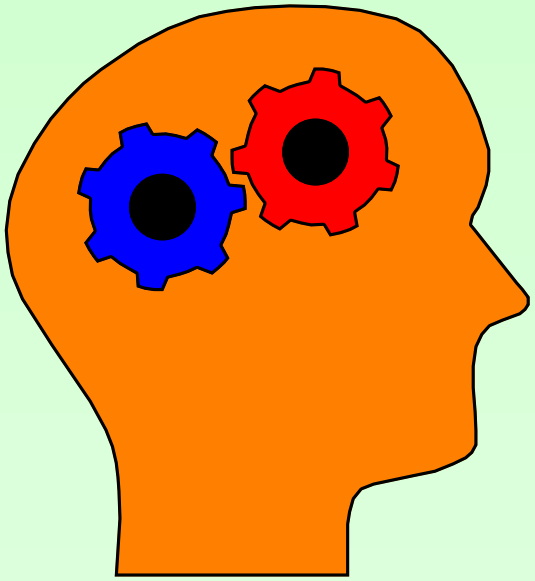
CS2104: Programming Languages Concepts

Lecture 1 : **Overview**



"Language Concepts to Support Programming and Abstraction"

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Course Objectives

- cover key concepts in programming languages
- knowledge of language paradigms
- support for software *abstraction*, *reuse* and *safety*
- improving your programming skills
- make learning a new programming language easier
- highlight successful/advanced languages

Course Outline

- Lecture Topics (12 weeks)
  - Key programming concepts (C, Java, Haskell, OCaml)
  - Values, Types, Functions and Recursion (Haskell)
  - Higher-Order Programming+ Lambda Calculus
  - Type Classes, Monads and Parser Generators (Haskell)
  - Imperative Programming Concepts (with OCaml)
  - OOP Concepts (with Java + Scala)
  - Dynamic Languages (with Python)
  - Logic Programmg (with Prolog)
  - Constraint Programming (with CLP)

Administrative Matters

- IVLE for forum/lecture notes/exercises/submissions

- 2-hour Tutorial/Labs
  - (i) tutorial questions
  - (ii) lab exercises (5 assignments)

- course CA/exams breakdown

- tutorial participation	5%
- lab/project assignments	35%
- term test	15%
- final examination	45%

Online ReadingTextbooks

- lecture slides/notes via IVLE

- Reading Materials (mostly online):

  ocaml.org
  caml.inria.fr
  www.haskell.org
  www.python.org
  www.scala-lang.org
  www.swi-prolog.org
  Free PL books :
  http://www.freebookcentre.net/Language/langCategory.html
  http://www.e-booksdirectory.com/programming.php

Optional Textbooks

- Concepts of Programming Languages
  Robert W Sebesta

- Concepts in Programming Languages
  John W Mitchell

- Concepts, Techniques and Models of Computer Programming
  Peter Van Roy and Self Haridi (NUS online library)

Lab Assignment/Homework

- Lab assignments in different successful and advanced languages (OCaml, **Scala**, Haskell, Prolog, Python).
- Reinforce concepts taught in class.
- Programming is a skill. It requires lots of practice.
- Pre-requisite to passing course
  Do Homework seriously → Pass Course

Why Study Concepts of PLs?

- Inside any successful software system is a good PL

  Emacs : *Elisp*

  Word, PPT : *VBScript*

  Quake : *QuakeC*

  Facebook : *FBML, FBJS, Hack (in HHVM)*

  Twitter : *Ruby on Rails/Scala*

  Also: *Latex, XML, SQL, PS/PDF*

Benefits of Good PL Features

- Readability
- Extensibility.
- Modifiability.
- Reusability.
- Correctness.
- Easy Debugging

What Drives the Development of PL?

- Novel ways of expressing computation
- Better execution model (e.g. dataflow)
- Tackle complex problems (with simpler solution)
- Proof of Concept
- Puristic viewpoint
- Better Reliability
- Domain-Specificity

History of Programming Languages

- Assembly (early 1950s)
- Fortran (late 1950s)
- Lisp (1958)
- Algol (1960s)
- Cobol (1960s)
- Prolog (1972)
- C (1973 – birth of Unix)
- Ada (1970s – defense)
- SQL (late 1970s)
- C++ (1985)
- ML (1980), OCaml (early 1990), Haskell (1987)
- Java (1995)
- Perl, Python, Javascript,PHP, VB (1990s)
- Scala (first released in 2003)
- C# (2000)
- Go (2009)

Lambda Calculus (1930s)

Programming Paradigms

- Imperative Programming
- *Functional Programming*
- Logic Programming
- Object-Oriented Programming
- Constraint Programming
- Event-Driven Programming (not covered)
- Aspect-Oriented Programming (not covered)

Future of Programming?

What's the future of programming? The answer lies in functional languages

By Nick Heath in Software on October 23, 2017, 3:35 AM PST

Simon Peyton Jones describes functional programming languages like Haskell as a proving ground where programmers can test new ideas.

https://www.techrepublic.com/article/whats-the-future-of-programming-the-answer-lies-in-functional-languages/

Advanced Language - Haskell

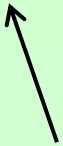
- Strongly-typed with polymorphism
- Higher-order functions
- Pure and Lazy Language.
- Algebraic data types + records
- Exceptions
- Type classes, Monads, Arrows, etc
- Advantages : concise, abstract, pure

- Why use Haskell ?

Cool, clean and Pure

Hello World in Haskell

```
putStrLn "Hello World!"
```



pure function with type `[Char] -> IO()`

Compilation:

```
ghc -o hello hello.hs
```

Execution:

```
./hello
```

Increment Method (in Haskell)

```
inc :: Int -> Int
inc x = x+1
```

```
\ x -> x+1
```

```
(+1)
```

Example - Haskell Program

- Finite and infinite lists.

a type variable

```
data List a = Nil | Cons a (List a)
```

```
finite_list  = Cons 1 (Cons 2 (Cons 3 Nil))
```

finite list of three elements

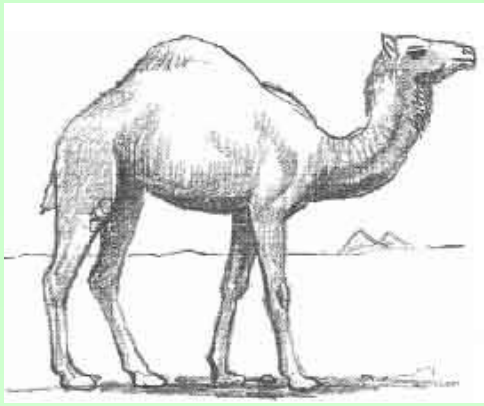
```
infint n = Cons n (infint (n+1))
```

infinite list starting from [n,n+1,n+2,...]

Type System – Lightweight Analysis

- Abstract description of code + genericity
- Compile-time analysis that is tractable
- Guarantees absence of some bad behaviors
- Issues – expressivity, soundness, completeness, inference?
- How to use type system to figure errors.
- Why? **detect bugs early**

Versatile Language - OCaml



- Rich data structures (algebraic data types, records, polymorphism, variants, GADT).
- Typeful higher-order functional and object-oriented language.
- Support for stateful imperative programming.
- Powerful module system.
- Advantages : versatile, abstract, easy reuse
- Why OCaml?

Powerful, Versatile and Practical

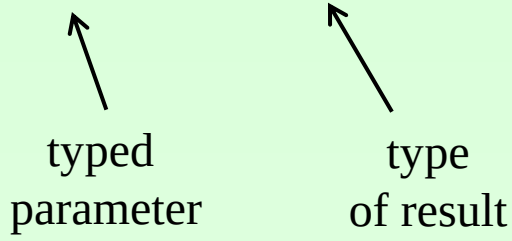
Examples (OCaml)

- Hello World

```
print_endline "Hello, World!"
```

- Increment method:

```
   fun x -> x+1 end
or
   let inc x = x+1
or
   let inc (x:int) : int = x+1
```



Example – OCaml Program

- Tree Data Structure.

generic tree with type variable ‘a

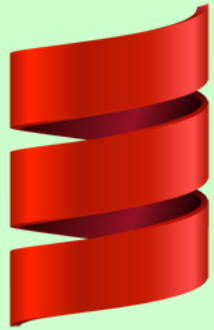
```
type 'a tree = Empty | Node of (`a * 'a tree * 'a tree)
```

type inferred : (‘a tree) → int

```
let rec height t =
   match t with
    | Empty -> 0
    | Node(val,lt,rt) -> 1+max(height lt,height rt)
```

Pattern Matching

Scala Programming Language



- stands for "scalable language" – building from reuseable components
- multi-paradigm language
- runs on standard Java and .NET platforms
- interoperates with all Java libraries
- Why study Scala?

concise, Java-compliant

Hello World in Scala

```
object HelloWorld extends App {
  println("Hello, World!")
}
```

Compilation:

```
scalac HelloWorld.scala
```

Execution:

```
scala HelloWorld
```

Increment Method

```
object XXX extends App {
  def inc (x:int) : int = x+1
}
```

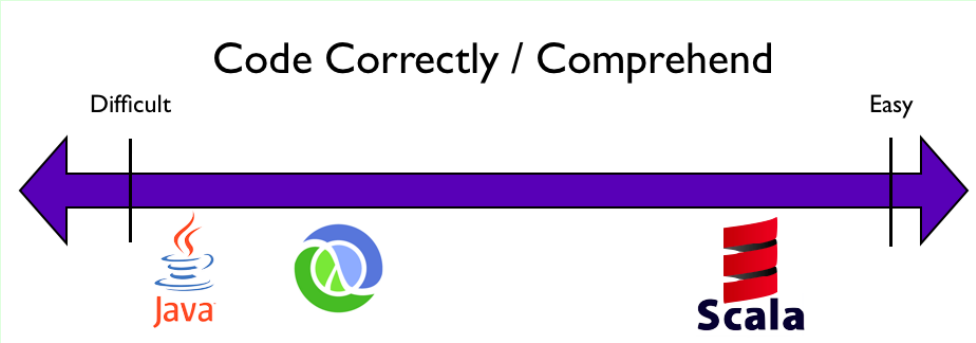

```
(x:Int) => x+1
```

```
new Function1[Int, Int] {
    def apply(x: Int): Int = x + 1
}
```

Scala Classes

- Support Java-style classes with Class Parameters, Explicit Overriding + Dynamic Dispatches only

```
class Point(xc: Int, yc: Int) {
  var x: Int = xc
  var y: Int = yc
  def move(dx: Int, dy: Int) {
    x = x + dx
    y = y + dy
  }
  override def toString(): String
       = "(" + x + ", " + y + ")";
}
```



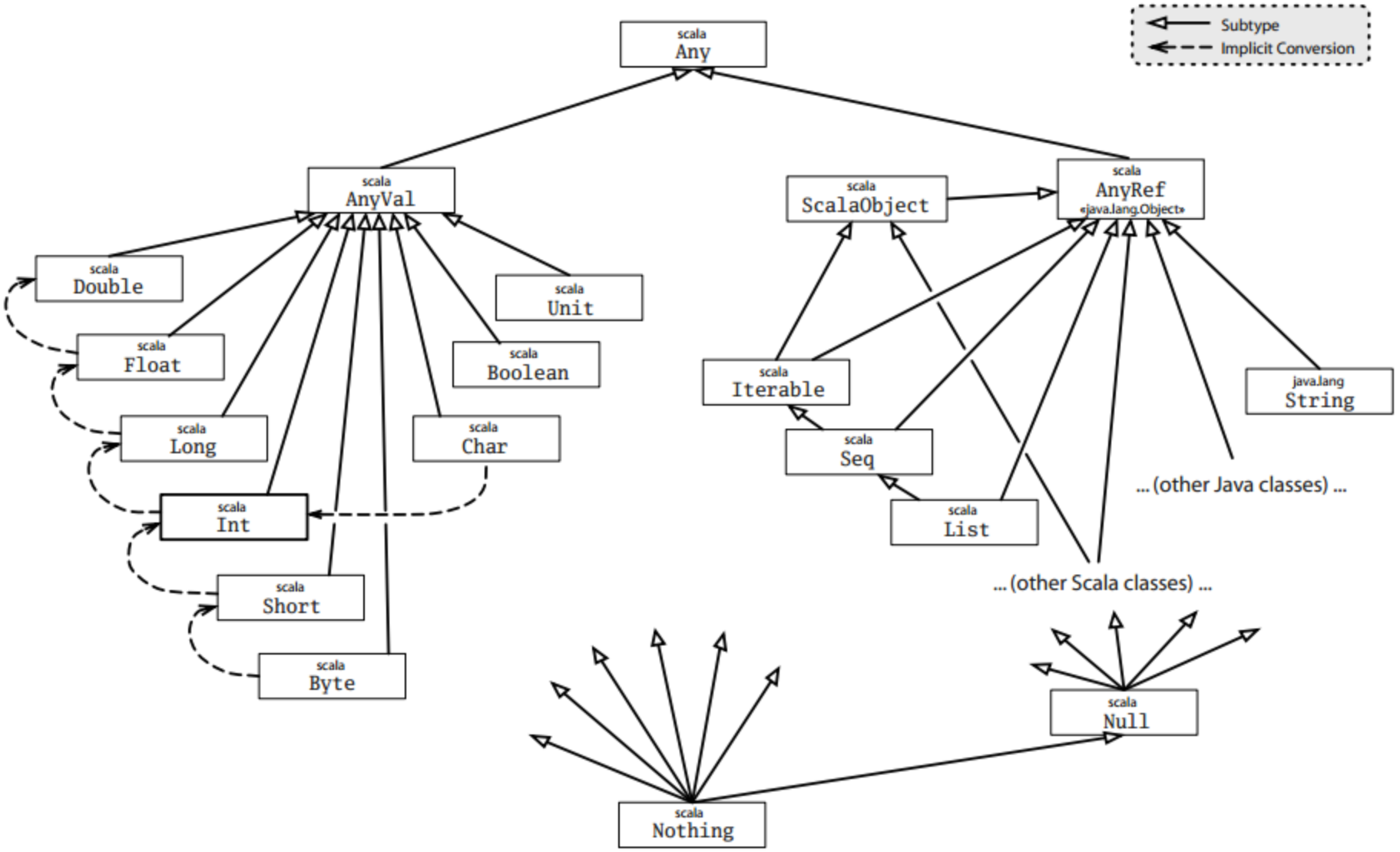
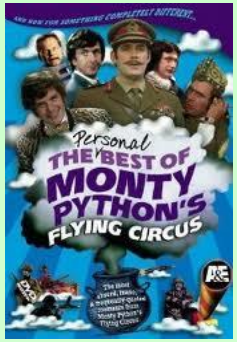


Figure 11.1 · Class hierarchy of Scala.

Python Language



- powerful dynamic programming language
- clear readable syntax (indentation and off-side rule)
- Strong introspection capability
- high-level dynamic types
- excellent "battery-included" libraries
- Why study Python?

fast, nimble
good for scripting

Python Example

Hello World:

```
print `Hello, World!'
```

Increment method:

```
def inc(x):
      return x+1
```

Python Example

A List of Things:

```
lst = ['hello','there',42,0.2]

n = len(lst)  # find length

if n<=0:
   print 'empty list'
elif x=1:
   print 'singleton'
else:
   print 'crowded list'
```

Repeating a list thrice:

```
lstlst = lst * 3
```

Prolog

- one of first language based on first-order logic
- it is used to define “relations” and relies on unification for execution
- Popular in AI and database applications (via datalog)
- Why study Prolog?

relations, logic and unification

Prolog Example

Hello World:

```
main :- write('Hello, World!'),nl.
```

Increment method:

```
inc(X,Res):- Res is X+1.
```

A Prolog Example

Facts (e.g. database):

```
parentOf(tom, sally).
parentOf(tony, ale).
parentOf(tony, alfred).
```

Derived Relations (e.g. query):

```
sibling(X,Y) :- parentOf(Z,X), parentOf(Z,Y)
grandparent(X,Y) :- parentOf(X,Z), parentOf(Z,Y).
grandfather(X,Y) :- male(X), grandparent(X,Y).
```

How to Pass CS2104

Expressible in Prolog:

```
pass2104(X):-
        attend_lecture(X,2104),
        attend_tutorial(X,2104),
        do_assignment(X,2104),
        attempt_exam(X,2104).
```

Untyped Lambda Calculus

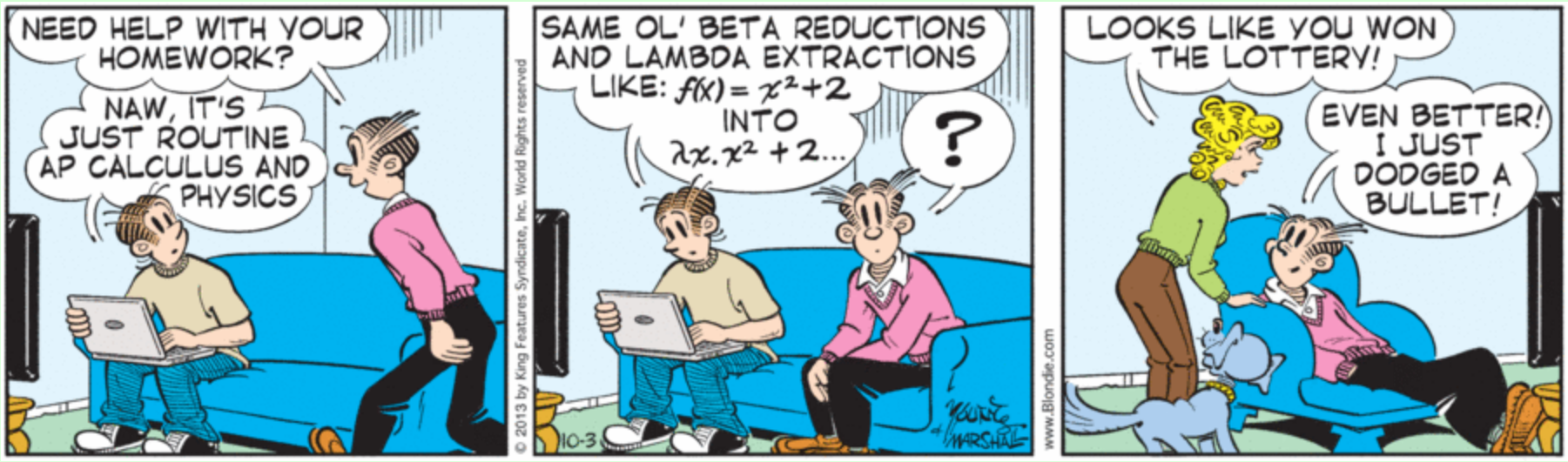
- Extremely simple programming language which captures *core* aspects of computation and yet allows programs to be treated as mathematical objects.
- Focused on *functions* and applications.
- Invented by Alonzo (1936,1941), used in programming (Lisp – 2nd oldest language) by John McCarthy (1959).
- Why is it significant?

Basis of Computability

Increment Method

With integer primitive, increment method can be written as:

$f\ x = x+1$ ➔ $(\lambda\ x\ .\ x+1)$



Syntax

In purest form (no constraints, no built-in operations), the lambda calculus has the following syntax.

t ::=		terms
	x	variable
	λ x . t	abstraction
	t t	application

This is simplest universal programming language!

Program vs Values

- Programs –expressions of lambda calculus
- Values – final irreducible expression.

Computation:

Examples of Lambda Expressions

- Function with one parameter:

  $\lambda\ x\ .\ x$
- Function with two parameters:

  $\lambda\ x\ y\ .\ x$
- Function that returns a function:

  $\lambda\ x\ .\ (\lambda\ y\ .\ x)$
- Function application/call:

  $(\lambda\ x.\ x)\ y \rightarrow y$

How Expressible is Lambda Calculus?

- Very expressive!
  - *Boolean*
  - Integer
  - Functions
  - Recursion
  - Data structures
  - Loops!
  - It is Turing-complete

Non-terminating Loop

$(\lambda\ x.\ x\ x)\ (\lambda\ x.\ x\ x)$

$\rightarrow (\lambda\ x.\ x\ x)\ (\lambda\ x.\ x\ x)$

$\rightarrow (\lambda\ x.\ x\ x)\ (\lambda\ x.\ x\ x)$

$\rightarrow \ldots$

$\rightarrow (\lambda\ x.\ x\ x)\ (\lambda\ x.\ x\ x)$

$\rightarrow \ldots$