universität innsbruck

WS 2023/2024

Functional Programming

Week 10 – Input and Output, Connect Four

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Last Lecture

- scoping rules determine visibility of function names and variable names
- larger programs should be structured in modules
  - explicit export-lists to distinguish internal and external parts
  - import of modules instead of copying code
  - qualified imports and qualifiers are useful for resolving name conflicts
  - defaults
    - if program does not contain module declaration, `module Main where` is added
    - `import Prelude` is implicitly added, if no other imports of `Prelude` are present
- example

```
module Rat(Rat,createRat) where ...

module Application where
import Prelude hiding (pi)      -- hide import of pi
import Rat
pi :: Rat                       -- so that here there won't be a conflict
pi = createRat                  -- pi with precision of 70 digits
  31415926535897932384626433832795028841971693993751058209749445923078164
  10000000000000000000000000000000000000000000000000000000000000000000000
```

Input and Output in Haskell

I/O: Input and Output

- aim: communicate with the user
  - ask user for inputs
  - print answers
  - outside the GHCI read-eval-print-loop
  - stand-alone programs that neither require ghc-installation nor Haskell knowledge of user
- I/O is not restricted to text-based user-I/O
  - reading and writing of files
    (e.g., compiler translates .hs to .exe, or .tex to .pdf)
  - reading and writing into memory
    (mutable state, arrays)
  - reading and writing of network channels
    (e.g., web-server and internet-browser)
  - start other programs and communicate with them
  - play/record sound, capture mouse-movements, ...

An Initial Example

- ```haskell
  main = do                           -- file: welcomeIO.hs
    putStrLn "Greetings! Please tell me your name."
    name <- getLine
    putStrLn $ "Welcome to Haskell's IO, " ++ name ++ "!"
  ```
- compile it with GHC (not GHCI) via

  ```
  $ ghc --make welcomeIO.hs
  ```
- and run it

  ```
  $ ./welcomeIO            # welcomeIO.exe on Windows
  Greetings! Please tell me your name.
  Homer                    # this was typed in
  Welcome to Haskell's IO, Homer!
  ```
- notes
  - `putStrLn` – prints string followed by newline
  - `getLine` – reads line from standard input
  - new syntax: `do` and `<-`
  ```

I/O and the Type System

- consider

```
ghci> :l welcomeIO.hs
ghci> :t putStrLn
putStrLn :: String -> IO ()
ghci> :t getLine
getLine :: IO String
ghci> :t main
main :: IO ()
```

- `IO a` is type of I/O actions delivering results of type `a` (in addition to their I/O operations)
- examples
  - `String -> IO ()` – after supplying a string, we obtain an I/O action (in case of `putStrLn`, "printing")
  - `IO ()` – just perform I/O (in case of `main`, run our program)
  - `IO String` – do some I/O and deliver a string (in case of `getLine`, user-input)

Combining I/O Actions

- I/O actions can be combined
- core building block: bind (syntax >>=)
  `(>>=) :: IO a -> (a -> IO b) -> IO b`
- consider `act1 >>= \ x -> act2`
  - on evaluation, this expressions first performs action `act1`
  - the result of action `act1` is stored in `x`
  - afterwards action `act2` is performed (which may depend on `x`)
  - in total, both actions are performed and the result is that of `act2`
- ignoring results: `(>>) :: IO a -> IO b -> IO b`, `a1 >> a2 = a1 >>= \_ -> a2`
- example

```
putStrLn "Hi. What's your name?" >>    -- ignore result, which is ()
getLine >>= \ name ->                  -- store result in variable name
let answer = "Hello " ++ name in       -- no I/O in this line
putStrLn answer                        -- final result from putStrLn: ()
```

  - the type of overall expression is `IO ()`, that of the last I/O action `putStrLn answer`
  - execution of actions is sequential, like in imperative programming

Do-Notation

- there is special syntax for combinations of binds, lambdas and lets

```
do x <- act            =      act >>= \ x -> do block
   block

do act                 =      act >> do block
   block

do let x = e           =      let x = e in do block
   block
```

- ```
  putStrLn "Hi. What's your name?" >>
  getLine >>= \ name ->
  let answer = "Hello " ++ name in
  putStrLn answer
  ```
  can be written as
  ```
  do putStrLn "Hi. What's your name?"
     name <- getLine
     let answer = "Hello " ++ name              -- no "in"!
     putStrLn answer
  ```
- as in `let`-syntax, `do`-blocks can also written via `do {..; ..; ..}`
  ```

Further Notes

- inside do-block, order is important; I/O actions are executed in order of appearance; result of block is result of last action
- `x <- a` is not available outside I/O actions,
  in particular there is no function of type `IO a -> a` which extracts the results of an action (of type `IO a`) without being an action itself (result type `a`)
  - once we are inside an IO action, we cannot escape
  - strict separation between purely functional code and I/O
  - when `IO a` does not appear inside type signature, we can be absolutely sure that no I/O ("side-effect") is performed
- `main :: IO ()` is the I/O action that is executed when running a compiled file via
  `ghc --make prog.hs` and then `./prog`
  (`prog.hs` must contain a module `Main` that exports `main`)

Using Purely Functional Code Inside I/O Actions

```haskell
-- reply is purely functional: no IO in type
reply :: String -> String
reply name =
  "Pleased to meet you, " ++ name ++ ".\n" ++
  "Your name contains " ++ n ++ " characters."
  where n = show $ length name

-- pure code can be invoked from I/O-part
main :: IO ()
main = do
  putStrLn "Greetings again. What's your name?"
  name <- getLine
  let niceReply = reply name
  putStrLn niceReply
```

- invoking purely functional code inside I/O is easy
- the other direction is not possible

Some Predefined I/O Functions

- `return :: a -> IO a` – turn anything into an I/O action which does nothing
- `System.Environment.getArgs :: IO [String]` – get command line arguments
- `putChar :: Char -> IO ()` – print character
- `putStr :: String -> IO ()` – print string
- `putStrLn :: String -> IO ()` – print string followed by newline
- `getChar :: IO Char` – read single character from stdin
- `getLine :: IO String` – read line (no newline-character in result)
- `interact :: (String -> String) -> IO ()` – use function that gets input as string and produces output as string
- `type FilePath = String`
- `readFile :: FilePath -> IO String` – read file content
- `writeFile :: FilePath -> String -> IO ()`
- `appendFile :: FilePath -> String -> IO ()`

Recursive I/O Actions

- branching and recursion is also possible with I/O actions
- example: implement `getLine` via `getChar`

```haskell
import Prelude hiding (getLine)

getLine = do
  c <- getChar
  if c == '\n'                -- branching
    then return ""
    else do
      l <- getLine            -- recursion
      return $ c : l
```

Examples – Imitating Some GNU Commands

- `cat.hs` – print file contents

```haskell
import System.Environment (getArgs)
main = do
  [file] <- getArgs      -- assume there is exactly one file
  s <- readFile file
  putStr s
```

- `wc.hs` – count number of lines/words/characters in input

```haskell
count s = nl ++ "  " ++ nw ++ "  " ++ nc ++ "\n"
  where nl = show $ length $ lines s
        nw = show $ length $ words s
        nc = show $ length s
main = interact count
```

- `sort.hs` – sort input lines

```haskell
import Data.List (sort)
main = interact (unlines . sort . lines)
```

Laziness and I/O Actions

- consider a simple copying program

```
main = do                    -- imports omitted
  [src, dest] <- getArgs
  s <- readFile src
  writeFile dest s
```

  - `readFile` and `writeFile` are lazy, e.g., `readFile` only reads characters on demand
  - positive effect: large files can be copied without fully loading them into memory
- laziness might lead to problems

```
main = do                    -- imports omitted
  [file] <- getArgs
  s <- readFile file
  writeFile file (map toUpper s)
```

  - since `readFile` is lazy, when executing `s <- readFile file` nothing is read immediately
  - but then the same file should be opened for writing; conflict, which will result in error
  - solution: more fine-grained control via file-handles which explicitly open and close files, see lecture Operating Systems

Higher-Order on I/O Actions

- ```
  foreach :: [a] -> (a -> IO b) -> IO ()
  foreach []     io = return ()
  foreach (a:as) io = do { io a; foreach as io }
  ```
- better `cat.hs`

  ```
  main = do
    files <- getArgs
    if null files then interact id else do
      foreach files readAndPrint
      where readAndPrint file = do
                s <- readFile file
                putStr s
  ```
  ```

Example Application: Connect Four

Connect Four

- aim: implement Connect Four, MB Spiele

- with textual user interface

```
0123456

.......
.XO.X..
.XOOOXO
XOXOXOX
OXXOXOO
XXOXOOX

Player X to go
Choose one of [0,1,2,3,4,5,6]
```

Connect Four: Implementation

- clear separation between
  - user interface (I/O)
    - ask for a move
    - print the current state
    - ...
  - game logic (purely functional code)
    - type to represent a state (board + next player)
    - perform a move
    - check for a winner
    - display a state as string
    - ...
- each part is written as a separate module
  - `Logic` contains the game logic
  - `Main` contains the user interface and the `main` function

Game Logic: Interface

- types: `State`, `Move` and `Player`
- constant `initState :: State`
- function `showPlayer :: Player -> String`
- function `showState :: State -> String`
- function `winningPlayer :: State -> Maybe Player`
- function `validMoves :: State -> [Move]`
- function `dropTile :: Move -> State -> State`
- in total

```
module Logic(State, Move, Player,
  initState, showPlayer, showState,
  winningPlayer, validMoves, dropTile) where
  ... -- details, which the user interface doesn't have to know
```

The `Read`-Class

- class `Read` provides methods to convert `String`s into other types
  - `read :: Read a => String -> a`
  - `readMaybe :: Read a => String -> Maybe a`
    import of module `Text.Read` required
  - when using `read`, often the type `a` has to be chosen explicitly
  - examples
    - `(read "(41, True)" :: (Integer,Bool)) = (41, True)`
    - `(read "(41, True)" :: (Integer,Integer)) = error ...`
    - `(readMaybe "1" :: Maybe Integer) = Just 1`
    - `(readMaybe "one" :: Maybe Integer) = Nothing`
- for the `Logic` module, we assume that the type `Move` is an instance of `Show` and `Read`

User Interface

```haskell
module Main(main) where    -- module name must be "Main" for compilation
import Logic
main = do
  putStrLn "Welcome to Connect Four"
  game initState
game state = do
  putStrLn $ showState state
  case winningPlayer state of
    Just player -> putStrLn $ showPlayer player ++ " wins!"
    Nothing -> let moves = validMoves state in
      if null moves then putStrLn "Game ends in draw."
      else do
        putStr $ "Choose one of " ++ show moves ++ ": "
        hFlush stdout          -- flush print buffer
        moveStr <- getLine
        let move = (read moveStr :: Move)
        game (dropTile move state)
```

Game Logic: Encoding a State and Initial State

```
type Tile   = Int   -- 0, 1, or 2
type Player = Int   -- 1 and 2
type Move   = Int   -- column number
data State = State Player [[Tile]]  -- list of rows

empty :: Tile
empty = 0

numRows, numCols :: Int
numRows = 6
numCols = 7

startPlayer :: Player
startPlayer = 1

initState :: State
initState = State startPlayer
  (replicate numRows (replicate numCols empty))
```

Game Logic: Valid Moves and Displaying a State

```
validMoves :: State -> [Move]
validMoves (State _ rows) =
  map fst . filter ((== empty) . snd) . zip [0 .. numCols - 1] $ head rows

showPlayer :: Player -> String
showPlayer 1 = "X"
showPlayer 2 = "O"

showTile :: Tile -> Char
showTile t = if t == empty then '.' else head $ showPlayer t

showState :: State -> String
showState (State player rows) = unlines $
    map (head . show) [0 .. numCols - 1] :
    map (map showTile) rows
     ++ ["\nPlayer " ++ showPlayer player ++ " to go"]
```

Game Logic: Making a Move

```haskell
otherPlayer :: Player -> Player
otherPlayer = (3 -)

dropTile :: Move -> State -> State
dropTile col (State player rows) = State
  (otherPlayer player)
  (reverse $ dropAux $ reverse rows)
    where
      dropAux (row : rows) =
        case splitAt col row of
         (first, t : last) ->
           if t == empty
             then (first ++ player : last) : rows
             else row : dropAux rows
```

Game Logic: Winning Player

```
winningRow :: Player -> [Tile] -> Bool
winningRow player [] = False
winningRow player row = take 4 row == replicate 4 player
  || winningRow player (tail row)

transpose ([] : _) = []
transpose xs = map head xs : transpose (map tail xs)

winningPlayer :: State -> Maybe Player
winningPlayer (State player rows) =
  let prevPlayer = otherPlayer player
      longRows = rows ++ transpose rows          -- ++ diags rows
   in if any (winningRow prevPlayer) longRows
      then Just prevPlayer
      else Nothing
```

Connect Four: Final Remarks

- implementation is quite basic
  - diagonal winning-condition missing
  - crashes when invalid moves are entered
  - no iterated matches
- exercise: improve implementation

Summary

Summary

- in Haskell I/O is possible, `IO a` is type of I/O-actions with result of type `a`
- clear separation between purely functional and I/O-code
- multiple actions can be connected via `(>>=)` or `do`-blocks
- several predefined functions to access I/O
- more information on I/O in Haskell:
  `http://book.realworldhaskell.org/read/io.html`
- `Read` class provides method `read :: String -> a`, opposite to `Show`
- connect four: separate implementation of game logic (pure) and user interface (I/O)