Programming Paradigms
Unit 13 — Input/Output and Error Handling

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Outline

1. Input/Output

2. Handling Errors
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1 Input/Output

2 Handling Errors
Input/Output

- Remember that Haskell is pure (referential transparency), that is:
  - Functions take inputs and compute outputs (and for the same input always the same output); nothing else happens in-between
  - In particular, they have no side-effects/external effects
    - do not modify global variables or depend on it
    - may not print anything on the screen
    - may not read from the keyboard, or filesystem, or network

- Adding IO to a purely functional language is a challenge, since IO operations are not functions
  - Input does not need an input parameter, and may return different values
  - Output does not return a value, but clearly has side effects: it changes the state of the output device

- If IO operations were functions, this would create problems, e.g.,
  - two calls of an input function getchar, getchar would be executed only once as the result is reused, which makes no sense for IO;
  - a fake parameter could be introduced, e.g., getchar 1, getchar 1, etc., to ensure that each call is actually executed

- As we will see, it is possible to do IO in Haskell, but it looks very different than in most other languages
The solution to I/O in Haskell is a special type, called **IO**.

Values of type `IO a` are called **IO actions** and are “descriptions of effectful computations”.

If executed, an IO action `IO a`:
- performs some effectful I/O operations (side-effect, impure), and
- produces a return value of type `a` (pure).

The description itself is safe as it has no effects: IO is just a description on how to produce `a`.

Compare it to a cake vs. a recipe on how to make a cake:
- `c :: Cake`
- `r :: Recipe Cake`

Hence, IO actions in Haskell separate the functional ("pure") parts of a program from the non-functional ("impure") parts.
Haskell has `getLine` to read a string and `putStrLn` to print a string.

Let's have a look at the types of `getLine` and `putStrLn`?

```haskell
> :t getLine
getLine :: IO String
```

- `getLine` has no input parameter and returns an IO action.
- The IO action does some "dirty" stuff in IO, but the result is a "clean" data type, namely a string.

```haskell
> :t putStrLn
putStrLn :: String -> IO ()
```

- `putStrLn` gets a string as input parameter and returns an IO action.
- The IO action does some "dirty" stuff and returns `()`.

The type `()` is called `unit` and has one value, namely `()` (similar to `void`).
Recall that the value of an IO action is just a recipe, which **does not do anything**

But how can we actually execute IO actions?

For an **executable Haskell program**, there is only one way to execute an IO action: **assign it to `main`, which will run it for you**

```haskell
module Main where
main = putStrLn "Hello World!"
```

The use of the name `main` is important: `main` is defined to be the entry point of a Haskell program (similar to the main function in C)

- Some versions might also support different names from “main”

Actually, `main` forwards the execution of IO actions to the Haskell runtime system

You can put the above in a file `helloworld.hs` and run it through `ghc` to get an executable program
Running a single IO action would not lead to very exciting programs

Haskell allows you to “glue” together IO actions using the do notation

```haskell
main = do
    putStrLn "Hi there, what’s your name?"
    name <- getLine
    putStrLn ("Hello " ++ name ++ "!")
```

The lines in a do-block work similar to an imperative execution

- Allows to execute a sequence of IO actions, one after the other

<- extracts the “pure” part (the string) from `getLine`’s return value, which has type IO String

- Can only be used in a do-block

Notice that `name = getLine` and `putStrLn ("Hello " ++ getLine )` would not work
The IO action carries along the “baggage of the impure” context
- So you don’t have to worry about it

If you want to do a “pure” assignment in the context of IO, you have to use let

module Main where
import Data.Char

main = do
    putStrLn "What’s your name?"
    name <- getLine
    let bigName = map toUpper name
    putStrLn ("Hi " ++ bigName ++ "!")

The let statement in a do-block allows you to create a new variable bound to a “pure” value
In summary, a do-block
- introduces a sequence of statements
- and executes these statements in order

A statement can be one of the following:
- an IO action
- a <-, binding the (“pure”) result of an action
- a let, expressing “pure” definitions
An IO action can also be executed directly in the interactive Haskell shell, like any other function

> putStrLn "Hello World!"
Hello World!

We can also use IO functions in the body of other functions

> let hw = putStrLn "Hello World!"
> hw
Hello World!

So, there's no need to go via main in the shell
That means, in the shell we are in an IO environment
Consequently, we had to use let to do "pure" stuff
File IO – Reading

- Lets look at file IO, using an example that counts the number of lines of a file.

```haskell
module Main where
import System.IO
main = do
  theInput <- readFile "countlines.hs"
  putStrLn (countLines theInput)

countLines :: String -> String
countLines str = show (length (lines str))
```

- `import System.IO` is a so-called language pragma, which imports features that are not part of the standardized Haskell language.
- The `readFile` function reads a file and returns the contents of the file as a string; the file is read lazily, on demand.
- The function `lines :: String -> [String]` breaks a string on newline and returns an array of strings.
- The function `length :: [a] -> Int` returns the length of a finite list.
File IO – Writing

- Writing to a file is simple

```haskell
module Main where
import System.IO
main = do
  putStrLn "Writing to a file ..."
  putStrLn "What do you want to write?"
  what <- getLine
  putStrLn "To which file?"
  file <- getLine
  writeFile file what
```

- `writeFile` will overwrite an existing file
- Use `appendFile` if you’d like to append instead
Monads

- The principle used for IO actions can be generalized and not only applied to IO.
- Haskell uses the concept of a monad to handle “impurity.”
  - For example, for IO, non-determinism, and exceptions.
- We are going to introduce the general principle a bit later.
- First, we are going to look at another example where Haskell meets the messy “real world.”
Outline

1. Input/Output

2. Handling Errors
Handling Errors

- Sometimes things go wrong, i.e., a function is not able to return a value.
- For example, if we call `head` on an empty list, we get an error.
- We don’t necessarily want the program to just stop working and output an error in a case like that.
- However, a function always has to return a value.
- So we have to be able to handle the concept of failure (which is “impure” in Haskell’s eyes).
Errors and the Maybe Type

- Haskell offers the type constructor `Maybe` that has a type parameter `a`:
  
  ```haskell
data Maybe a = Nothing | Just a
```

- `Maybe a` is a normal data type, but it "lifts" a data type `a` into a new context.

- A value of type `Maybe a` represents a value of type `a` with the context of a possible failure attached to it.
  - A value of `Just 1` means that the number 1 is there.
  - The extra value `Nothing` represents the lack of value of type `a` or a computation failure or...

- The type system then requires that you check for that extra value, which prevents a remarkable number of bugs.

- Many other languages handle this sort of "no-value" value with NULL.
Handling Errors with the `Maybe` Type/1

Now we can “wrap” the result of a function call inside of a `Maybe`:
- if the function call was successful, we hand it to the value constructor `Just`
- otherwise, it becomes `Nothing`

Let's write an alternative version of `head` that can cope with empty lists

```haskell
safeHead :: [a] -> Maybe a
safeHead [] = Nothing
safeHead (x:xs) = Just x

> safeHead [1,2,3]
Just 1

> safeHead []
Nothing
```
However, this comes at a price: we've introduced “impurity” into our function.

For example, the following expression will raise an error:

```haskell
doubleMe (safeHead [1,2,3])
```

The result of `safeHead` is `Just 1` (of type `Maybe`), but `doubleMe` expects a pure integer.

So, how can we use the “impure” result of `safeHead` in other pure functions?

Hint: `Maybe` is an instance of the type class `Functor`.

- Quick reminder: a functor can be seen as content “wrapped” in a box.
- So, Haskell does not allow the concept of failure to escape its impure box.
- So we have to get inside of the box.
Handling Errors with the `Maybe` Type/3

- The typeclass `Functor` provides the function `fmap` to get inside the “box”
- `fmap` gets us on the inside of `Maybe`
  ```
  > fmap doubleMe (safeHead [1,2,3])
  Just 2
  ```
- `safeHead [1,2,3]` returns `Just 1`
- `fmap` pushes the execution of `doubleMe` inside the “Just box”
  ```
  > fmap doubleMe (safeHead [])
  Nothing
  ```
- If there is `Nothing` inside, `fmap` will not even apply the function, but return `Nothing`
How to Extract a Pure Value from `Maybe`?

- The easiest way is to use function `fromMaybe` from `Data.Maybe`.
- You have to supply a default value that will be used in case the value is `Nothing`.

```haskell
> import Data.Maybe
Just 2

Data.Maybe> fromMaybe 0 (Just 42)
42

Data.Maybe> fromMaybe 0 Nothing
0
```