Functional Programming? Haskell?

Functional Programming

Utrecht University

```haskell
import Data.Char(toUpper)

mkWelcome                  :: (String -> String) -> Int -> Int -> String
mkWelcome stylize year n = concat [ stylize "Welcome"
                                  , " to INFOFP in " ++ show year ++ "!\n\n"
                                  , "We have " ++ show n ++ " students.\n\n"
                                  , "So we will have to grade " ++
                                    show (numExams n) ++ " exams...."
                                  ]
  where numExams m = 2 * m

capitalize s = map toUpper s

welcomeMsg = mkWelcome capitalize 2023 317
```

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                                  ]
  where numExams m = 2 * m

capitalize s = map toUpper s

welcomeMsg = mkWelcome capitalize 2023 317

main = putStrLn welcomeMsg
```

WELCOME to INFOFP in 2023!

We have 317 students.

So we will have to grade 634 exams....

What is Functional Programming?

What is Functional Programming?

- A way of thinking about problems:

Define what something *is* rather than *how* to compute it.

Imperative (C#) vs. Functional (Haskell)

```csharp
int sumUpTo(int n) {
  int total = 0;
  for (int i = n; n > 0; i--)
    total += i;
  return total;
}
```

```haskell
sumUpTo 0 = 0
sumUpTo n = n + sumUpTo (n-1)
```

Our aim is to

Teach you *functional programming* techniques

- Using functions as first-class values
- Separating pure and impure computations
- Reasoning about your programs
- Use strong types
- ...

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- Use strong types
- ...

You can write “functional code” in almost any language!

Why Functional Programming?

To create better software

1. Short term: fewer bugs
    - *Purity* means fewer surprises when programming
        - A function can no longer mutate a global state
    - *Purity* makes it easier to *reason* about programs
        - Reasoning about OO $\implies$ master/PhD course
        - Reasoning about FP $\implies$ this course
    - Higher-order functions *remove* lots of *boilerplate*
        - Also, less code to test and fewer edge cases
    - *Types* prevent the “stupid” sort
        - What does `True + "1"` mean?

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2. Long term: more maintainable
    - Types are *always updated* documentation
    - Types help a lot in *refactoring*
        - Change a definition, fix everywhere the compiler tells you there is a problem

How?

How

Lectures:

- Tuesday, 11.00 to 12.45
- Thursday, 15.15 to 17.00

Instructions !!!!!: Once a week

- Thursday, 13.15 to 15.00

Practicals

- Tuesday, 09.00 to 10.45

Who?

Matthijs Vakar and Frank Staals (me) in the lectures

- Contact us through email
- We both speak Dutch

10 teaching assistants in the labs

- Most of them are Dutch speakers

Guest lecture at the end of the course

Resources

1. **Slides** contain most of the content
    - In some cases, supplemented by additional material
2. Pen-and-paper **exercises**
    - There's more than programming in this course
    - Ask questions during instruction sessions
    - Remember: there is *no compiler* at the exam
3. Book: *Programming in Haskell* (2nd edition) by Graham Hutton
    - The course follows it, except for chapters 13 and 17
    - More resources can be found in the website

Midterm & Final Exam

- ‘Pen-and-Paper’ style exam questions
  - Closed book
  - No compiler
- Remindo-based

Practical assignments

1. The first one helps you getting started
2. Three small ones with DOMJudge, one per week
3. One bigger project at the end

DOMJudge assignments

- Submissions are **individual**
  - Do not plagiarize!
- Graded automatically : Pass vs Fail
  - correct = Pass, not fully correct = Fail
- You need to pass at least 2 out of 3 DOMJudge Assignments

Style

- Hints in DOMJudge for good style
- Ask TAs for advice during practicals
- Important part of the final project grade

Final project

Develop your own **game** in Haskell

- Work in **pairs** is allowed and recommended
- Submission in two parts
  1. Preliminary design document
  2. Code of the project

Optional bonus assignment

Learn and explain a Haskell library or language feature

- Up to additional 0.5 points for the final grade
- Work in groups of at most three

Grading

Linear combination of three grades

- *Theory* T = 0.3 × midterm + 0.7 × final
- *Practical* = Final project
- *Optional* assignment O

Final grade F = 0.5 × T + 0.5 × P + 0.05 × O

To pass the course, you essentially need

- F >= 5.5, T >= 5, P >= 5
- Pass at least two DOMJudge assignments

See website for details.

If you did the course last year

- **Resubmit** your DOMJudge assignments
- Redo the **final project**
  - Using the same code as last year is *not* allowed
- Redo **all** the **exams**

Communication channels

- E-mail
  - Check your UU-mail regularly
- Teams
  - For questions about any of the material.
- Blackboard
  - As a means to access your grades.

Course Website

`http://www.cs.uu.nl/docs/vakken/fp`

- All important information is found there
- Schedule, slides, assignments, exercises

Getting Started:

Functional Programming ***Features***?

Some distinguishing **features** of FP:

1. Recursion instead of iteration
2. Pattern matching on values
3. Expressions instead of statements
4. Functions as first-class citizens

Try it!

1. Go to `https://play.haskell.org`
2. Write your definitions on the left pane

   ```
   sumUpTo 0 = 0
   sumUpTo n = n + sumUpTo (n-1)

   main = print (sumUpTo 3)
   ```

3. Click *Run*
4. The right pane should now show:

   ```
   6
   ```

Alternatively, use the interpreter ‘ghci’

1. Write your definitions in a file ‘main.hs’:

   ```
   sumUpTo 0 = 0
   sumUpTo n = n + sumUpTo (n-1)
   ```

2. Load your your code with “ghci main.hs”
3. Execute your functions:

   ```
   > sumUpTo 3
   6
   ```

Small exercise

Update the example to compute $n! = n * (n-1) * (n-2) * .. * 1$ instead.

Recursion instead of iteration

Iteration = repeating a process a number of times

```
int sumUpTo(int n) {
  int total = 0;
  for (int i = n; n > 0; i--)
    total += i;
  return total;
}
```

Recursion = defining something in terms of itself

```
sumUpTo 0 = 0
sumUpTo n = n + sumUpTo (n-1)
```

Pattern matching on values

A function is defined by a series of **equations**

- The value is compared with each left side until one "fits"
- In `sumUpTo`, if the value is zero we return zero, otherwise we fall to the second one

```
sumUpTo 0 = 0
sumUpTo n = n + sumUpTo (n-1)
```

Expressions instead of statements

What code does versus what code is

- Statements manipulate the **state** of the program
- Statements have an inherent **order**
- *Variables* name and store pieces of state

```
int sumUpTo(int n) {
  int total = 0;
  for (int i = n; n > 0; i--)
    total += i;
  return total;
}
```

Expressions instead of statements

What code does versus what code is

- Value of a *whole expr.* depends only on its *subexpr.*
- Easier to compose and **reason** about
    - We will learn how to reason about programs

```
sumUpTo 3  -->  3 + sumUpTo 2
           -->  3 + 2 + sumUpTo 1
           -->  ...
```

The factorial example:

Update the example to compute $n! = n * (n-1) * (n-2) * .. * 1$ instead.

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```
fac   :: Int -> Int
fac 0 = 1
fac n = n * fac (n-1)
```

The factorial example:

Update the example to compute $n! = n * (n-1) * (n-2) * .. * 1$ instead.

```
fac   :: Int -> Int
fac 0 = 1
fac n = n * fac (n-1)
```

- Each equation goes into its own line
- Equations are checked in order
  - If n is `0`, then the function equals 1
  - If n is different from `0`, then it goes to the second
- *Good style*: always write the type of your functions

Question

What happens if we write?

```
fac :: Int -> Int
fac n = n * fac (n-1)
fac 0 = 1
```

Functions as first-class citizens

Function = mapping of arguments to a result

```
greet name = "Hello, " ++ name ++ "!"
```

- Functions can be parameters of another function
- Functions can be returned from functions

```
> map greet ["Mary", "Joe"]
["Hello, Mary!", "Hello, Joe!"]
```

`map` applies the function `greet` to each element of the list

Try it yourself!

Build `greet` with two arguments

```
> greet "morning" "Paul"
"Good morning, Paul!"
```

```
-- Here is the version with one argument
greet name = "Hello, " ++ name ++ "!"
```

Why Haskell?

Haskell can be defined with four adjectives

- Functional
- Statically typed
- Pure
- Lazy

Haskell is statically typed

- Every expression and function has a *type*
- The compiler *prevents* wrong combinations

```
> :t greet  -- Give me the type of greet
greet :: [Char] -> [Char]
> greet "Joe"
"Hello, Joe!"
> greet True
Couldn't match expected type ‘[Char]’
            with actual type ‘Bool’
```

Inference = if no type is given for an expression, the compiler *guesses* one

Haskell is pure

- You **cannot** use statement-based programming
  - Variables do not change, only give names
  - Program is easy to compose, understand and paralellize
- Functions which interact with the “outer world” are marked in their type with `IO`
  - This prevents unintended side-effects

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

Haskell is lazy

We shall get to this one...

Why Haskell?

From a pedagogical standpoint

- Haskell *forces* a functional style
  - In contrast with imperative and OO languages
  - We can do *equational reasoning*
- Haskell teaches the value of static types
  - Compiler finds bugs long before run time
  - We can express really detailed invariants

How do I “run” Haskell?

GHC

- We are going to use GHC in this course
  - The (Glorious) **G**lasgow **H**askell **C**ompiler
  - State-of-the-art and open source
- Installing
  - Go to `https://www.haskell.org/ghcup`
  - Follow the installation instructions for installing ‘ghcup’ and ‘ghc’ on your OS.

Compiler versus interpreter

- Compiler (ghc)
  - Takes one or more files as an input
  - Generates a library or complete executable
  - There is **no interaction**
  - How you do things in *Imperatief/Mobiel/Gameprogrammeren*
- Interpreter (`ghci`)
  - **Interactive**, expressions are evaluated on-the-go
  - Useful for **testing** and **exploration**
  - You can also *load* a file
    - Almost as if you have typed in the entire file

GHC interpreter, `ghci`

1. Open a command line, terminal or console
2. Write `ghci` and press ⏎

```
GHCi, version 8.10.2: http://www.haskell.org/ghc/  :? for help
Prelude>
```

3. Type an expression and press ⏎ to evaluate

```
Prelude> 2 + 3
5
Prelude>
```

4. Ctrl + D (⌘ + D in Mac) or `:q` ⏎ to quit

```
Prelude> :q
Leaving GHCi.
```

First examples

```
> length [1, 2, 3]
3
> sum [1 .. 10]
55
> reverse [1 .. 10]
[10,9,8,7,6,5,4,3,2,1]
> replicate 10 3
[3,3,3,3,3,3,3,3,3,3]
> sum (replicate 10 3)
30
```

- Integer numbers appear as themselves
- `[1 .. 10]` creates a list from 1 to 10
- Functions are called (applied) **without** parentheses
  - In contrast to `replicate(10, 3)` in other languages

More about parentheses

- Parentheses delimit subexpressions
  - `sum (replicate 10 3)`: sum takes 1 parameter
  - `sum replicate 10 3`: sum takes 3 parameters

```
> sum replicate 10 3
<interactive>: error:
    • Couldn't match type ‘[t0]’ with ‘t1 -> t’
      Expected type: Int -> t0 -> t1 -> t
        Actual type: Int -> t0 -> [t0]
```

```
> sum (replicate 10 3)
30
```

First examples of types

```
> :t reverse
reverse :: [a] -> [a]
> :t replicate
replicate :: Int -> a -> [a]
```

- `->` separates each argument and the result
- `Int` is the type of (machine) integers
- `[Something]` declares a list of `Somethings`
    - For example, `[Int]` is a list of integers
- `[a]` means list of *anything*
    - Note that a starts with a lowercase letter
    - a is called a *type variable*

Operators

```
> [1, 2] ++ [3, 4]
[1, 2, 3, 4]
> (++) [1, 2] [3, 4]
> :t (++)
(++) :: [a] -> [a] -> [a]
```

- Some names are completely made out of symbols
  - Think of +, *, &&, ||, ...
  - They are called **operators**
- Operators are used *between* the arguments
  - Anywhere else, you use parentheses

Question

What happens if we do?

```
> [1, 2] ++ [True, False]
```

Question

What happens if we do?

```
> [1, 2] ++ [True, False]
```

Type error!

Define a function in the interpreter

```
> let average ns = sum ns `div` length ns
> average [1,2,3]
2
> :t average
average :: Foldable t => t Int -> Int
```

- Functions are defined by one or more **equations**
- You turn a function into an operator with backticks
- Naming requirements
  - Function names must start with a lowercase
  - Arguments names too
- GHC has *inferred* a type for your function

Define a function in a file

You can write this definition in a file

```haskell
average :: [Int] -> Int
average ns = sum ns `div` length ns
```

and then load it in the interpreter

```
> :load average.hs
[1 of 1] Compiling Main ( average.hs, interpreted )
> average [1,2,3]
2
```

or even work on it an then reload

```
> :r
[1 of 1] Compiling Main ( average.hs, interpreted )
```

More basic types

- `Bool`: `True` or `False` (note the uppercase!)
  - Usual operations like && (and), || (or) and `not`
  - Result of comparisons with ==, /=, <, …
  - **Warning!** = defines, == compares

```
> 1 == 2 || 3 == 4
False
> 1 < 2 && 3 < 4
True
> nand x y = not (x && y)
> nand True False
True
```

More basic types

- `Char`: one single symbol
  - Written in *single* quotes: `'a'`, `'b'`, …
- `String`: a sequence of characters
  - Written in *double* quotes: `"hello"`
  - They are simply `[Char]`
    - All list functions work for `String`

```
> ['a', 'b', 'c'] ++ ['d', 'e', 'f']
"abcdef"
> replicate 5 'a'
"aaaaa"
```

First example of higher-order function

```
> map fac [1 .. 5]
[1,2,6,24,120]
> map not [True, False, False]
[False,True,True]

> :t map
map :: (a -> b) -> [a] -> [b]
```

- `map` takes *two* arguments
  - The first argument is a function `a -> b`
  - The second argument is a list `[a]`
- `map` works for every pair of types `a` and `b` you choose
  - We say that `map` is *polymorphic*

Homework

1. Install GHC in your machine
2. Try out the examples
3. Define some simple functions
   - Sum from `m` to n
   - Build `greeter` with two arguments

     ```
     > greeter "morning" ["P", "Z"]
     ["Good morning, P!", "Good morning, Z!"]
     ```
4. Think about the types of those functions
5. Do Practical Assignment 0.

Three pieces of advice

1. **Get yourself a good editor**
    - At the very least, with syntax highlighting
    - Visual Studio Code and Atom are quite nice
        - Available at `code.visualstudio.com` and `atom.io`
        - Install Haskell syntax highlighting afterwards
    - vi or Emacs for the adventurous
2. **Get comfortable with the command line**
    - `https://tutorial.djangogirls.org/en/intro_to_command_line/`

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3. **Go to the Instruction sessions !!!**

   - And do the pen-and-paper exercises !!!