



# Functional Programming? Haskell?

Functional Programming

---

```

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 2022 312

```

```

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mkWelcome :: (String -> String)
          -> Int -> Int -> String
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    show (numExams n) ++ " exams...."
  ]
  where numExams m = 2 * m

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welcomeMsg = mkWelcome capitalize 2022 312

```

WELCOME to INFOFP in 2022!

We have 312 students.

So we will have to grade 624 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)

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

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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Teach you *functional programming* techniques

- Using functions as first-class values
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- Reasoning about your programs
- 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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- *Types* prevent the “stupid” sort
  - What does `True + "1"` mean?

## 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?**

---

*Lectures:*

- Tuesday, 9.00 to 10.45
- Thursday, 13.15 to 15.00

*Instructions !!!!!: Once a week*

- Tuesday, 11.00 to 12.45

*Practicals*

- Thursday, 17.15 to 19.00

# 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



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

- 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

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

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
- More details after mid-term exam

Linear combination of three grades

- *Theory*  $T = 0.3 \times \text{midterm} + 0.7 \times \text{final}$
- *Practical* = Final project
- *Optional* assignment  $O$

**Final grade  $F = 0.5 \times T + 0.5 \times P + 0.05 \times O$**

To pass the course, you essentially need

- $F \geq 5.5, T \geq 5, P \geq 5$
- 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**

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

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

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

## Getting Started:

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## 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 <http://repl.it/languages/haskell>

2. Write your definitions on the left pane

```
sumUpTo 0 = 0
```

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

3. Click *Run*

4. Load your code with “ghci main.hs”

5. Execute your functions on the right pane

```
> sumUpTo 3
```

```
6
```

6. 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;  
}
```

## 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:

6. 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:

6. 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

-- In the left pane

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

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

-- In the right pane

```
> 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 parallelize
- Functions which interact with the “outer world” are marked in their type with IO
  - This prevents unintended side-effects

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

We shall get to this one...

## 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?

---

- 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
  - `repl.it` is web-based ghci




## GHC interpreter, ghci

1. Open a command line, terminal or console

- Right now, just `repl.it`

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.  +  ( +  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

```
> 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

```
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 and 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/](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 !!!