# Introduction to Programming in Haskell

Chalmers & GU

Emil Axelsson and John Hughes

*(with thanks to Koen Lindström Claessen)*

# Programming

- Exciting subject at the heart of computing
- Never programmed?
  - Learn to make the computer obey you!
- Programmed before?
  - Lucky you! Your knowledge will help a lot...
  - ...as you learn a completely new way to program
- *Everyone* will learn a great deal from this course!

## Goal of the Course

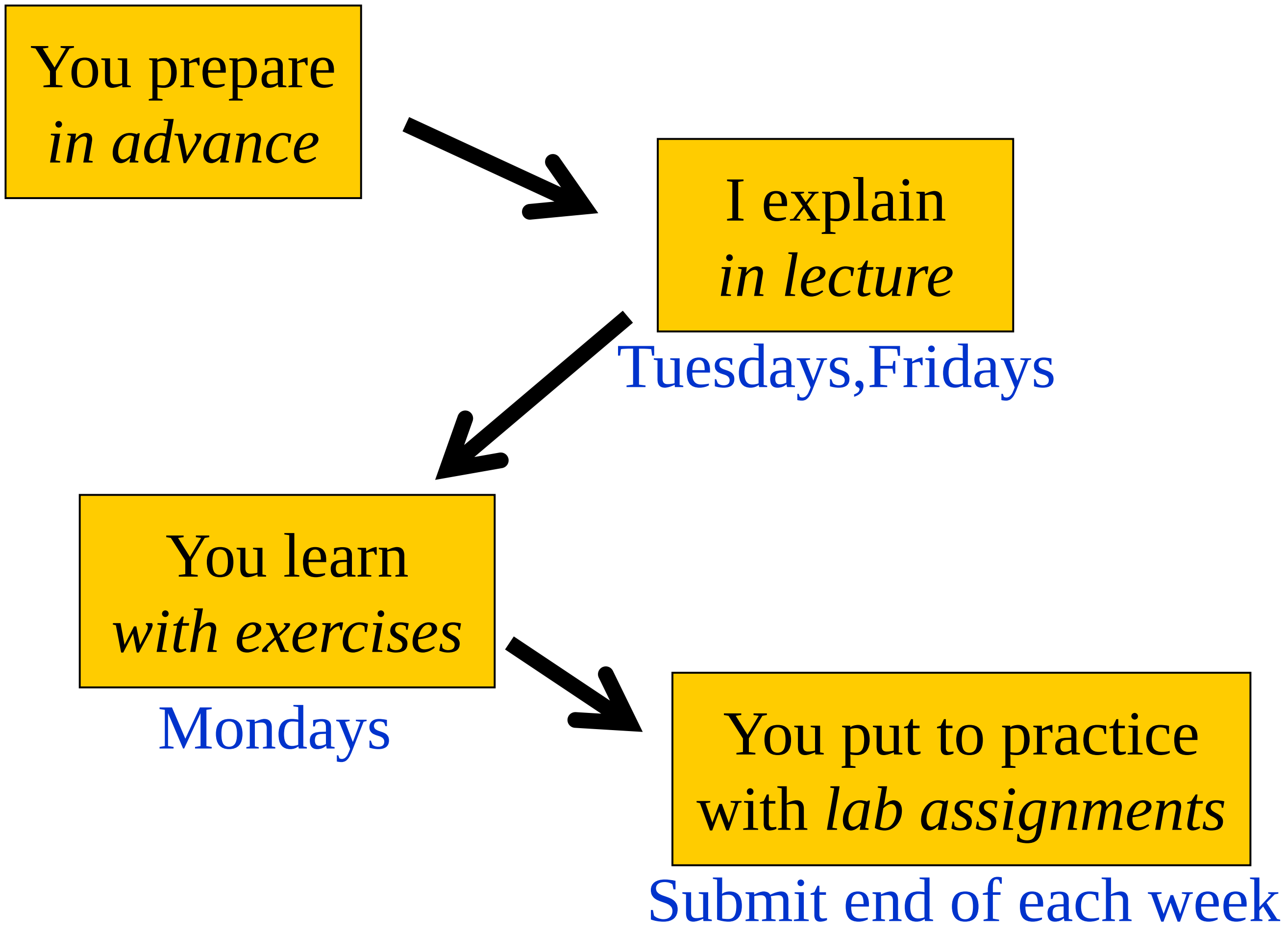
- Start from the basics, after *Datorintroduktion*

- Learn to write small-to-medium sized programs in Haskell

- Introduce basic concepts of computer science

# The Flow

Do not *break the flow*!



# 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

- Work in **pairs**
  - (Almost) no exceptions!
- Lab supervision
  - Book a time in advance
  - One time at a time!

bring pen and paper

- Start working on lab when you have understood the matter
- Submit end of each week

even this week!

- Feedback
  - Return: The tutor has something to tell you; fix and submit again
  - OK: You are done

## Getting Help

- Weekly group sessions
  - personal help to understand material
- Lab supervision
  - specific questions about programming assignment at hand
- Discussion forum
  - general questions, worries, discussions

## 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

- 7 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 lecture notes each week
  - Make sure you can solve the problems
  - Go to the weekly exercise sessions
  - *From the beginning*

## Course Homepage

- The course homepage will have ALL up-to-date information relevant for the course
  - Schedule
  - Lab assignments
  - Exercises
  - Last-minute changes
  - (etc.)

Or go via the student portal

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

## Software

Software = Programs + Data

## Data

Data is any kind of storable information. Examples:

- Numbers
- Letters
- Email messages
- Songs on a CD
- Maps
- Video clips
- Mouse clicks
- Programs

## Programs

Programs compute new data from old data.

**Example**: *Starcraft II* computes a sequence of screen images and sounds from a sequence of mouse clicks.

## Building Software Systems

A large system may contain many *millions* of lines of code.

Software systems are among the most complex artefacts ever made.

Systems are built by combining existing components as far as possible.

Volvo buys engines from Mitsubishi. $\longleftrightarrow$ Facebook buys video player from Adobe

## 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.

# Programming Langu

which language should we teach?

Scheme

Lisp

C

BASIC

C++

Haskell

Java

C#

ML

Python

JavaScript

csh

Curry

Perl

O'CaML

bash

Erlang

Prolog

Ruby

Lustre

Mercury

PostScript

VHDL

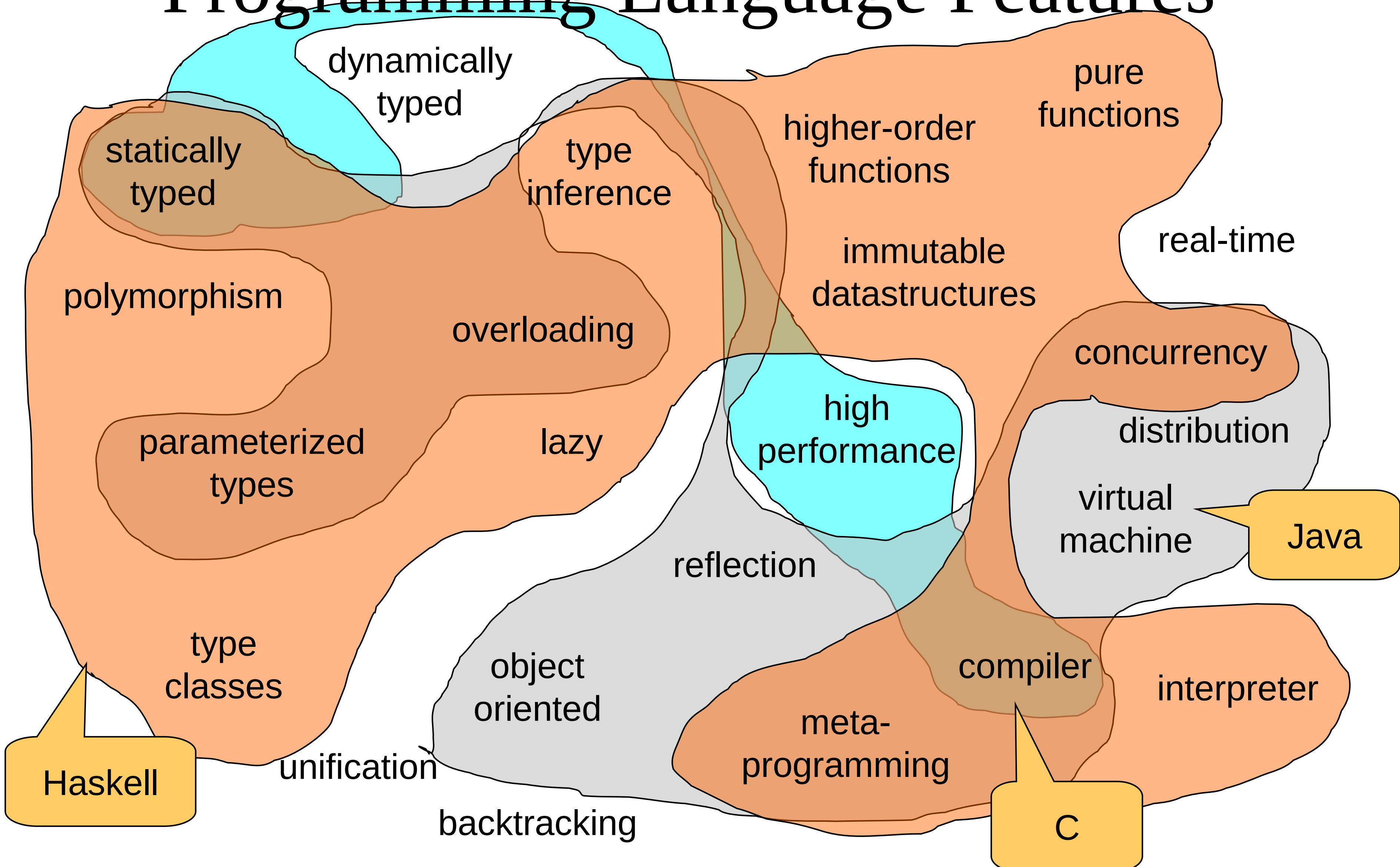
Esterel

PDF

SQL

Verilog

# Programming Language Features



# Teaching Programming

- Give you a broad basis
  - Easy to learn more programming languages
  - Easy to adapt to new programming languages
- Haskell is defining state-of-the-art in programming language development
  - Appreciate differences between languages
  - Become a better programmer!

## ”Functional Programming”

•**Functions** are the basic building blocks of programs

•**Functions** are used to compose these building blocks into larger programs

•A (pure) **function** computes results from arguments – *consistently the same*

# 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)

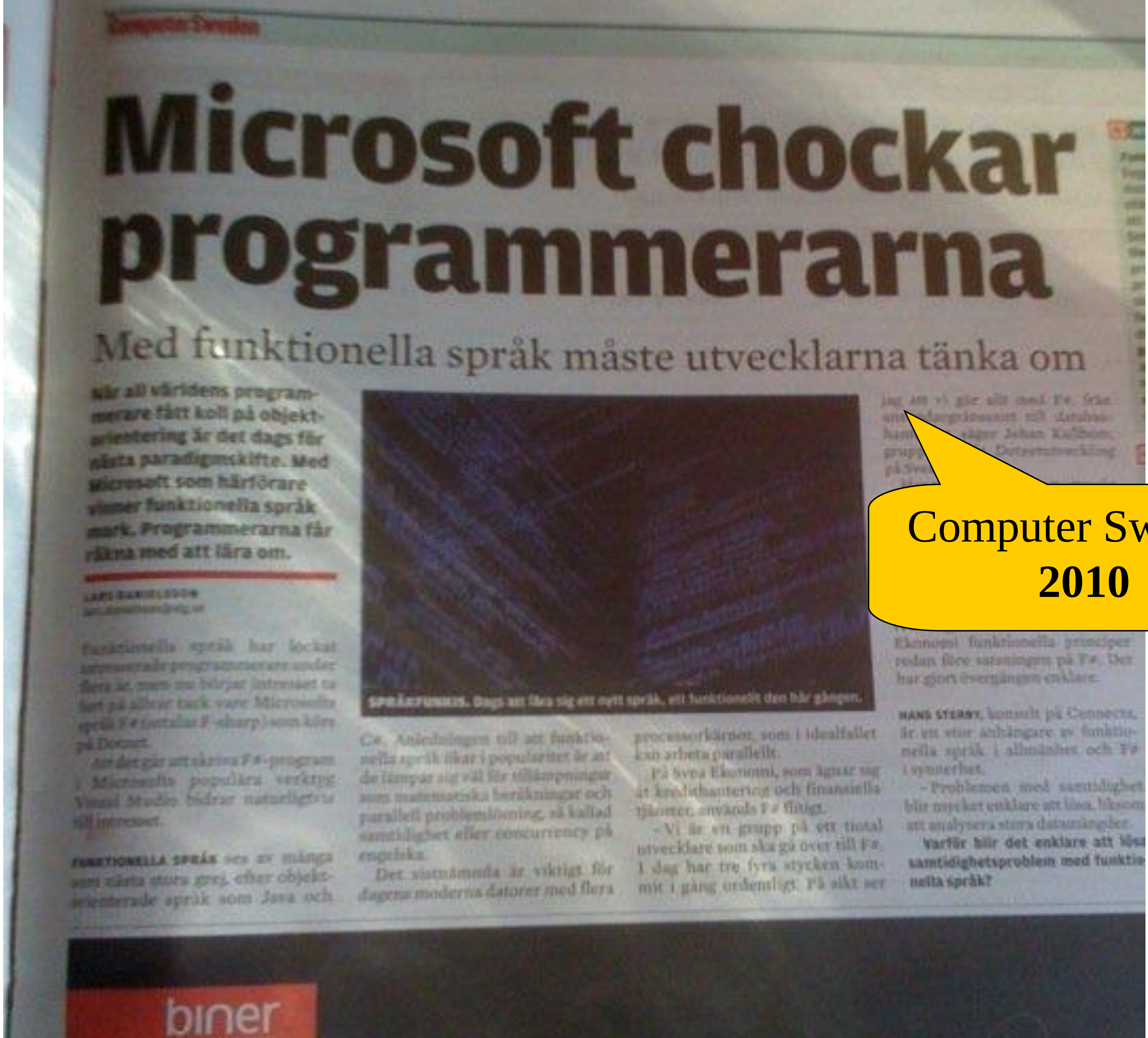
Motorola (test generation)

Thompson (radar tracking)

Microsoft (F#)

Jasper (hardware verification)

**And many more!**



Computer Sweden

# Microsoft chockar programmerarna

## Med funktionella språk måste utvecklarna tänka om

**När all världens programmerare fått koll på objektorientering är det dags för nästa paradigmskifte. Med Microsoft som härförare vinner funktionella språk mark. Programmerarna får räkna med att lära om.**

LARS DANIELSSON
[illegible]

Funktionella språk har lockat intresserade programmerare under flera år, men nu börjar intresset ta fart på allvar tack vare Microsofts språk *F#* (uttalas *F-sharp*) som körs på Dotnet.

Att det går att skriva *F#*-program i Microsofts populära verktyg Visual Studio bidrar naturligtvis till intresset.

**FUNKTIONELLA SPRÅK** ses av många som nästa stora grej, efter objektorienterade språk som Java och C#. Anledningen till att funktionella språk ökar i popularitet är att de lämpar sig väl för tillämpningar som matematiska beräkningar och parallell problemlösning, så kallad samtidighet eller concurrency på engelska.

Det sistnämnda är viktigt för dagens moderna datorer med flera processorkärnor, som i idealfallet kan arbeta parallellt.

På Svea Ekonomi, som ägnar sig åt kredithantering och finansiella tjänster, används F# flitigt.

– Vi är en grupp på ett tiotal utvecklare som ska gå över till F#. I dag har tre fyra stycken kommit i gång ordentligt. På sikt ser jag att vi gör allt med F#, från användargränssnitt till databashantering, säger Johan Kullbom, gruppchef [illegible] Dotnetutveckling på Sve[illegible]

[illegible]

Ekonomi funktionella principer redan före satsningen på F#. Det har gjort övergången enklare.

**HANS STERBY,** konsult på Connecta, är en stor anhängare av funktionella språk i allmänhet och F# i synnerhet.

– Problemen med samtidighet blir mycket enklare att lösa, liksom att analysera stora datamängder.

**Varför blir det enklare att lösa samtidighetsproblem med funktionella språk?**

**SPRÅKFUNKIS.** Dags att lära sig ett nytt språk, ett funktionellt den här gången.

biner

Computer Sweden,
**2010**

# Keynotes at Developer Conferences

Don Syme

Simon Peyton Jones

*John Hughes*

- Eclipse Summit Europé 2009
  - *Taking Functional Programming into the Mainstream*
- YOW! 2011, Australia
  - *Escape From the Ivory Tower: The Haskell Journey*
- Qcon 2012, San Francisco
  - *Testing the Hard Stuff and Staying Sane*

## Why Haskell?

•Haskell is a very *high-level language* (many details taken care of automatically).

•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 **not** a particularly high-performance language (prioritise programmer-time over computer-time).

## Cases and Recursion

# Example: The squaring function

- Example: a function to 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 nu

Programs must often choose between alternatives

- 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 = 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,* ¸

## 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
```

## Example: Computing Powers

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

# Example: Computing Powers

- 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 = $\underbrace{x * \ldots * x}_{\text{n times}}$

# A Table of Powers

| n | power x n |
|---|---|
| 0 | 1 |
| 1 | x |
| 2 | x*x |
| 3 | x*x*x |

- Each row is x* the previous one
- Define power x n to compute the nth 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

First row of the table

## A Definition?

```
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

## Recursion

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# 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 * 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!

# Replication

- Replicate a given word n times

```
repli :: Integer -> String -> String
repli ...
```

```
GHCi> repli 3 “apa”
“apaapaapa”
```

# An Answer

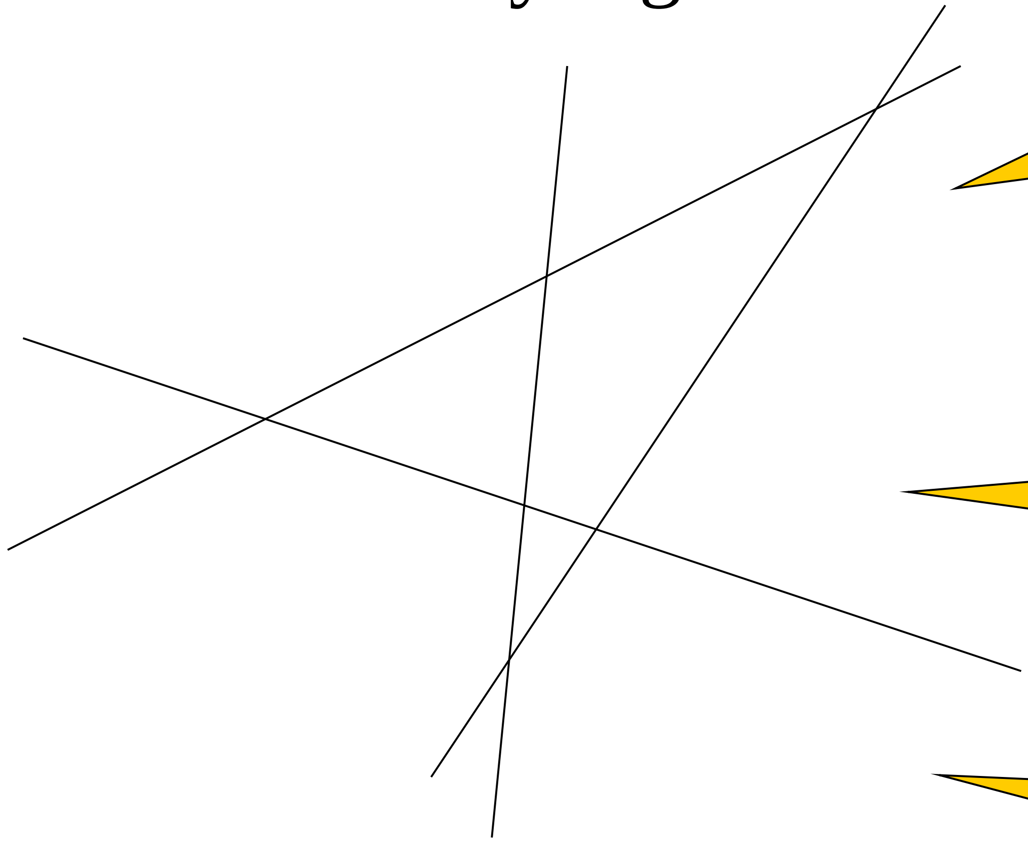
```
repli :: Integer -> String -> String
repli 1 s           = s
repli n s | n > 1 = s ++ repli (n-1) s
```

```
repli :: Integer -> String -> String
repli 0 s           = “”
repli n s | n > 0 = s ++ repli (n-1) s
```

make base case as simple as possible!

# Counting the regions

- n lines. How many regions?



remove one line ...

problem is easier!

when do we stop?

## 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 pick the base case as simple as possible!

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

# Group

- Divide up a string into groups of length n

```
group :: ...
group n s = ...
```

*LIVE CODING!!!*

## Types

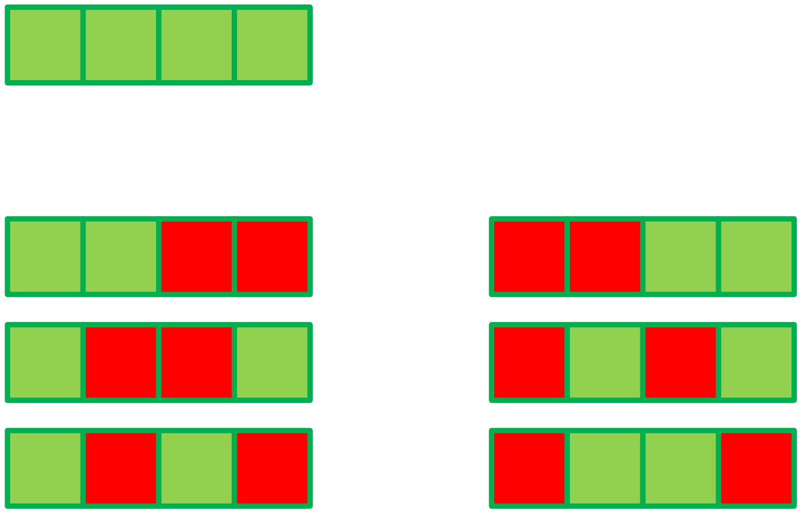
- What are the types of repli and group?

```
repli :: Integer -> String -> String
group :: Integer -> String -> [String]
```

```
repli :: Integer -> [a] -> [a]
group :: Integer -> [a] -> [[a]]
```

## How many ways are there to choose *k* of *n* elements?

- *e.g.*



2 of 4?

6!

*LIVE CODING!!!*

## There is no book!

If you want a book anyway, try:

*The Craft of Functional Programming*, by Simon Thompson. Available at Cremona.

# Course Web Pages

Updated almost daily!

**URL:**

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

- These slides
- Schedule
- Practical information
- Assignments
- Discussion board