

# Advanced Functional Programming

Chalmers & GU  
2013

Patrik Jansson  
(slides by Jansson, Norell & Bernardy)

## Organization

- 2 Lectures per week
  - Except for one or two holes (to be determined)
- 3 Programming Assignments (labs)
  - Done in pairs
- 1 Written Exam

## This Course

- Advanced Programming Language Features
  - Type systems
  - Programming techniques
- In the context of Functional Programming
  - Haskell (and a touch of Agda)
- Applications
  - Signals, graphics, web programming
  - Domain Specific Languages

## Getting Help

- Course Homepage
  - Should have all information
  - Complain if not!
- Discussion Board (afp2013 google groups)
  - Everyone should become a member
  - Discuss general topics
- e-mail teachers (Patrik + Jonas)
  - Organizational help, lectures, etc. (Patrik)
  - Specific help with programming labs (Jonas)
- Office Hours
  - 1-2 times a week, time: Mon. 15-16, (Thu. 13-14)

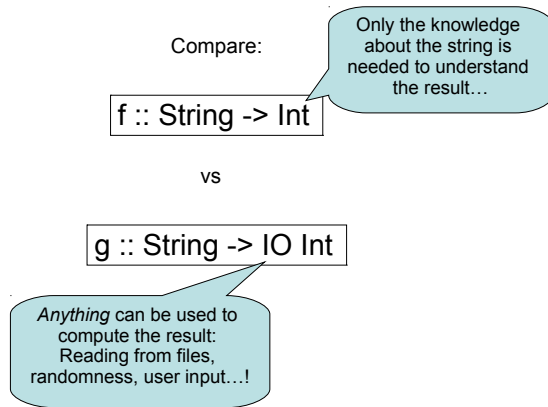
## Self Study

- You need to read yourself
- Find out information yourself
- Solve problems yourself
  
- With a lot of help from us!
  - All information is on the web (soon;-)
  - Discussion board (afp2013 google group)
  - Office hours: Mon. 15-16, (Thu. 13-14)

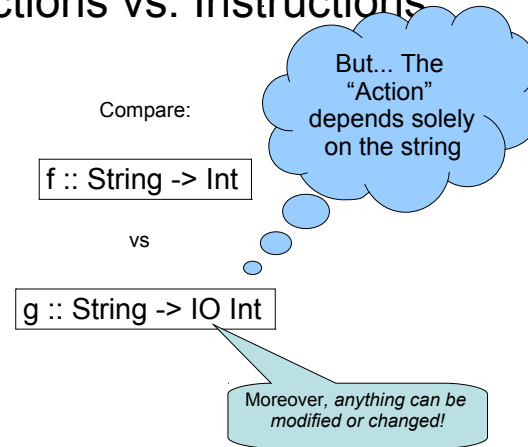
## Recalling Haskell

- Purely Functional Language
  - Referential transparency
- Lazy Programming Language
  - Things are evaluated at most once
- Advanced Type System
  - Polymorphism
  - Type classes
  - ...

## Functions vs. Instructions



## Functions vs. Instructions



## Programming with IO

```
hello :: IO ()
hello =
  do putStrLn "Hello! What is your name?"
     name <- getLine
     putStrLn ("Hi, " ++ name ++ "!")
```

## Programming with IO

```
printTable :: [String] -> IO ()
printTable xs = prnt 1 xs
  where
    prnt i [] = return ()
    prnt i (x:xs) = do putStrLn (show i ++ ":" ++ x)
                     prnt (i+1) xs
```

IO actions are first class.

```
printTable :: [String] -> IO ()
printTable xs =
  sequence_ [ putStrLn (show i ++ ":" ++ x)
            | (x,i) <- xs `zip` [1..length xs]
            ]
```

sequence\_ :: [IO a] -> IO ()

## A Function

```
fun :: Maybe Int -> Int
fun mx | mx == Nothing = 0
       | otherwise     = x + 3
  where
    x = fromJust mx
```

Could fail... What happens?

## Another Function

```
expn :: Integer -> Integer
expn n | n <= 1 = 1
       | otherwise = expn (n-1) + expn (n-2)
```

```
choice :: Bool -> a -> a -> a
choice False f t = f
choice True f t = t
```

```
Main> choice False 17 (expn 99)
17
```

Without delay...

## Laziness

- Haskell is a *lazy* language
  - Things are evaluated *at most once*
  - Things are only evaluated when they are needed
  - Things are never evaluated twice

(We will now explore what this means.)

## Understanding Laziness

- Use **error "message"** or **undefined** to see whether something is evaluated or not
  - choice False 17 undefined
  - head [3,undefined,17]
  - head (3:4:undefined)
  - head [undefined,17,13]
  - head undefined

## Lazy Programming Style

- Separate
  - Where the computation of a value is defined
  - Where the computation of a value happens

Modularity!

## When is a Value "Needed"?

```
strange :: Bool -> Integer
strange False = 17
strange True  = 17
```

```
Main> strange undefined
Program error: undefined
```

An argument is evaluated when a *pattern match* occurs

But also *primitive functions* evaluate their arguments

## At Most Once?

```
foo :: Integer -> Integer
foo x = f x + f x
```

f x is evaluated twice

```
bar :: Integer -> Integer -> Integer
bar x y = f 17 + x + y
```

```
Main> bar 1 2 + bar 3 4
310
```

Quiz: How to avoid recomputation?

f 17 is evaluated twice

## At Most Once!

```
foo :: Integer -> Integer
foo x = fx + fx
where
  fx = f x
```

So... *bindings* are evaluated at most once...

```
bar :: Integer -> Integer -> Integer
bar x y = f17 + x + y
```

```
f17 :: Integer
f17 = f 17
```

... in their scope. So, top level ones are really evaluated at most once!

## Infinite Lists

- Because of laziness, values in Haskell can be *infinite*
- Do not compute them completely!
- Instead, only use parts of them

## Examples

- Uses of infinite lists
  - take n [3..]
  - xs `zip` [1..]

## Example: PrintTable

```
printTable :: [String] -> IO ()
printTable xs =
  sequence_ [ putStrLn (show i ++ ":" ++ x)
            | (x,i) <- xs `zip` [1..]
            ]
```

lengths adapt  
to each other

## Iterate

```
iterate :: (a -> a) -> a -> [a]
iterate f x = x : iterate f (f x)
```

```
Main> iterate (2*) 1
[1,2,4,8,16,32,64,128,256,512,1024,...]
```

## Other Handy Functions

```
repeat :: a -> [a]
repeat x = x : repeat x

cycle :: [a] -> [a]
cycle xs = xs ++ cycle xs
```

Quiz: How to  
define repeat  
with iterate?

## Alternative Definitions

```
repeat :: a -> [a]
repeat x = iterate id x

cycle :: [a] -> [a]
cycle xs = concat (repeat xs)
```

## Problem: Replicate

```
replicate :: Int -> a -> [a]
replicate = ?
```

```
Main> replicate 5 'a'
"aaaaa"
```

## Problem: Replicate

```
replicate :: Int -> a -> [a]
replicate n x = take n (repeat x)
```

## Problem: Grouping List Elements

```
group :: Int -> [a] -> [[a]]
group = ?
```

```
Main> group 3 "apabepacepa!"
["apa", "bep", "ace", "pa!"]
```

## Problem: Grouping List Elements

```
group :: Int -> [a] -> [[a]]
group n = takeWhile (not . null)
        . map (take n)
        . iterate (drop n)
```

. connects  
"stages" --- like  
Unix pipe symbol |

## Problem: Prime Numbers

```
primes :: [Integer]
primes = ?
```

```
Main> take 4 primes
[2,3,5,7]
```

## Problem: Prime Numbers

```
primes :: [Integer]
primes = sieve [2..]
where
  sieve (p:xs) = p : sieve [ y | y <- xs, y `mod` p /= 0 ]
```

Commonly mistaken for  
*Eratosthenes' sieve*<sup>1</sup>

<sup>1</sup> Melissa E. O'Neill, The Genuine Sieve of Eratosthenes. JFP 2008.

## Infinite Datastructures

```
data Labyrinth
  = Crossroad
  { what :: String
  , left :: Labyrinth
  , right :: Labyrinth
  }
```

How to make an interesting labyrinth?

## Infinite Datastructures

```
labyrinth :: Labyrinth
labyrinth = start
  where
    start = Crossroad "start" forest town
    town  = Crossroad "town"  start forest
    forest = Crossroad "forest" town  exit
    exit  = Crossroad "exit"  exit  exit
```

What happens when we print this structure?

## Laziness Conclusion

- Laziness
  - Evaluated at most once
  - Programming style
- Do not have to use it
  - But powerful tool!
- Can make programs more "modular"

## Type Classes

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

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

```
instance Eq Int where ...
instance Eq a => Eq [a] where ...
```

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

## Type Classes

```
class Finite a where
  domain :: [a]
```

What types could be an instance of this class?

Can you make functions instance of Eq now?

## Focus of This Course

- Libraries ~ Little Languages
    - Express and solve a *problem*
    - in a *problem domain*
  - Programming Languages
    - General purpose
    - *Domain-specific*
      - *Description languages*
  - Embedded Language
    - A little language implemented as a library
- E.g. JavaScript
- E.g. HTML, PostScript
- Little languages

## Typical Embedded Language

- Modelling elements in problem domain
- Functions for *creating* elements
  - *Constructor functions*
- Functions for *modifying* or *combining*
  - *Combinators*
- Functions for observing elements
  - *Run functions*