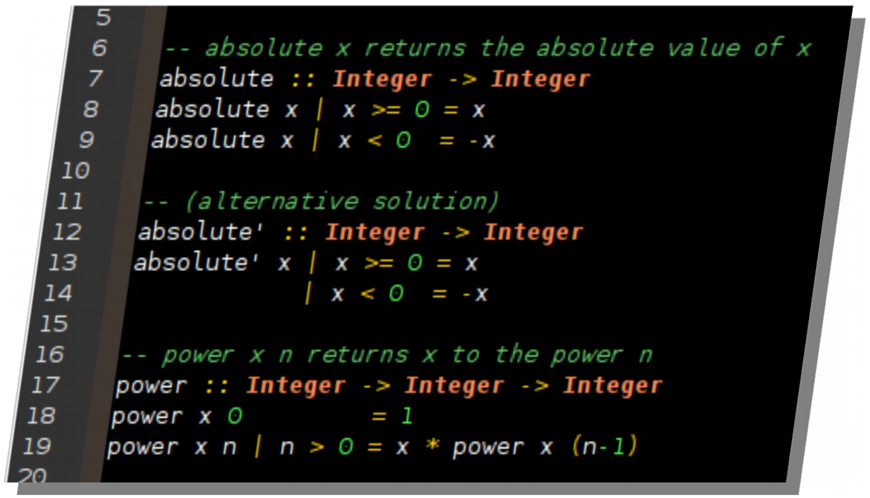
Introduction to Functional Programming



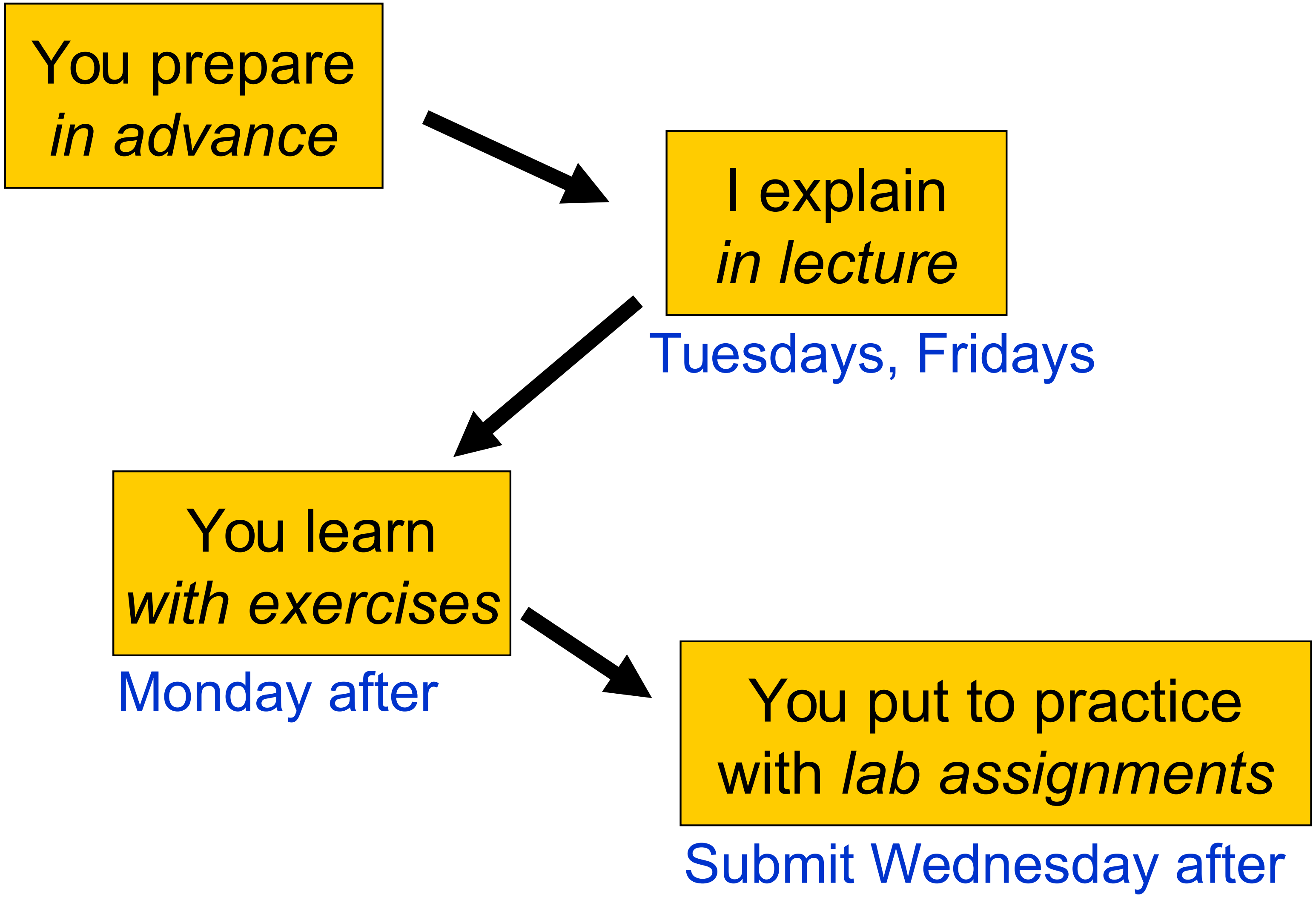
Slides by Koen Claessen and Emil Axelsson

Goal of the Course

- Start from the basics
- Learn to write small-to-medium sized programs in *Haskell*
- Introduce basic concepts of computer science

The Flow

Do not *break the flow*!



Course Homepage

The course homepage will have <u>all</u> up-to-date information relevant for the course

- Schedule and slides
- Lab assignments
- Exercises
- Last-minute changes
- (etc.)

Or go via the student portal

http://www.cse.chalmers.se/edu/course/TDA555/

Exercise Sessions

- Mondays
  - Group rooms
- Come prepared
- Work on exercises together
- Discuss and get help from tutor
  - Personal help
- Make sure you understand this week’s things before you leave

Lab Assignments

- General information

  http://www.cse.chalmers.se/edu/course/TDA555/labs.html

- Start working on lab *immediately* when you have understood the matter
- Submit each ~~Wednesday~~
  ~~(except in study week 1)~~

  `Monday at midday (12.00)`

Getting Help

- Weekly group sessions
  - Personal help to understand material
- Lab supervision
  - Specific questions about programming assignment at hand
- Discussion forum `ifp18.slack.com`
  - General questions, worries, discussions
  - *Finding lab partners*

Assessment

- Written exam (4.5 credits)
  - Consists of small programming problems to solve on paper
  - You need Haskell “in your fingers”
- Course work (3 credits)
  - Complete all labs successfully

A Risk

- 8 weeks is a short time to learn programming
- So the course is fast paced
  - Each week we learn a lot
  - Catching up again is hard
- So do keep up!
  - Read the material for each week
  - Make sure you can solve the problems
  - Go to the weekly exercise sessions
  - *From the beginning*

Lectures

You are welcome to bring your laptops and/or smart phones to the lectures

- Use laptop to follow my live coding
- Use smart phone to take part in quizzes

... but this is completely optional!

Software

Software = Programs + Data

Software = Programs + Data

- Data is any kind of storable information, e.g:
  - numbers, letters, email messages
  - maps, video clips
  - mouse clicks, *programs*
- Programs compute new data from old data:
  - A computer game computes a sequence of screen images from a sequence of mouse clicks
  - vasttrafik.se computes an optimal route given a source and destination bus stop

Programming Languages

- Programs are written in *programming languages*
- There are hundreds of different programming languages, each with their strengths and weaknesses
- A large system will often contain components in many different languages

Two major paradigms

Imperative programming:

- Instructions are used to change the computer's state:
  - x := x+1
  - deleteFile(”slides.pdf”)
- Run the program by following the instructions top-down

Functional programming:

- Functions are used to declare dependencies between data values:
  - y = f(x)
- Dependencies drive evaluation

Two major paradigms

Imperative programming:

- **Instructions** are used to change the computer's **state**:
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Functional programming:

- **Functions** are used to declare dependencies between **data values**:
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Functional Programming

- **Functions** are used to declare dependencies between data values:
  - $y = f(x)$
- **Functions** are the basic building blocks of programs
- **Functions** are used to compose **functions** into larger **functions**
- In a (pure) **function**, the result depends *only* on the argument (no external communication)

Industrial Uses of Functional Languages

Intel (microprocessor verification)

Hewlett Packard (telecom event correlation)

Ericsson (telecommunications)

Jeppesen (air-crew scheduling)

Facebook (chat engine)

Credit Suisse (finance)

Barclays Capital (finance)

Hafnium (automatic transformation tools)

Shop.com (e-commerce)

Motorola (test generation)

Thompson (radar tracking)

Microsoft (F#)

Jasper (hardware verification)

And many more!

Teaching Programming

We want to give you a broad basis

- Easy to learn more programming languages
- Easy to adapt to new programming languages
- Appreciate differences between languages
- Become a better programmer!

This course uses the functional language *Haskell*

- *http://haskell.org/*

Why Haskell?

- Haskell is a very *high-level language*
  - Lets you focus on the important aspects of programming
- Haskell is expressive and concise
  - Can achieve a lot with a little effort
- Haskell is good at handling complex data and combining components
- Haskell is defining the state of the art in programming language development
- Haskell is *not* a particularly high-performance language
  - Prioritizes programmer-time over computer-time

Why Haskell?

To get a feeling for the maturity of Haskell and its ecosystem, check out:

- State of the Haskell ecosystem – August 2015

Haskell programming:

Cases and recursion

Example: The squaring function

- Given *x*, compute x^2

```
-- sq x returns the square of x
sq :: Integer -> Integer
sq x = x * x
```

Evaluating Functions

- To evaluate sq 5:
  - *Use the definition*—substitute 5 for x throughout
    - sq 5 = 5 * 5
  - Continue evaluating expressions
    - sq 5 = 25
- Just like working out mathematics on paper

sq x = x * x

Example: Absolute Value

- Find the absolute value of a number

```
-- absolute x returns the absolute value of x
absolute :: Integer -> Integer
absolute x = undefined
```

Example: Absolute Value

- Find the absolute value of a number
- Two cases!
  - If x is positive, result is x
  - If x is negative, result is -x

Programs must often choose between alternatives

```
-- absolute x returns the absolute value of x
absolute :: Integer -> Integer
absolute x | x > 0 = undefined
absolute x | x < 0 = undefined
```

Think of the cases! These are *guards*

Example: Absolute Value

- Find the absolute value of a number
- Two cases!
  - If x is positive, result is x
  - If x is negative, result is -x

```
-- absolute x returns the absolute value of x
absolute :: Integer -> Integer
absolute x | x > 0 = x
absolute x | x < 0 = -x
```

Fill in the result in each case

Example: Absolute Value

- Find the absolute value of a number
- Correct the code

```
-- absolute x returns the absolute value of x
absolute :: Integer -> Integer
absolute x | x >= 0 = x
absolute x | x < 0   = -x
```

>= is *greater than or equal*, $\geq$

Evaluating Guards

- Evaluate absolute (-5)
  - We have two equations to use!
  - Substitute
    - absolute (-5) | -5 >= 0 = -5
    - absolute (-5) | -5 < 0 = -(-5)

```
absolute x | x >= 0 = x
absolute x | x < 0    = -x
```

Evaluating Guards

- Evaluate absolute (-5)
  - We have two equations to use!
  - Evaluate the guards
    - absolute (-5) | False = -5
    - absolute (-5) | True = -(-5)

Discard this equation

Keep this one

```
absolute x | x >= 0 = x
absolute x | x < 0    = -x
```

Evaluating Guards

- Evaluate absolute (-5)
  - We have two equations to use!
  - Erase the True guard
    - absolute (-5) = -(-5)

```
absolute x | x >= 0 = x
absolute x | x < 0    = -x
```

Evaluating Guards

- Evaluate absolute (-5)
  - We have two equations to use!
  - Compute the result
    - absolute (-5) = 5

```
absolute x | x >= 0 = x
absolute x | x < 0   = -x
```

Notation

- We can abbreviate repeated left hand sides

```
absolute x | x >= 0 = x
absolute x | x < 0   = -x
```

```
absolute x | x >= 0 = x
           | x < 0   = -x
```

- Haskell also has if then else

absolute x = **if** x >= 0 **then** x **else** -x

Boolean values

- False and True are values of type Bool:

```
False :: Bool
True  :: Bool
```

- Examples:

```
even :: Integer -> Bool
(>=)  :: Integer -> Integer -> Bool
```

Boolean values

- False and True are values of type Bool:

```
False :: Bool
True  :: Bool
```

The actual types are more general – work for any "integral" or "ordered" types

- Examples:

```
even :: Integral a => a -> Bool
(>=)  :: Ord a => a -> a -> Bool
```

Example: Computing Powers

- Compute x^n (without using built-in x^n)

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- Compute x^n (without using built-in x^n)
- Name the function

power

Example: Computing Powers

- Compute x^n (without using built-in x^n)
- Name the inputs

```
power x n = undefined
```

Example: Computing Powers

- Compute x^n (without using built-in x^n)
- Write a comment

```
-- power x n returns x to the power n
power x n = undefined
```

Example: Computing Powers

- Compute x^n (without using built-in x^n)
- Write a type signature

```
-- power x n returns x to the power n
power :: Integer -> Integer -> Integer
power x n = undefined
```

How to Compute power?

- We cannot write
  - power x n = x * … * x

n times

A Table of Powers

n	power x n
0	1
1	x
2	x·x
3	x·x·x

$x^n = x \cdot x^{(n-1)}$

- Each row is *x* times the previous one
- Define (power x n) to compute the *n*th row

A Definition?

```
power x n = x * power x (n-1)
```

- Testing:
  Main> power 2 2
  ERROR - stack overflow

Why?

A Definition?

```
power x n | n > 0 = x * power x (n-1)
```

- Testing:
  Main> power 2 2
  Program error: pattern match failure: power 2 0

A Definition?

First row of the table

```
power x 0 = 1
power x n | n > 0 = x * power x (n-1)
```

- Testing:
  Main> power 2 2
  4

The **BASE CASE**

Recursion

- First example of a *recursive* function
  - Defined in terms of itself!

```
power x 0 = 1
power x n | n > 0 = x * power x (n-1)
```

- Why does it work? Calculate:
  - power 2 2 = 2 * power 2 1
  - power 2 1 = 2 * power 2 0
  - power 2 0 = 1

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Recursion

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```
power x 0 = 1
power x n | n > 0 = x * power x (n-1)
```

- Why does it work? Calculate:
  - power 2 2 = 2 * 2
  - power 2 1 = 2 * 1
  - power 2 0 = 1

No circularity!

Recursion

- First example of a *recursive* function
  - Defined in terms of itself!

```
power x 0 = 1
power x n | n > 0 = x * power x (n-1)
```

- Why does it work? Calculate:
  - power 2 2 = 2 * power 2 1
  - power 2 1 = 2 * power 2 0
  - power 2 0 = 1

The **STACK**

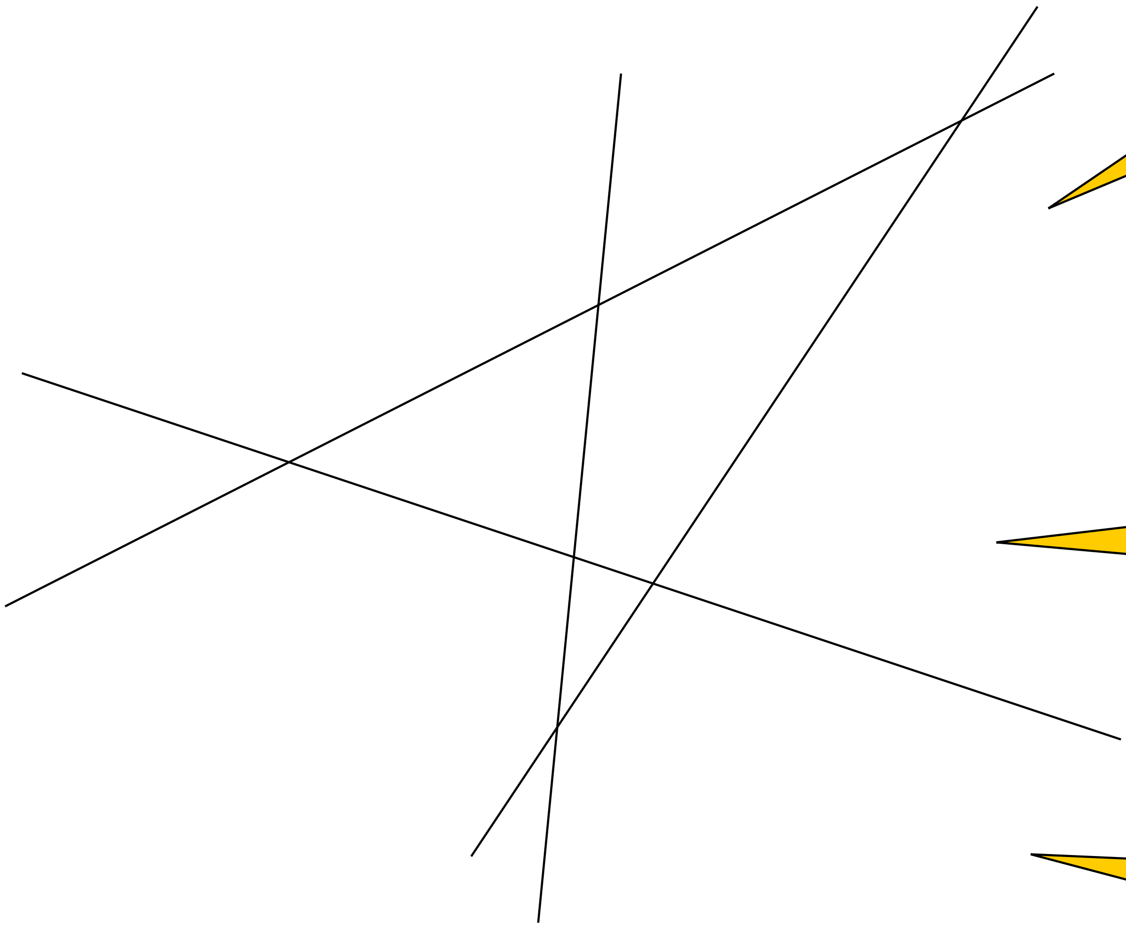
Recursion

- Reduce a problem (e.g. power x n) to a *smaller* problem of the same kind
- So that we eventually reach a “smallest” *base case*
- Solve base case separately
- Build up solutions from smaller solutions

Powerful problem solving strategy
in *any* programming language!

Counting the regions

- n lines. How many regions?



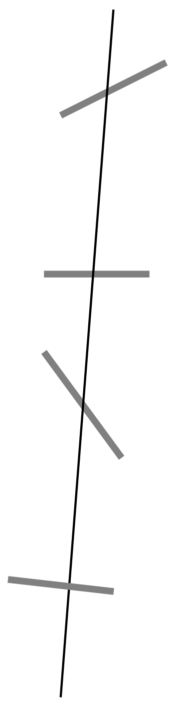
remove one line ...

problem is easier!

when do we stop?

Counting the regions

- The nth line creates n new regions



A Solution

- Don't forget a base case

```
regions :: Integer -> Integer
regions 1             = 2
regions n | n > 1 = regions (n-1) + n
```

A Better Solution

- Always make the base case as simple as possible!

```
regions :: Integer -> Integer
regions 1             = 2
regions n | n > 1 = regions (n-1) + n
```

```
regions :: Integer -> Integer
regions 0             = 1
regions n | n > 0 = regions (n-1) + n
```

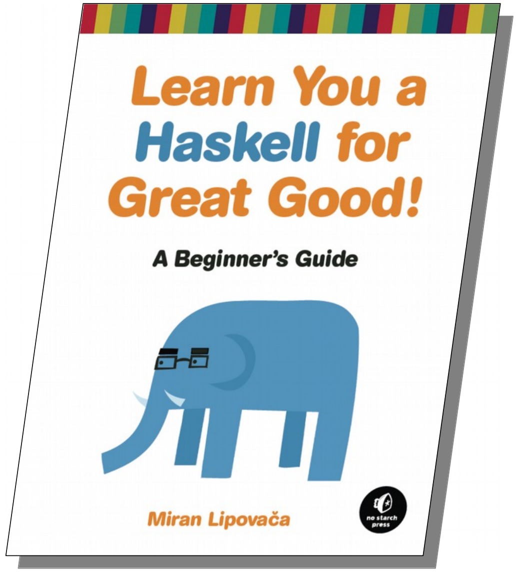
Important data structure: lists

- Example: [1,2,3,4]
- Types:
  - [1,2,3] :: [Integer]
  - [True, False] :: [Bool]
  - [[1,2,3],[4,5,6]] :: [[Integer]]
- Strings are lists
  - “Haskell” :: String
  - “Haskell” :: [Char]
  - ['H', 'a', 's', 'k', 'e', 'l', 'l'] :: String

- More in coming lectures
- For now: Read section 2.3 in LYAH

Material

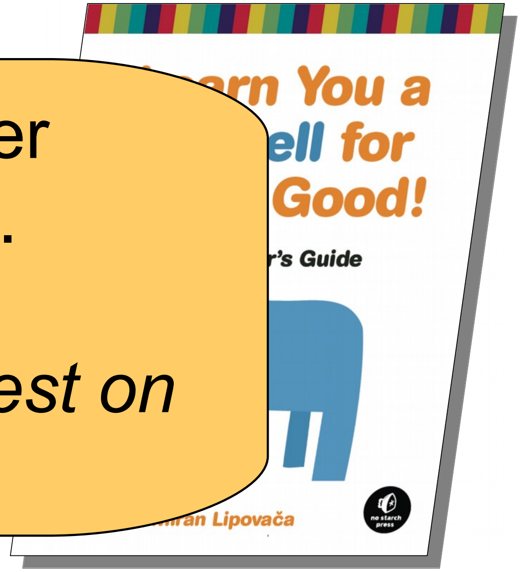
- Book (online):
  http://learnyouahaskell.com/



- Lecture slides

- Overview for each lecture:
  http://www.cse.chalmers.se/edu/course/TDA555/lectures.html

Material



I may not have time to cover everything in each lecture.

You are expected to read the rest on your own!

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