ()
main = do
  line1 <- readFromUser
  putStrLn line1
  line2 <- justReturn
  putStrLn "after justReturn"
  putStrLn line2
```

A `do` block returns the value of the last expression, which must be of type `IO t` and cannot be a `let` or `<-`.

*Return* is a vacuous I/O action that puts a value in an `IO t`.

Set the return value of a `do` block with a `return` at the end.

```bash
$ stack runhaskell do1
I typed this
I typed this
justReturn invoked
after justReturn
this string
```
Return does not return control; <- is the inverse of return

-- do2.hs
main :: IO ()
main = do
  return "tree falls in the forest"  -- No one is listening
  return ()                         -- No control transfer
  a <- return "something "          -- Effectively let a = "something 
  b <- do
    return "silence"                -- do runs actions in sequence
    putStrLn "return did not return"
    return "else "                  -- Also does not return
  let c = "was returned"
  putStrLn $ a ++ b ++ c

$ stack runhaskell do2
return did not return
something else was returned
Basic I/O Functions

putChar :: Char -> IO ()
putStr :: String -> IO ()
putStrLn :: String -> IO ()  -- Adds a newline
print :: Show a => a -> IO ()  -- putStrLn . show

getChar :: IO Char  -- End-of-file throws an exception
getLine :: IO String  -- Read up to newline
getContents :: IO String  -- Read entire input (lazily)
interact :: (String -> String) -> IO ()  -- Read, apply f, print
readIO :: Read a => String -> IO a  -- Parse a string in a do
readLn :: Read a => IO a  -- Read a line and parse

import Data.Char(toUpper)

main :: IO ()
main = interact $ map toUpper

$ stack runhaskell interact < interact.hs
IMPORT DATA.CHAR(TOUPPER)
MAIN :: IO ()
MAIN = INTERACT $ MAP TOUPPER
Implementations of Input Functions

putChar is a primitive

\[
\begin{align*}
\text{putStr} & \quad :: \quad \text{String} \to \text{IO}() \quad -- \quad \text{Equivalent to the Prelude def.} \\
\text{putStr} \; [] & \quad = \quad \text{return} () \quad -- \quad \text{Produces an IO ()} \\
\text{putStr} \; (x:xs) & \quad = \quad \text{do} \quad \text{putChar} \; x \\
& \quad \text{putStr} \; xs \quad -- \quad \text{Recurse}
\end{align*}
\]

\[
\begin{align*}
\text{putStrLn} & \quad :: \quad \text{String} \to \text{IO}() \\
\text{putStrLn} \; s & \quad = \quad \text{do} \quad \text{putStr} \; s \\
& \quad \text{putStr} \; "\n" \quad -- \quad \text{Print a newline after the string}
\end{align*}
\]

\[
\begin{align*}
\text{print} & \quad :: \quad \text{Show} \; a \Rightarrow a \to \text{IO}() \\
\text{print} \; x & \quad = \quad \text{putStrLn} \; (\text{show} \; x) \quad -- \quad \text{Transform to string with show}
\end{align*}
\]
Implementations of Output Functions

```haskell
getLine :: IO String
getLine = do c <- getChar
            if c == '
' then return "" else
            do s <- getLine -- Recurse: get the rest
               return (c:s)
```

```haskell
interact :: (String -> String) -> IO ()
interact f = do hSetBuffering stdin NoBuffering -- Disable
                hSetBuffering stdout NoBuffering -- buffering
                s <- getContents -- Lazily read all the input
                putStrLn (f s) -- Starts before input is done
```
When is an *if* without an *else* for *do* blocks

```haskell
when :: Bool -> IO () -> IO () -- Prelude definition is more general
when p s = if p then s else return ()

-- when.hs
import Control.Monad (when) -- “Monad” in Category Theory is “Action”

main :: IO ()
main = do c <- getChar
          when (c /= ' ') $ do putChar c
                          main

The default is line buffering: a whole line is read before it is examined

$ stack runhaskell when
This-will-stop-at-the-first-space did it?
This-will-stop-at-the-first-space$
```
sequence Applies a List of I/O Actions and Captures the Result

sequence :: [IO a] -> IO [a] -- Prelude definition is more general

main :: IO () -- Like Unix head: print the first 10 input lines
main = do
  inputLines <- sequence $ replicate 10 getline
  sequence_ $ map putStrLn inputLines -- sequence_ discards result

mapM or mapM_, which discards the result, is better for the second sequence

mapM :: (a -> IO b) -> [a] -> IO [b] -- Not the actual type;
mapM_ :: (a -> IO b) -> [a] -> IO () -- Prelude def. is more general

main :: IO ()
main = do
  inputLines <- sequence $ replicate 10 getline
  mapM_ putStrLn inputLines -- Apply putStrLn to lines, return IO ()
forM and forM_ are just mapM with arguments reversed
Why? Because it makes forM look like a traditional for loop (well, foreach)

import Control.Monad(forM, forM_)

main :: IO ()
main = do
  colors <- forM ([1..4] :: [Int]) $ \a -> do
    putStrLn $ "What color is #" ++ show a ++ "?"
    getLine
    putStrLn "You ranked the colors"
  forM_ colors putStrLn

The version in Learn You a Haskell... is redundant:

colors <- forM [1,2,3,4] (\a -> do -- Unnecessary parentheses
  putStrLn $ "Which .."
  color <- getLine
  return color) -- This is what getLine would return anyway
*Main> main
What color is #1?
Red
What color is #2?
Green
What color is #3?
Blue
What color is #4?
Black
You ranked the colors
Red
Green
Blue
Black

\texttt{mapM f as = sequence (map f as)} \quad \texttt{-- Prelude definitions}
\texttt{forM = flip mapM}
Forever Loops Forever

```haskell
-- forever.hs
import Control.Monad (forever)
import Data.Char (toUpper)

main :: IO ()
main = forever $ do
  l <- getLine
  putStrLn $ map toUpper l
```

```
$ stack runhaskell forever < forever.hs
-- FOREVER.HS
IMPORT Control.Monad(FOREVER)
IMPORT Data.Char(TOUPPER)

MAIN :: IO ()
MAIN = FOREVER $ DO
  L <- GETLINE
  PUTSTRNLN $ MAP TOUPPER L
forever: <stdin>: hGetLine: end of file
```
import System.IO (openFile, IOMode(ReadMode), hGetContents, hClose, hPutStrLn, stderr)
import System.Exit(exitFailure); import Data.Char(isAlpha, toLower)
import System.Environment(getArgs, getProgName)

main :: IO () -- Report whether each line of a file is a palindrome
main = do args <- getArgs
    case args of
      [filename] -> do -- Expects one filename
        h <- openFile filename ReadMode
        contents <- hGetContents h -- Read the file
        mapM_ (putStrLn . isAPalindrome) $ lines contents
        hClose h
      _ -> do pn <- getProgName -- Usage message
        hPutStrLn stderr $ "Usage: "++pn++" <filename>"
        exitFailure -- Terminate the program

isAPalindrome :: String -> String -- Report whether the string is one
isAPalindrome s = s ++ ":: " ++ show (ls == reverse ls)
  where ls = map toLower $ filter isAlpha s
palindromes.txt:

Able was I saw elba
Taco cat
Race car
Palindrome
A man, a plan, a canal, Panama!

$ stack runhaskell palindrome palindromes.txt
Able was I saw elba: True
Taco cat: True
Race car: True
Palindrome: False
A man, a plan, a canal, Panama!: True
-- System.Environment  Command-line args; environment variables
getArgs :: IO [String]  -- The list of command-line arguments
getProgName :: IO String  -- Name of the invoked program (argv[0])

-- System.IO  File Handle; open; close; read; write; “h” I/O action variants

type FilePath = String
openFile :: FilePath -> IOMode -> IO Handle
data IOMode = ReadMode | WriteMode | AppendMode | ReadWriteMode
stderr :: Handle  -- Handle for standard error
hGetContents :: Handle -> IO String  -- getContents from a Handle
hPutStrLn :: Handle -> String -> IO ()  -- putStrLn to a Handle
hClose :: Handle -> IO ()  -- Close the (file) handle
withFile :: FilePath -> IOMode -> (Handle -> IO r) -> IO r
readFile :: FilePath -> IO String

-- System.Exit  Like exit() in the C standard library
exitFailure :: IO a  -- Terminate program with a failure code
import System.IO (withFile, IOMode (ReadMode), hGetContents, hPutStrLn, stderr)
import System.Exit (exitFailure); import Data.Char (isAlpha, toLower)
import System.Environment (getArgs, getProgName)

main :: IO ()
main = do
  args <- getArgs
  case args of
    [filename] -> do
      withFile filename ReadMode (\h -> do
        contents <- hGetContents h
        mapM_ (putStrLn . isAPalindrome) $ lines contents)
    _ -> do
      pn <- getProgName
      hPutStrLn stderr $ "Usage: " ++ pn ++ " <filename>"
      exitFailure

isAPalindrome :: String -> String
isAPalindrome s = s ++ ":\n  where ls = map toLower $ filter isAlpha s
import System.IO
import System.Exit(die); import Data.Char(isAlpha, toLower)
import System.Environment(getArgs, getProgName)

main :: IO ()
main = do args <- getArgs
    case args of
        [filename] -> do
            contents <- readFile filename -- Even simpler
            mapM_ (putStrLn . isAPalindrome) $ lines contents
        _ -> do pn <- getProgName
            die $ "Usage: " ++ pn ++ " <filename>"

isAPalindrome :: String -> String
isAPalindrome s = s ++ "": " ++ show (ls == reverse ls)
    where ls = map toLower $ filter isAlpha s
-- More in System.IO

hGetChar :: Handle -> IO Char
hGetLine :: Handle -> IO String
hPutStr  :: Handle -> String -> IO ()
hFlush   :: Handle -> IO ()

data BufferMode = NoBuffering | LineBuffering | BlockBuffering (Maybe Int)

hSetBuffering :: Handle -> BufferMode -> IO ()

openTempFile :: FilePath -> String -> IO (FilePath, Handle)
writeFile   :: FilePath -> String -> IO ()
appendFile  :: FilePath -> String -> IO ()

-- System.Directory

removeFile   :: FilePath -> IO ()
renameFile   :: FilePath -> FilePath -> IO ()
renamePath   :: FilePath -> FilePath -> IO ()
listDirectory :: FilePath -> IO [FilePath]
ByteString: Faster strings

```haskell
type String = [Char]
```

Data.ByteString implements strings as packed Word8 (byte) arrays: compact and faster

Data.ByteString is strict (no laziness, infinite lists, etc.)

Data.ByteString.Lazy is “lazy” on 64K blocks

Data.ByteString.Char8 and Data.ByteString.Lazy.Char8 work with Char8 arrays instead of Word8
import Data.List(isInfixOf)
import System.Environment(getArgs, getProgName)
import System.Exit(die)

main :: IO ()
main = do args <- getArgs
  (pat, filename) <- case args of
    [p, f] -> return (p, f)
    _ -> do pn <- getProgName
            die $ "Usage: "+pn++" <pattern> <filename>"
            file <- readFile filename
            putStr $ grep filename

grep :: String -> String -> String
grep pat input =
  unlines $ filter (isInfixOf pat) $ lines input
"grep" with Data.ByteString.Char8

```haskell
import qualified Data.ByteString.Char8 as B
import System.Environment (getArgs, getProgName)
import System.Exit (die)

main :: IO ()
main = do 
    args <- getArgs
    (pat, filename) <- case args of
        [p, f] -> return (p, f)
        _ -> do 
            pn <- getProgName
            die $ "Usage: " ++ pn ++ " <pattern> <filename>"
    file <- B.readFile filename
    B.putStr $ grep (B.pack pat) file
        -- pack :: String → Bytestring

grep :: B.ByteString → B.ByteString → B.ByteString

grep pat input =
    B.unlines $ filter (B.isInfixOf pat) $ B.lines input
```
"grep" with Data.ByteString.Lazy.Char8

import qualified Data.ByteString.Lazy.Char8 as B
import System.Environment (getArgs, getProgName)
import System.Exit (die)

main :: IO ()
main = do args <- getArgs
      (pat, filename) <- case args of
        [p, f] -> return (p, f)
        _ -> do pn <- getProgName
               die $ "Usage: " ++ pn ++ " <pattern> <filename>"
               file <- B.readFile filename
               B.putStr $ grep (B.pack pat) file
               -- pack :: String → Bytestring

grep :: B.ByteString → B.ByteString → B.ByteString
grep pat input =
  B.unlines $ filter (isInfixOf pat) $ B.lines input where
  isInfixOf p s = any (B.isPrefixOf p) $ B.tails s
Quick Experiment

Selecting 3500 lines that contain “fe” from a 49M/218 kl log file:

$ stack ghc -- --make -O bgrep.hs
$ /usr/bin/time -f "%E %M" ./bgrep fe /tmp/log > /dev/null

<table>
<thead>
<tr>
<th>Version</th>
<th>Time</th>
<th>Memory</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>String</td>
<td>2600 ms</td>
<td>6.2 MB</td>
<td>[Char]</td>
</tr>
<tr>
<td>ByteString.Lazy</td>
<td>1300 ms</td>
<td>6.2 MB</td>
<td>64K blocks</td>
</tr>
<tr>
<td>ByteString</td>
<td>110 ms</td>
<td>56 MB</td>
<td>Single byte array; naïve isInfixOf</td>
</tr>
<tr>
<td>grep</td>
<td>40 ms</td>
<td>2.5 MB</td>
<td>GNU implementation; &gt;3000 LoC</td>
</tr>
</tbody>
</table>
Exceptions

TL;DR: Don’t use ‘em; use something like Maybe or Either

Work best in I/O contexts (sequential evaluation; lots to go wrong)

Only I/O code can catch exceptions, but they may be thrown anywhere

Some of the I/O exception handling functions in System.IO.Error:

\[
\begin{aligned}
\text{catchIOError} &:: \text{IO} \ a \rightarrow (\text{IOError} \rightarrow \text{IO} \ a) \rightarrow \text{IO} \ a \\
\text{isUserError} &:: \text{IOError} \rightarrow \text{Bool} \\
\text{isDoesNotExistError} &:: \text{IOError} \rightarrow \text{Bool} \\
\text{isPermissionError} &:: \text{IOError} \rightarrow \text{Bool} \\
\text{ioeGetFileName} &:: \text{IOError} \rightarrow \text{Maybe} \ FilePath
\end{aligned}
\]

More extensive exception facilities in Control.Exception
import System.Environment(getArgs)
import System.IO.Error(catchIOError,.isUserError, isDoesNotExistError, ioeGetFileName, isPermissionError)
import System.Exit(die)
import qualified Data.ByteString.Char8 as B

main :: IO ()
main = do [filename] <- getArgs  -- Match may fail
         contents <- B.readFile filename  -- Many possible failures
         print $ length $ B.lines contents

  `catchIOError` \ e -> die $ case ioeGetFileName e of
     Just fn | isDoesNotExistError e -> fn ++ " : No such file"
     | isPermissionError e      -> fn ++ " : Permission denied"
     _ | isUserError e          -> "Usage: lc <filename>"
     | otherwise                -> show e
Line Count in Action

```bash
$ stack ghc -- --make -O -Wall lc.hs
[1 of 1] Compiling Main (lc.hs, lc.o)
Linking lc ...
$ ./lc
Usage: lc <filename>
$ ./lc foo bar
Usage: lc <filename>
$ ./lc foo
foo: No such file
$ ./lc /var/log/btmp
/var/log/btmp: Permission denied
$ ./lc /var/log/syslog
4705
```