Utrecht University

Introduction

Advanced functional programming

Wouter Swierstra

Welcome to the Utrecht AFP Summer School

This morning

- Introduce myself and the other lecturers
- Overview of the course
- Basic Haskell review
- Answer any questions regarding organizational issues

UU Lecturers

- Wouter Swierstra
- Gabriele Keller
- Ivo Gabe de Wolff
- Marco Vassena
- Guest lecturer: Jesper Cockx (TU Delft)

Lectures

- Lectures held in room BBG - but different rooms throughout the week.
- 2×45 minute slots with a 15 minute break

Short breaks between lectures; longer break for lunch.

Coffee & drinks will be provided after the morning/afternoon lecture.

Lab organization

Labs will be held in the same room as the lectures.

We have lab machines for you to use – but you may prefer to use your own computer.

We have a series of exercises for you to work on, grouped thematically.

Our PhD candidates are around to ask questions!

Lab exercises

1. Tools and laziness
2. Monads, monad transformers and applicative functors
3. Fancy types - GADTs, type families, nested types
4. A simple database - parsing, monads, I/O
5. Lambda calculus

Choose the exercises that fit your interests best.

Homepage

Course homepage:

`https://www.afp.school`

We will update the homepage regularly with slides and further information.

Topics

- Haskell refresher & programming style
- Monads & I/O
- Lambda calculus
- Applicative, foldable & traversable
- Generalized Algebraic Data Types
- Type families
- ...

Lunch and dinner

- Catered lunches will be provided in the canteen of the Minnaert building.
- Dinner each night will be at different restaurant across Utrecht.

Both lunches and dinners are included in your registration fee.

Two drinks are included with dinner – feel free to order more drinks at your own expense.

Software installation

What do you need during the labs?

- A recent version of GHC, such as the one shipped with the Haskell Platform.
- We recommend using the Haskell Platform (libraries, Cabal, Haddock, Alex, Happy).

Some suggested further reading

- *Parallel and concurrent programming in Haskell* by Simon Marlow
- *Fun of Programming* edited by Jeremy Gibbons and Oege de Moor
- *Purely Functional Data Structures* by Chris Okasaki
- *Types and Programming Languages* by Benjamin Pierce
- *AFP summer school* series of lecture notes on various topics

All the slides will be put online after each lecture – feel free to revisit them later.

Questions?

Haskell review

- A pure functional language
- Data types and pattern matching
- Higher order functions
- Polymorphism
- Type classes

Function definitions

Functions are typically defined by pattern matching:

```haskell
map :: (a -> b) -> [a] -> [b]
map f []     = []
map f (x:xs) = f x : map f xs
```

Here the map function takes a function and input list as argument;

It produces a new list, where the function has been applied to every element of the input list.

Data types and pattern matching

Besides defining functions on *lists* we can declare our own data types:

```
data Tree a = Leaf a | Node (Tree a) (Tree a)
```

```
mapTree :: (a -> b) -> Tree a -> Tree b
mapTree f (Leaf x)   = Leaf (f x)
mapTree f (Node l r) = Node (mapTree f l)
                            (mapTree f r)
```

We can define functions on trees by *pattern matching*.

Higher-order functions

Functions such as `map` and `mapTree` are *higher-order functions* – functions that take functions as arguments.

In Haskell, functions are *first class citizens* – they can be bound to variables or passed to other functions.

This pattern pops up again and again; we'll see lots of higher-order functions in the lectures on monads, testing and elsewhere.

Polymorphism

Functions such as `map` and `mapTree` are *polymorphic*:

```
incrementList = map (\x -> x + 1)
checkList = map (\x -> x > 3)
```

The two calls to `map` pass functions of different **types** as arguments.

Question: What are the types of these two functions?

Classes

Polymorphic functions are *oblivious* to the values on which they operate.

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

The first argument could be *any* function!

Classes

Polymorphic functions are *oblivious* to the values on which they operate.

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

The first argument could be *any* function!

Oftentimes, we want know something about the data which we manipulate.

```
sort :: [a] -> [a]
```

To define a sorting function, we need to compare the elements of type `a`.

Haskell classes

Haskell classes define an *interface*:

```
class Eq a where
  (==) :: a -> a -> Bool
```

We can define *instances* by providing operations on a specific type:

```
instance Eq Bool where
  True == True   = True
  False == False = True
  _ == _         = False
```

Haskell classes

We can define more complicated instances, such as the `Eq` instance for lists, assuming that we have already defined an `Eq` instance for its elements:

```
instance Eq a => Eq [a] where
  [] == []          = True
  (x:xs) == (y:ys) = x == y && xs == ys
  _ == _            = False
```

We can now compare lists of booleans, lists of lists of booleans, etc.

Question: What should the `Eq` instance for pairs be?

Using classes

When we declare a type signature using a class constraint such as `Eq a`, we can use the equality function to compare elements of type `a`.

For example, the `elem` function checks if a specific element occurs in a list or not:

```
elem :: Eq a => a -> [a] -> Bool
elem e []     = False
elem e (x:xs) = e == x || elem e xs
```

We can use `elem` on lists of any types, provided there is a corresponding `Eq` instance.

This is sometimes referred to as *ad-hoc polymorphism*.

Packages and modules

Code in the large

Once you start to organize larger units of code, you typically want to split this over several different files.

In Haskell, each file contains a separate *module*.

Let’s start with a quick recap and reviewing the strengths and weaknesses of Haskell’s module system.

Goals of the Haskell module system

- Units of separate compilation (not supported by all compilers).
- Namespace management

There is (or rather was until recently) language concept of interfaces or signatures in Haskell, except for the class system.

Syntax

```
module M(D(),f,g) where
import Data.List(unfoldr)
import qualified Data.Map as M
import Control.Monad hiding (mapM)
```

- Hierarchical modules
- Export list
- Import list, hiding list
- Qualified, unqualified
- Renaming of modules

Module `Main`

- If the module header is omitted, the module is automatically named `Main`.
- Each full Haskell program has to have a module `Main` that defines a function

```
main :: IO()
```

Hierarchical modules

Module names consist of at least one identifier starting with an uppercase letter, where each identifier is separated from the rest by a period.

- This former extension to Haskell 98, has been formalized in an addendum to the Haskell 98 Report and is now widely used.
- Implementations expect a module `X.Y.Z` to be named `X/Y/Z.hs` or `X/Y/Z.lhs`
- There are no relative module names – every module is always referred to by a unique name.

Hierarchical modules

Most of Haskell 98 standard libraries have been extended and placed in the module hierarchy – moving `List` to `Data.List`.

Good practice: Use the hierarchical modules where possible. In most cases, the top-level module should only refer to other modules in other directories.

Importing modules

- The `import` declarations can only appear in the module header, i.e., after the `module` declaration but before any other declarations.
- A module can be imported multiple times in different ways.
- If a module is imported qualified, only the qualified names are brought into scope. Otherwise, the qualified and unqualified names are brought into scope.
- A module can be renamed using `as`. Then, the qualified names that are brought into scope are using the new `modid`.
- Name clashes are reported lazily.

Prelude

- The module `Prelude` is imported implicitly as if

```
import Prelude
```

has been specified.

- An explicit `import` declaration for `Prelude` overrides that behaviour

```
qualified Prelude
```

causes all names from `Prelude` to be available only in their qualified form.

Module dependencies

- Modules are allowed to be mutually recursive.
- This is not supported well by GHC, and therefore somewhat discouraged.

Question: Why might it be difficult?

Best practices

Designing packages

- Use qualified names instead of pre- and suffixes to disambiguate.
- Use renaming of modules to shorten qualified names.
- Avoid `hiding`
- Recall that you can import the same module multiple times.

Haskell package management

- Packages are collections of modules that are distributed together.
- Packages are *not* part of the Haskell standard.
- Packages are versioned and can depend on other packages.
- Packages contain modules. Some of those modules may be hidden.

Never use TABs

- Haskell uses layout to delimit language constructs.
- Haskell interprets TABs to have 8 spaces.
- Editors often display them with a different width.
- TABs lead to layout-related errors that are difficult to debug.
- Even worse: mixing TABs with spaces to indent a line.

Question: What might go wrong?

Never use TABs

- Never use TABs.
- Configure your editor to expand TABs to spaces, and/or highlight TABs in source code.

Alignment

- Use alignment to highlight structure in the code!
- Do not use long lines.
- Do not indent by more than a few spaces.

```
map :: (a -> b) -> [a] -> [b]
map f []        =  []
map f (x : xs)  =  f x : map f xs
```

Identifier names

- Use informative names for functions.
- Use CamelCase for long names.
- Use short names for function arguments.
- Use similar naming schemes for arguments of similar types.

Spaces and parentheses

- Generally use exactly as many parentheses as are needed.
- Use extra parentheses in selected places to highlight grouping, particularly in expressions with many less known infix operators.
- Function application should always be denoted with a space.
- In most cases, infix operators should be surrounded by spaces.

Blank lines

- Use blank lines to separate top-level functions.
- Also use blank lines for long sequences of `let`-bindings or long `do`-blocks, in order to group logical units.

Avoid large functions

- Try to keep individual functions small.
- Introduce many functions for small tasks.
- Avoid local functions if they need not be local.

Question: Why?

Type signatures

- Always give type signatures for top-level functions.
- Give type signatures for more complicated local definitions, too.
- Use type synonyms.

```
checkTime :: Int -> Int -> Int -> Bool
```

Type signatures

- Always give type signatures for top-level functions.
- Give type signatures for more complicated local definitions, too.
- Use type synonyms.

```
checkTime :: Int -> Int -> Int -> Bool

checkTime :: Hours -> Minutes -> Seconds -> Bool


type Hours = Int
type Minutes = Int
type Seconds = Int
```

Type signatures

Or even better, use new types or data types generously:

```
checkTime :: Hours -> Minutes -> Seconds -> Bool
```

```
newtype Hours   = Hours Int
newtype Minutes = Minutes Int
newtype Seconds = SecondsInt
```

Question: what are the relative advantages and disadvantages of newtypes vs type synonyms?

Comments

- Comment top-level functions.
- Also comment tricky code.
- Write useful comments, avoid redundant comments!
- Use Haddock.

Booleans

Keep in mind that Booleans are first-class values.

Negative examples:

```
f x | isSpace x == True = ...
```

```
if x then True else False
```

Use (data)types!

- Whenever possible, define your own datatypes.
- Use `Maybe` or user-defined types to capture failure, rather than `error` or default values.
- Use `Maybe` or user-defined types to capture optional arguments, rather than passing `undefined` or dummy values.
- Don't use integers for enumeration types.
- By using meaningful names for constructors and types, or by defining type synonyms, you can make code more self-documenting.

Use common library functions

- Don't reinvent the wheel. If you can use a `Prelude` function or a function from one of the basic libraries, then do not define it yourself.
- If a function is a simple instance of a higher-order function such as `map` or `foldr`, then use those functions.

Pattern matching

- When defining functions via pattern matching, make sure you cover all cases.
- Try to use simple cases.
- Do not include unnecessary cases.
- Do not include unreachable cases.

Avoid partial functions

- Always try to define functions that are total on their domain, otherwise try to refine the domain type.
- Avoid using functions that are partial.

Negative example

```
if isJust x then 1 + fromJust x else 0
```

Use pattern matching!

Use `let` instead of repeating complicated code

Write

```
let x = foo bar baz in x + x * x
```

rather than

```
foo bar baz + foo bar baz * foo bar baz
```

Questions

- Is there a semantic difference between the two pieces of code?
- Could/should the compiler optimize from the second to the first version internally?

Type-driven development

- Try to make your functions as generic as possible (why?).
- If you have to write a function of type `Foo -> Bar`, consider how you can destruct a `Foo` and how you can construct a `Bar`.
- When you tackle an unknown problem, think about its type first.
- You can insert ‘holes’ into your program to help develop your program piece by piece:

```
myFunction : (Foo -> Foo) -> Bar -> Baz
myFunction f b =
  let i = computeResult f _ in
  i + _
```

This is particularly helpful if you choose your types carefully!

Questions?