universität innsbruck

WS 2018/2019

Functional Programming

Lecture 1

Cezary Kaliszyk Jonas Schöpf
Christian Sternagel Vincent van Oostrom

Department of Computer Science

Organization

Lecture (VO 2)

- LV-Number: 703024
- lecturer: Christian Sternagel
- course website:
  http://cl-informatik.uibk.ac.at/teaching/ws18/fp/
  (slides are available online)
- consultation hours: Friday 14:00 – 15:30 in 3M03
- online registration required before 23:59 on November 30

Lecture (VO 2)

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- consultation hours: Friday 14:00 – 15:30 in 3M03
- online registration required before 23:59 on November 30
- grading: written exam (closed book)
  - 1st exam on February 1, 2019
  - online registration required before 23:59 on January 18, 2019

Exercises (PS 1)

- LV-Number: 703025
- group 1 Vincent van Oostrom Friday 08:15–09:00 HS 11
  group 2 Cezary Kaliszyk Friday 09:15–10:00 HS 11
  group 3 Christian Sternagel Friday 10:15–11:00 HS 11
  group 4 Jonas Schöpf Friday 11:15–12:00 HSB 7
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- if you want to change to group 5, please contact CS
  (indicating valid justification might increase priority)
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  (deadline: 7:30 a.m. before PS on Friday)
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lecture 1	October	5	lecture 7	December	7
lecture 2	October	12	lecture 8	December	14
lecture 3	November	9	lecture 9	January	11
lecture 4	November	16	lecture 10	January	18
lecture 5	November	23	lecture 11	January	25
lecture 6	November	30	1st exam	February	1

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Topics

abstract data types, algebraic data types, binary search trees, combinator parsing, efficiency, encoding data types as lambda-terms, evaluation strategies, formal verification, first steps, guarded recursion, Haskell introduction, higher-order functions, historical overview, induction, infinite data structures, input and output, lambda-calculus, lazy evaluation, list comprehensions, lists, modules, pattern matching, polymorphism, property-based testing, reasoning about functional programs, recursive functions, sets, strings, tail recursion, trees, tupling, type checking, type inference, types, types and type classes, unification, user-defined types

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Overview

- History
- Notions
- A Taste of Haskell
- First Steps

History

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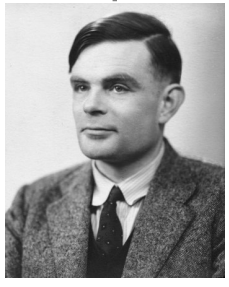

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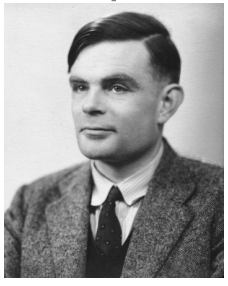

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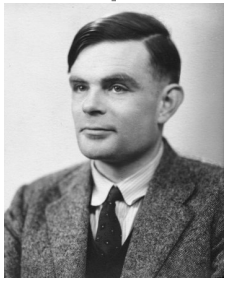

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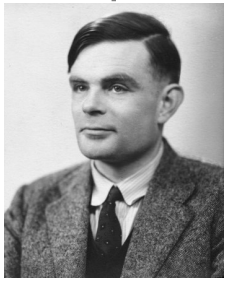

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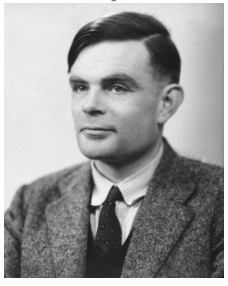

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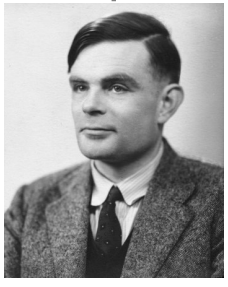

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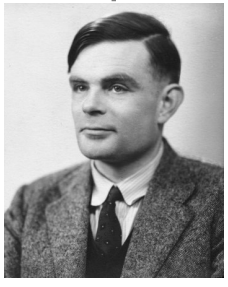

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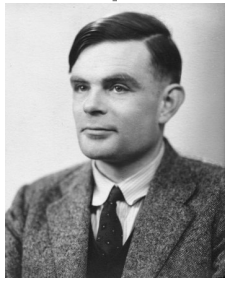

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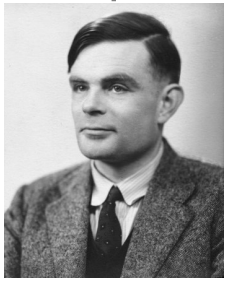

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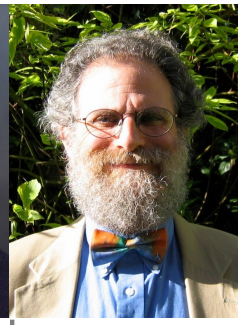

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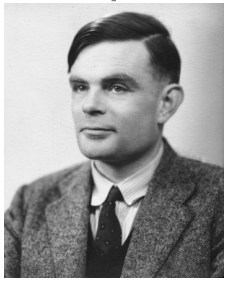

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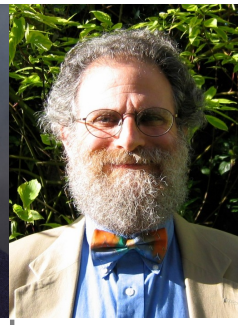

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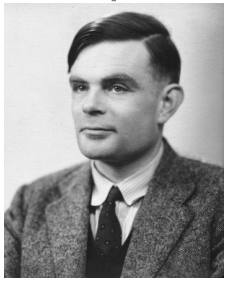

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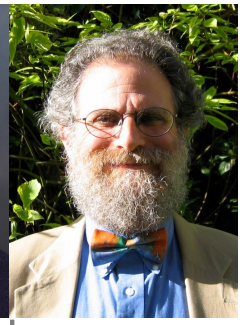

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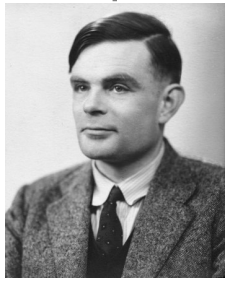

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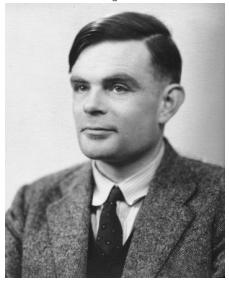

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- variables point to storage locations in memory
- state is content of variables in scope at given execution point

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Example – $\sum_{i=0}^{n} i$

```
count := 0
total := 0
while count < n
  count := count + 1
  total := total + count
```

Example – $\sum_{i=0}^{n} i$

the Haskell way of summing up the numbers from `0` to `n` is

```
sum [0..n]
```

- `[0..4]` generates list `[0,1,2,3,4]`
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- `sum xs` computes sum of elements in `xs`

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mySum [] = 0
mySum (x:xs) = x + mySum xs
```

Pure Functions

a function is pure if it always returns same result on same input

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Counterexample – Random Numbers

the C function `rand` (producing random numbers) is not pure

```
rand() = 0
rand() = 10
rand() = 42
```

Immutable Data

data that does not change after initial creation

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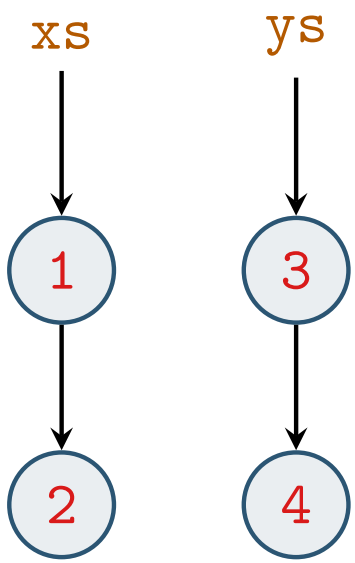
Example – Immutable Linked Lists

- consider two linked lists `xs = [1,2]` and `ys = [3,4]`



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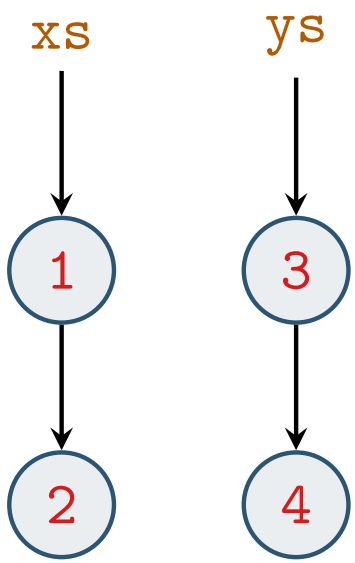

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append elements of `ys` to `xs`

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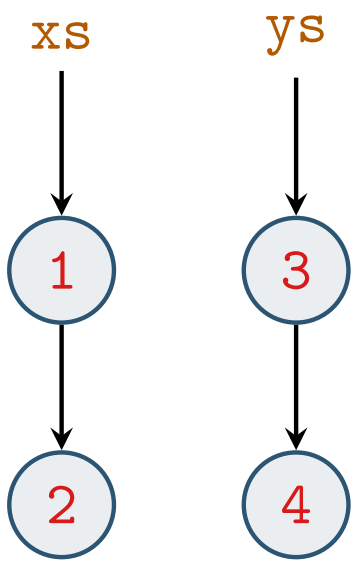

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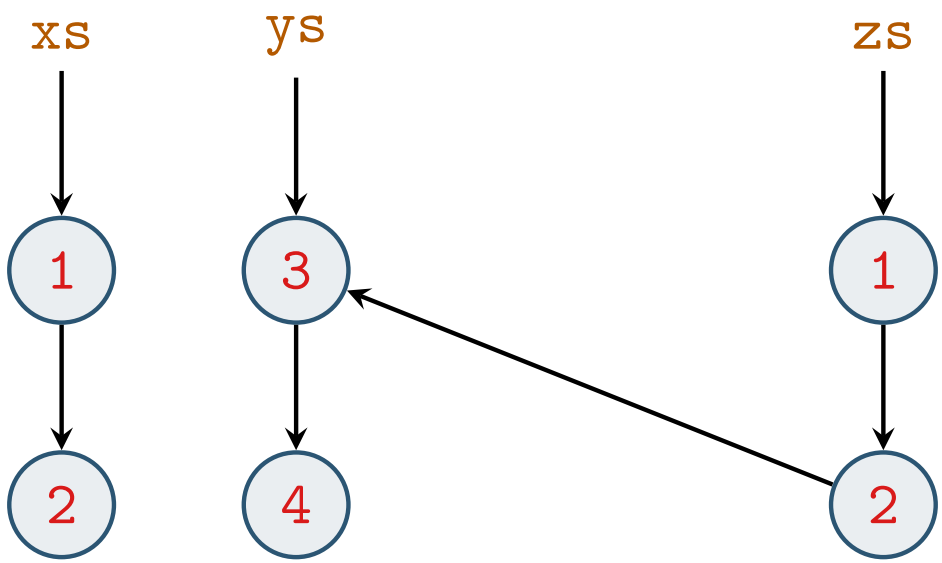

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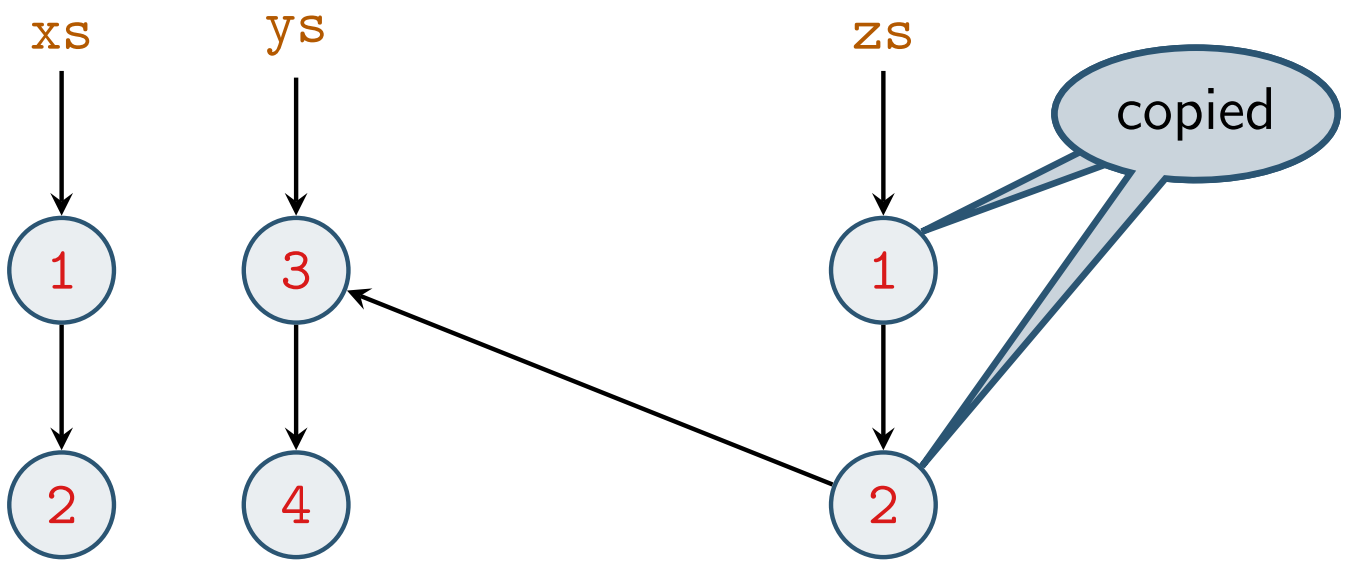

Recursion

a function (definition) is recursive if it refers to itself

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Example – Factorial Numbers

```
factorial n =
  if n < 2 then 1
  else n * factorial (n - 1)
```

Evaluating Functions by Hand (aka Equational Reasoning)

- functions are defined by equations and pattern matching
- general idea: "replace equals by equals"

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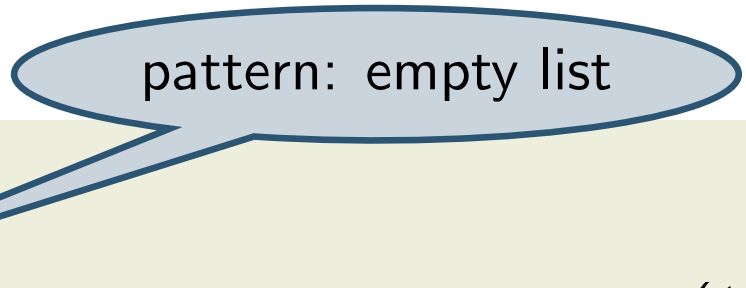

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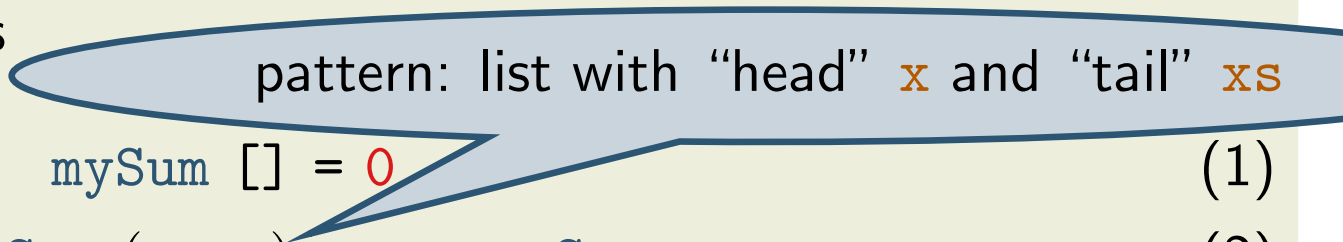


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                = 1 + (2 + (3 + mySum []))  using (2)
```

Evaluating Functions by Hand (aka Equational Reasoning)

- functions are defined by equations and pattern matching
- general idea: "replace equals by equals"

Example – mySum

given the two equations

```
mySum []     = 0          (1)
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                = 6                          by def. of +
```

A Taste of Haskell

Haskell

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Example – Quicksort

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```
qsort []     = []
qsort (x:xs) = qsort le ++ [x] ++ qsort gt
  where
    le = [a | a <- xs, a <= x] -- list comprehension
    gt = [b | b <- xs, b > x]
```

First Steps

Haskell on the Web

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- most widely used Haskell compiler: GHC
- with interpreter GHCi

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Starting the Interpreter (GHCi)

```
$ ghci
GHCi, version 8.2.2: http://www.haskell.org/ghc/
:? for help
...
Prelude>
```

The Standard Prelude

on startup GHCi loads the "Prelude," importing many standard functions

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Examples

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- lists

`drop n xs`	drop first `n` elements from list `xs`
`head xs`	extract first element from list `xs`
`length xs`	number of elements in list `xs`
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- note: in code examples Prelude functions are colored green and others blue; variables are colored dark orange

Function Application

- in mathematics: function application is denoted by enclosing arguments in parentheses, whereas multiplication of two arguments is often implicit (by juxtaposition)
- in Haskell: reflecting its primary status, function application is denoted silently (by juxtaposition), whereas multiplication is denoted explicitly by $*$

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Examples

Mathematics	Haskell
$f(x)$	`f x`
$f(x, y)$	`f x y`
$f(g(x))$	`f (g x)`
$f(x, g(y))$	`f x (g y)`
$f(x)\,g(y)$	`f x * g y`
$f(a, b) + c\,d$	`f a b + c * d`

Haskell Scripts

- define new functions inside scripts
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My First Script – `test.hs`

- set editor from inside GHCi `:set editor vim`
- start editor `:edit test.hs` and type

```
double x     = x + x
quadruple x = double (double x)
```

- load script

```
Prelude> :load test.hs
[1 of 1] Compiling Main ( test.hs, interpreted )
Ok, modules loaded: Main.
*Main>
```

Interpreter Commands

Command	Meaning
`:load` ⟨*filename*⟩	load script ⟨*filename*⟩
`:reload`	reload current script
`:edit` ⟨*filename*⟩	edit script ⟨*filename*⟩
`:edit`	edit current script
`:type` ⟨*expression*⟩	show type of ⟨*expression*⟩
`:set` ⟨*property*⟩	change various settings
`:show` ⟨*info*⟩	show various information
`:!` ⟨*command*⟩	execute ⟨*command*⟩ in shell
`:?`	show help text
`:quit`	bye-bye!

Example Session

```
> :load test.hs
> quadruple 10
40
> take (double 2) [1,2,3,4,5,6]
[1,2,3,4]
> :edit test.hs
```

```
factorial n = product [1..n]
average ns  = sum ns `div` length ns
```

```
> :reload
> factorial 10
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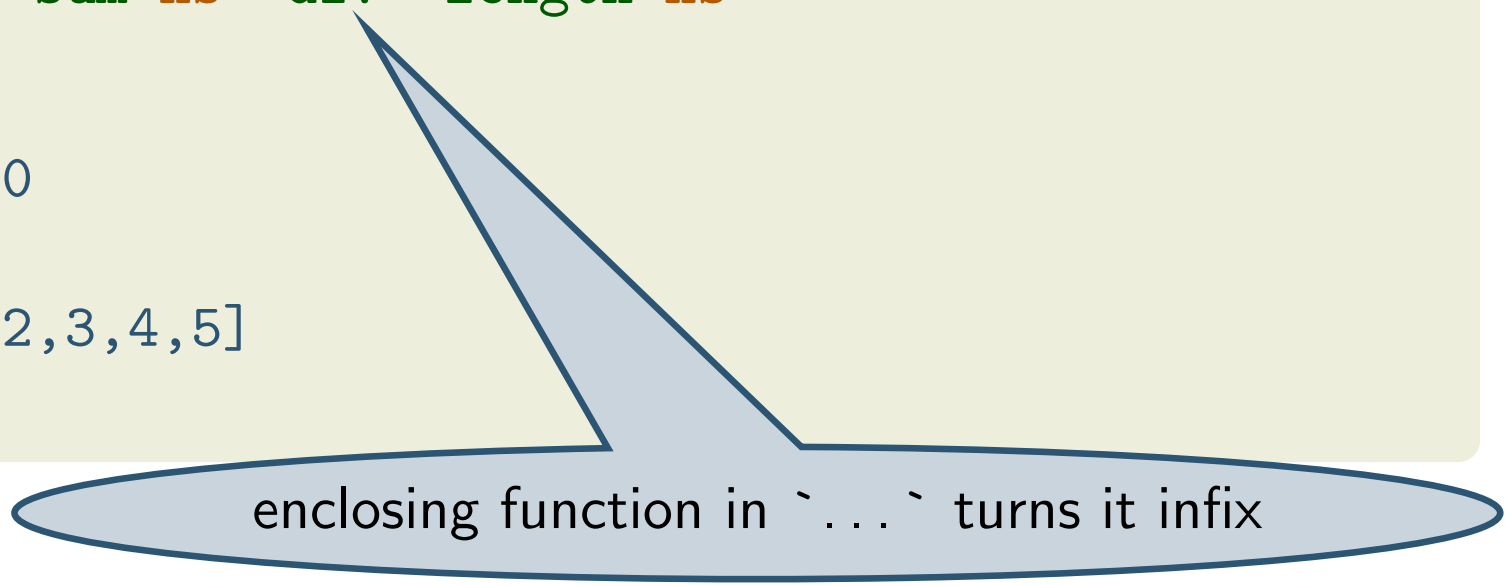

Naming Requirements

names of functions and their arguments have to conform to following syntax

$$
\begin{array}{rcl}
\langle \mathit{lower} \rangle & ::= & \texttt{a} \mid \ldots \mid \texttt{z} \\
\langle \mathit{upper} \rangle & ::= & \texttt{A} \mid \ldots \mid \texttt{Z} \\
\langle \mathit{digit} \rangle & ::= & \texttt{0} \mid \ldots \mid \texttt{9} \\
\langle \mathit{name} \rangle & ::= & (\langle \mathit{lower} \rangle \mid \texttt{\_})(\langle \mathit{lower} \rangle \mid \langle \mathit{upper} \rangle \mid \langle \mathit{digit} \rangle \mid \texttt{'} \mid \texttt{\_})^*
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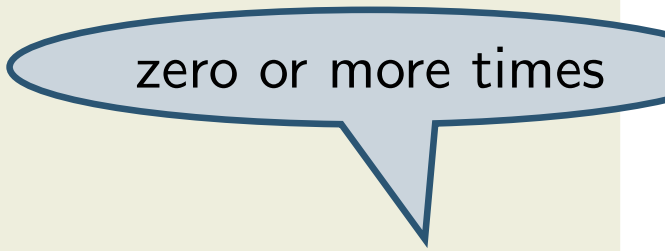

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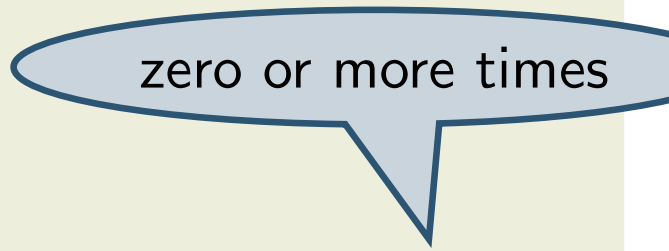

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Reserved Names

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case class data default deriving do else foreign if import in
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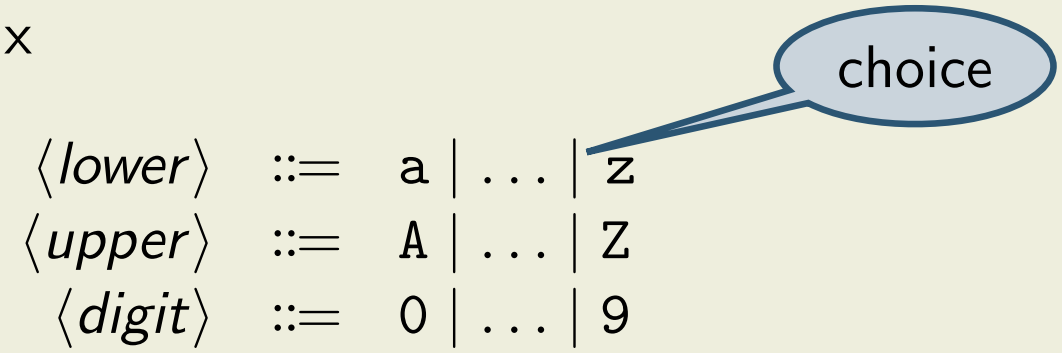

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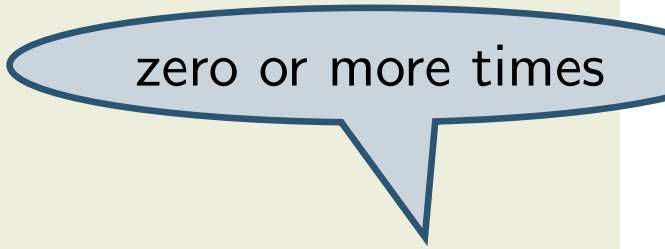

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```

Examples

```
myFun  fun1  arg_2  x'
```

The Layout Rule

- items that start in same column are grouped together
- by increasing indentation, single item may span multiple lines
- groups end at EOF or when indentation decreases
- script content is group, start nested group by **`where`**, **`let`**, **`do`**, or **`of`**
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Examples

with layout:

```
main =
  let x = 1
      y = 1
  in
  putStrLn (take
    (x+y) (zs++us))
  where
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    zs = []
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```

without layout:

```
main =
  let { x = 1; y = 1 } in
  putStrLn (take (x+y) (zs++us))
  where { zs = []; us = "abc" }
```

Comments

there are two kinds of comments

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Examples

```
-- Factorial of a positive number:
factorial n = product [1..n]

-- Average of a list of numbers:
average ns  = sum ns `div` length ns

{- currently not used
double x    = x + x
quadruple x = double (double x)
-}
```

Homework (for October 12th)

1. Read http://haskell.org/haskellwiki/Functional_programming and http://haskell.org/haskellwiki/Haskell_in_5_steps.
2. Work through lessons 1 to 3 on http://tryhaskell.org/.
3. Find, explain, and correct the 4 errors in the following code:

```
x = mod length data Y
  where
    { data = [1..10] Y = 5 }
```

4. Implement a function `nth`, where `nth xs i` yields the `i`s element of the list `xs`, in terms of the Prelude functions from this lecture.
   Example: `nth ["a","b","c"] 1 = "b"`
5. Implement a function `fromTo`, where `fromTo xs i j` yields the part of `xs` between positions `i` and `j`, in terms of the Prelude functions from this lecture.
   Example: `fromTo ["a","b","c","d"] 1 2 = ["b","c"]`
6. Use recursion to implement a function `allTrue` that, given a list of boolean values, checks whether they are all true.
   Example: `allTrue [True,False,True] = False`