CEng 3549 – Functional Programming

Histroy & Notions & A Taste of Haskell

Burak Ekici

September 22, 2022

About Me: Parcours/Carrier

Undergrad	IZTECH	CE	2004-2009, İzmir
Master's	Yaşar Üni	CE	2009-2012, İzmir
Traineeship	EC JRC	CE	2010-2011, Varese-Italy
PhD	U Joseph Fourier	CS & Math	2013-2015, Grenoble-France
PostDoc	U of Iowa	CS	2016-2017, IA-USA
PostDoc	U of Innsbruck	CS	2018-2019, Innsbruck-Austria
Assist. Prof. Dr.	Kültür Uni	CE	2019-2020, İstanbul
Assist. Prof. Dr.	TED Uni	CE	2021-2022, Ankara
Assist. Prof. Dr.	Muğla Sıtkı Koçman Uni	CE	2022-now, Muğla

Outline

Logistics

lecturer	Burak Ekici (burakekici@mu.edu.tr)

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lecturer	Burak Ekici (burakekici@mu.edu.tr)
teaching assistant	Erdem Türk (erdemturk@mu.edu.tr)

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teaching assistant	Erdem Türk (erdemturk@mu.edu.tr)
consultation	Thursday 13h30 – 16h30 at (no room assigned yet)

About the Course

- Prerequisites:
  - Strong motivation

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- Tentative Grading:

~~Attendance~~	Homeworks	Midterm	Final
~~5%~~	35%	30%	35%

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give an introduction to

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  - theoretical background – λ-Calculus
- logical programming and type theory
  - techniques that allow for verification of functional programs
  - verification developments within the Coq proof assistant

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Week 14	Final

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1918 2022

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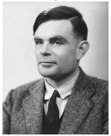

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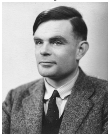

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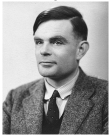

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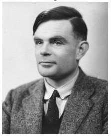

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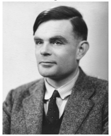

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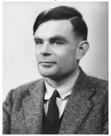

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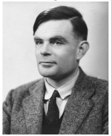

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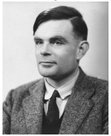

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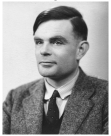

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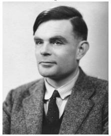

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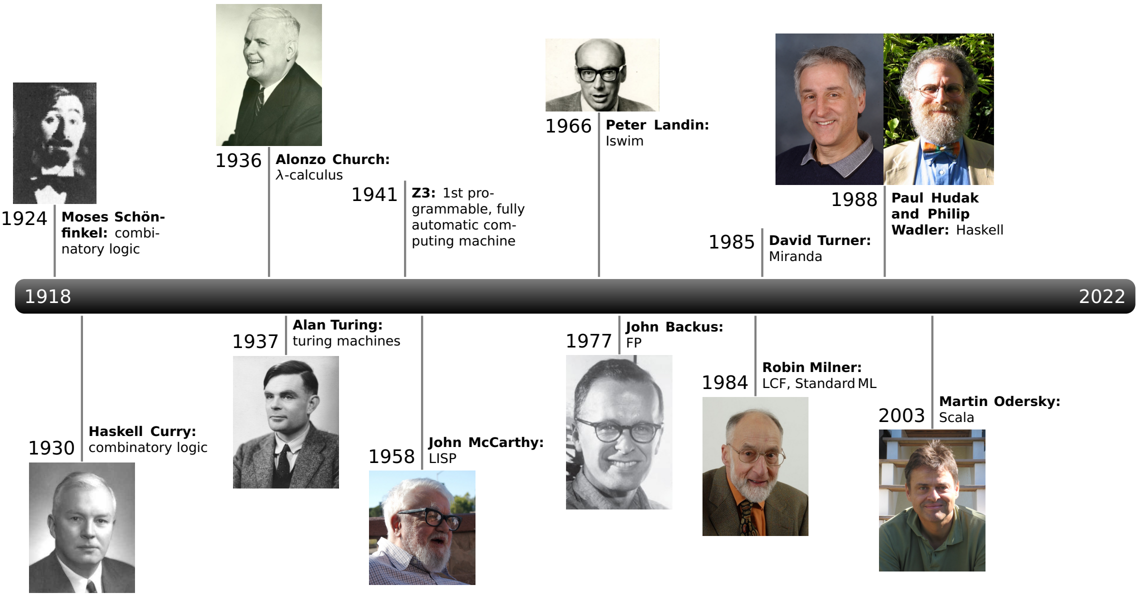
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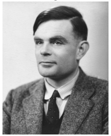

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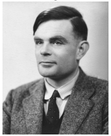

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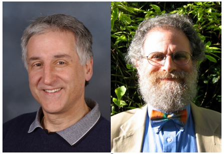

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2010 **Haskell2010**

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- variables point to storage locations in memory

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a function or expression has side effects if it modifies state

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Example ($\sum_{i=0}^{n} i$)

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

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

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sum [0..n]
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range m n =
  if m > n then []
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- `sum xs` computes sum of elements in `xs`

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

Definition (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
```

Definition (immutable data)

data that does not change after initial creation

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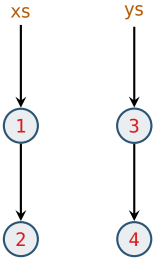
Example (immutable linked lists)

- consider two linked lists xs = [1,2] and ys = [3,4]
- after concatenation zs = xs ++ ys



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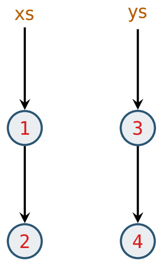
append elements of ys to xs



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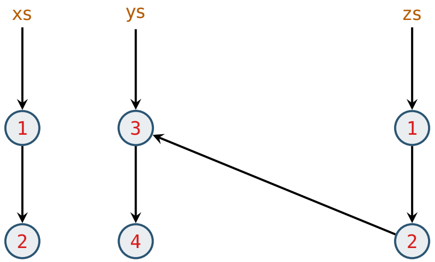

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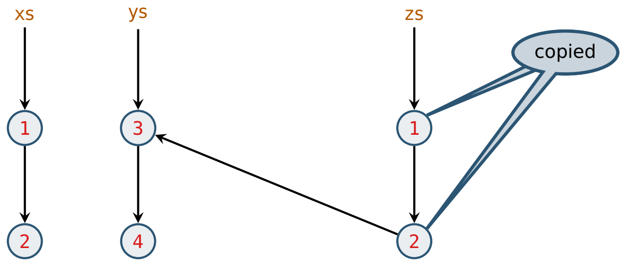

Recursion

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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pattern: empty list

Example (mySum)

given the two equations

$$\mathtt{mySum}\ [\,] = 0 \tag{1}$$

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

Evaluating Functions by Hand (aka Equational Reasoning)

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

Example (mySum)

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

given the two equations

```
mySum []     = 0                 (1)
mySum (x:xs) = x + mySum xs      (2)
```

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	`= 1 + (2 + mySum [3])`	using (2)
	`= 1 + (2 + (3 + mySum []))`	using (2)
	`= 1 + (2 + (3 + 0))`	using (1)

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Outline

Haskell

- is a pure language (only allowing “explicit” side effects)
- functions are defined by equations and pattern matching

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Example (quicksort)

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

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

Outline

Haskell on the Web

- main entry point `www.haskell.org`
- 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

- 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`	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

- 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
- text file containing definitions
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My First Script – `test.hs`

- set editor from inside GHCi `:set editor` **`code`**
- 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
3628800
> average [1,2,3,4,5]
3
```

enclosing function in `...` turns it infix

Naming Requirements

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

choice

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

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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\langle name \rangle &::= (\langle lower \rangle \mid \_)(\langle lower \rangle \mid \langle upper \rangle \mid \langle digit \rangle \mid {}' \mid \_)^*
\end{aligned}
$$

Reserved Names

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

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`**
- **ignore layout:** enclose groups in ‘{’ and ‘}’ and separate items by ‘;’

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- **ignore layout:** enclose groups in '{' and '}' and separate items by ';'

Examples

with layout:

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

without layout:

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

Comments

there are two kinds of comments

- single-line comments: starting with `--` and extending to EOL
- multi-line comments: enclosed in `{-` and `-}`

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Examples

```haskell
-- 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)
-}
```

Thanks! & Questions?