Functional Programming

Christian Sternagel Harald Zankl Evgeny Zuenko

Department of Computer Science
University of Innsbruck

WS 2017/2018

Lecture 1

Organization

Lecture

- LV-Number 703024
- VO 2
- http://cl-informatik.uibk.ac.at/teaching/ws17/fp/
- slides are also available online
- office hours: Friday 14:15 – 15:45 in 3M03
- online registration required before 23:59 on November 30

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- online registration required before 23:59 on November 30
- grading: written exam (closed book)
  - 1st exam on February 2, 2018
  - registration starts 5 weeks before exam
  - registration closes 2 weeks before exam

Exercises

- LV-Number 703025
- PS 1
- group 1 Christian Sternagel Friday 10:15 – 11:00 HS 11
  group 2 Harald Zankl Friday 11:15 – 12:00 HS 11
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- online registration required before 23:59 on September 21
- grading: 1 test (January 12, 2018) + weekly exercises
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Schedule

week 1	October	6	week 8	December	1
week 2	October	20	week 9	December	15
week 3	October	27	week 10	January	12
week 4	November	3	week 11	January	19
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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, implementing a type checker, 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

1936 **Alonzo Church:**
λ-calculus

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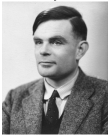

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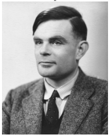

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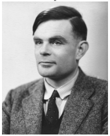

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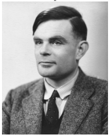

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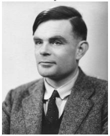

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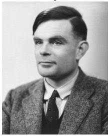

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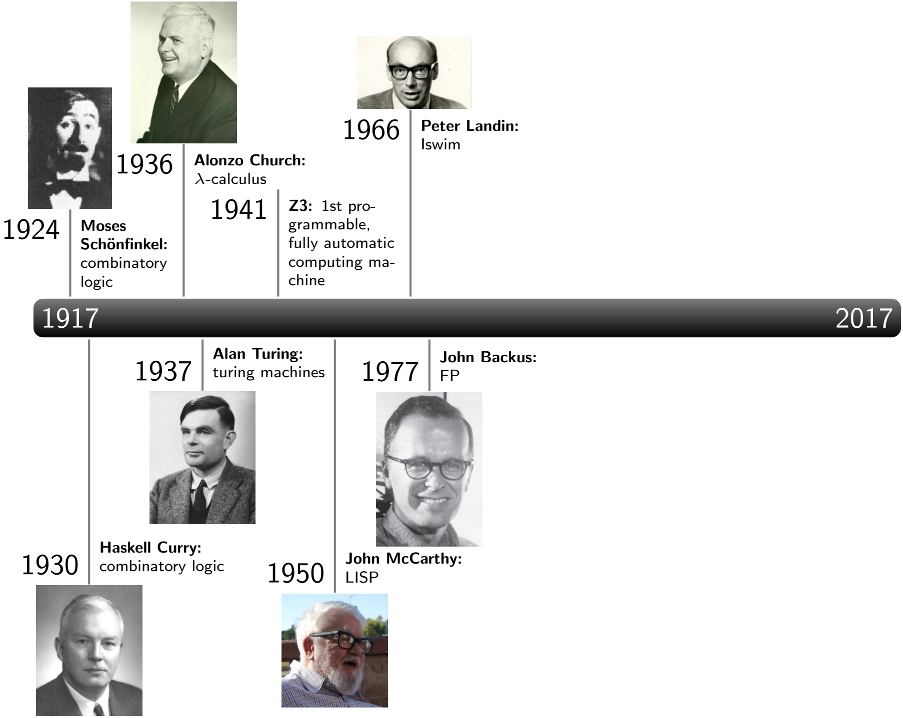
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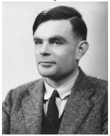

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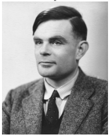

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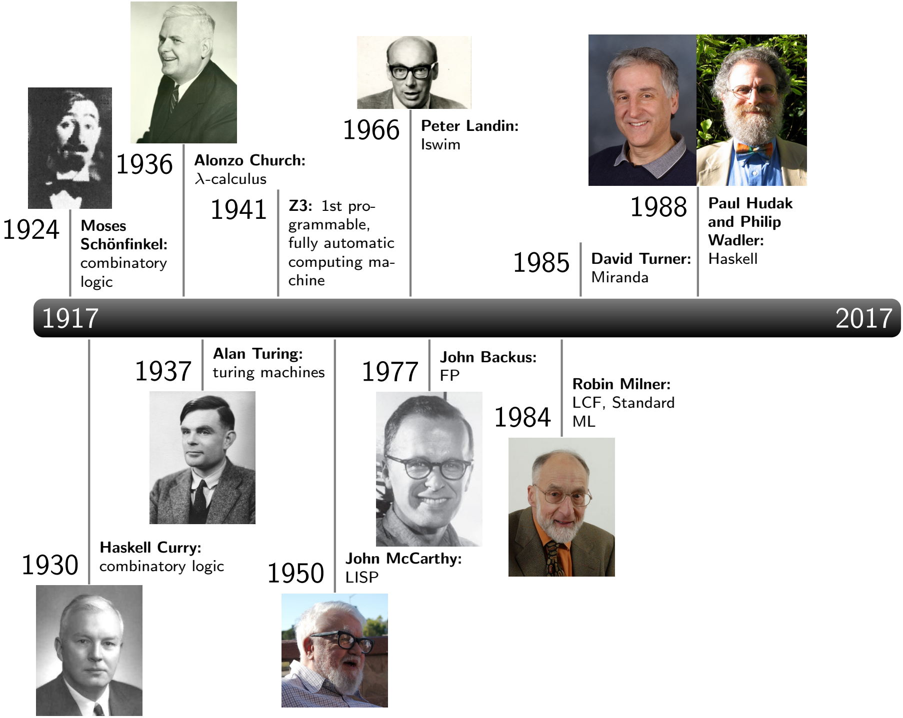
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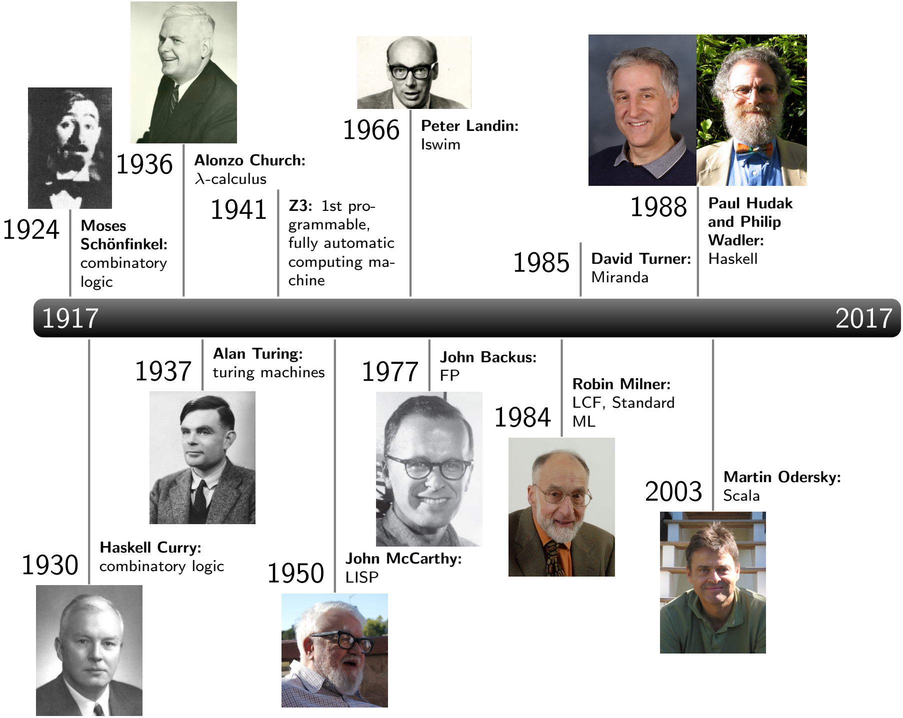
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Notions

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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]`
- `sum` is predefined function, summing up elements of a list

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  mySum [] = 0
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  ```

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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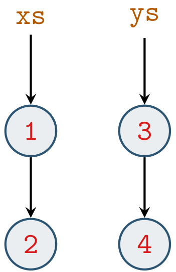
Example – Linked Lists

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



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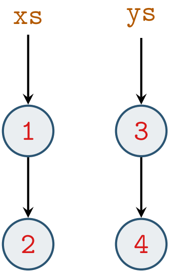

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append elements of `ys` to `xs`

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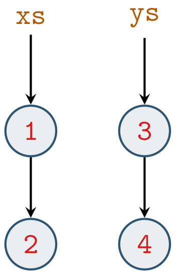

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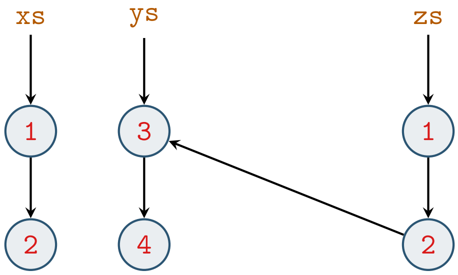

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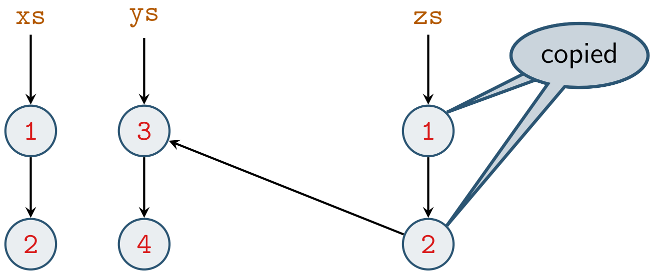

Recursion

a function is recursive if it is used in its own definition

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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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Example – mySum

given the two equations

```
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pattern: empty list

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pattern: list with “head” x and “tail” xs

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

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$$\texttt{mySum []} = \texttt{0} \tag{1}$$

$$\texttt{mySum (x:xs)} = \texttt{x + mySum xs} \tag{2}$$

we evaluate `mySum [1,2,3]` like

$$\begin{aligned}
\texttt{mySum [1,2,3]} &= \texttt{1 + mySum [2,3]} && \text{using (2)}\\
&= \texttt{1 + (2 + mySum [3])} && \text{using (2)}\\
&= \texttt{1 + (2 + (3 + mySum []))} && \text{using (2)}\\
&= \texttt{1 + (2 + (3 + 0))} && \text{using (1)}\\
&= \texttt{6} && \text{by def. of +}
\end{aligned}$$

A Taste of Haskell

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Example – Quicksort

- sort list of elements smaller than or equal to `x`
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- insert `x` in between

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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

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- most widely used Haskell compiler: GHC
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Starting the Interpreter (GHCi)

```
$ ghci
GHCi, version 8.0.2: 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

- arithmetic: `+`, `-`, `*`, `/`, `^`, `mod`, `div`
- 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`
`product xs`	multiply elements of list `xs`
`reverse xs`	as the name says: reverse list `xs`
`sum xs`	sum up elements of list `xs`
`tail xs`	obtain list `xs` without its first element
`take n xs`	take first `n` elements from list `xs`

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- note: in code examples Prelude functions are denoted in green and others in blue; variables are denoted in 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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- in Haskell: reflecting its primary status, function application is denoted silently (by juxtaposition), whereas multiplication is denoted explicitly by *

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
- text file containing definitions
- common suffix `.hs`

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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` ⟨*name*⟩	load script ⟨*name*⟩
`:reload`	reload current script
`:edit` ⟨*name*⟩	edit script ⟨*name*⟩
`:edit`	edit current script
`:type` ⟨*expr*⟩	show type of ⟨*expr*⟩
`:set` ⟨*prop*⟩	change various settings
`:show` ⟨*info*⟩	show various information
`:!` ⟨*cmd*⟩	execute ⟨*cmd*⟩ 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
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> :reload
> factorial 10
3628800
> average [1,2,3,4,5]
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enclosing function in `...` turns it infix

Naming Requirements

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

$$
\begin{aligned}
\langle \mathit{lower} \rangle &\stackrel{\text{def}}{=} \mathtt{a} \mid \ldots \mid \mathtt{z} \\
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\langle \mathit{digit} \rangle &\stackrel{\text{def}}{=} \mathtt{0} \mid \ldots \mid \mathtt{9} \\
\langle \mathit{name} \rangle &\stackrel{\text{def}}{=} (\langle \mathit{lower} \rangle \mid \mathtt{\_})(\langle \mathit{lower} \rangle \mid \langle \mathit{upper} \rangle \mid \langle \mathit{digit} \rangle \mid \mathtt{'} \mid \mathtt{\_})^*
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Reserved Names

case class data default deriving do else foreign if import in infix infixl infixr instance let module newtype of then type where _

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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, items 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

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main =
  let x = 1
      y = 1
  in
  putStrLn (take
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  where
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  where
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```

without layout:

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

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)
-}
```

Exercises (for October 20th)

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. Explain and correct the 3 syntactic errors in the script:

   ```
   N = a 'div' length xs
     where
         a = 10
       xs  = [1,2,3,4,5]
   ```

4. Show how the library function `last` (selecting the last element of a non-empty list) could be defined in terms of the Prelude functions used in this lecture. Can you think of another possible definition?
5. Show two possible definitions of the library function `init` (removing the last element from a list) in terms of the functions introduced so far.
6. Use recursion to define a function `gcd`, computing the greatest common divisor of two given numbers.