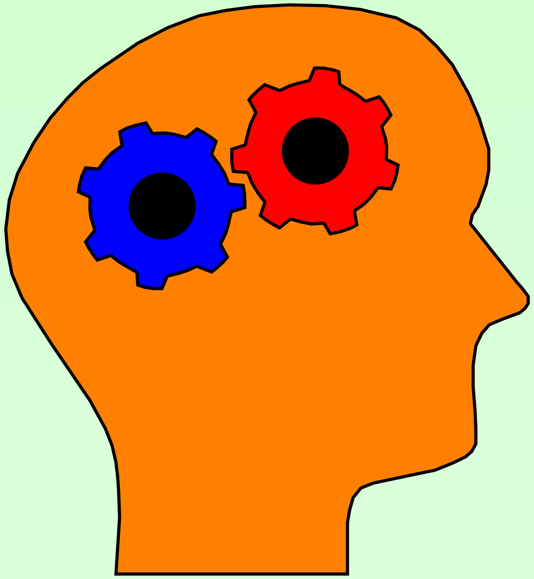
CS2104: Programming Languages Concepts

Lecture 2 : **Functions, Binders and Layout Rule**



"FP, Binders and Layout Mechanism with Haskell"

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Topics

- Declarative Programming Concepts
- Writing Functions
- Local Bindings
- Typeful Programming

Advanced Language - Haskell

Haskell

A Purely Functional Language

featuring static typing, higher-order functions, polymorphism, type classes and monadic effects

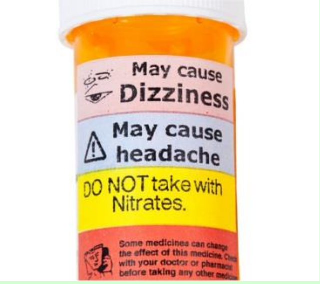
- Strongly-typed with polymorphism
- Higher-order functions
- Pure and Lazy Language.
- Algebraic data types + records
- Exceptions
- Type classes, Monads, Arrows, etc
- Advantages : concise, abstract, pure

- Why use Haskell ?

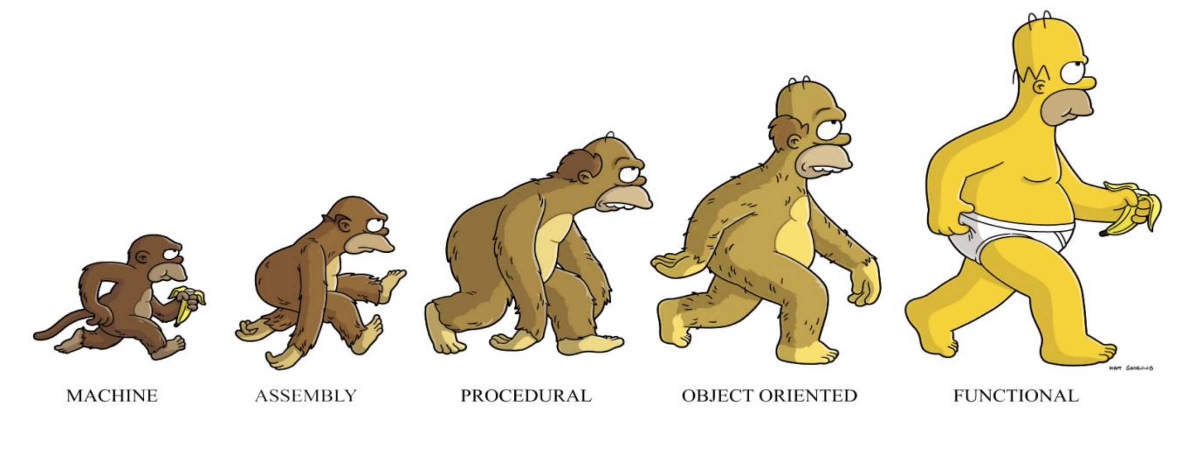
Cool, clean and Pure

What is Purely Functional?

No updates and side-effects.



Easier debugging and better abstraction



Declarative Programming Model Philosophy

- Ideal of declarative programming
  - say **what** you want to compute
  - let computer find **how** to compute it
- More pragmatically
  - let the computer provide more support
  - free the programmer from some burden

Properties of Declarative Models

- Focus on <u>functions</u> (or relation) which compute when given some data structures as inputs
- Widely used
  - functional languages: LISP, Scheme, ML, Haskell, …
  - logic languages: Prolog, Mercury, …
  - representation languages: XML, XSL, …
- Stateless programming
  - no update of data structures
  - Simple data transformer

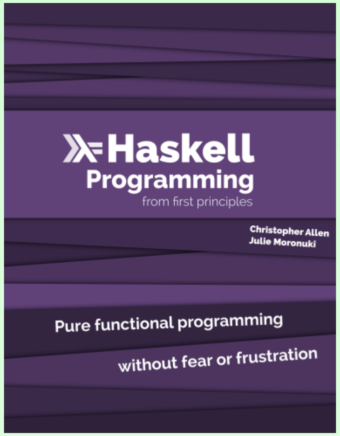
Pure Functions

- Pure functions are *mathematical* functions whose outputs depend and solely on its inputs.

- Declarative Haskell
  - One of the purest language.
  - data structures is immutable and moreover is lazy by default.

Reference

- Haskell home-page
  www.haskell.org/documentation
- A fast Haskell tutorial
  https://www.schoolofhaskell.com/school/starting-with-haskell/haskell-fast-hard
- A gentle and comprehensive Haskell book at haskellbook.com



Two Basic PL Concepts

- Writing Functions
- Local Bindings

Example - Haskell Program

- Computing Factorial.

-- written using conditional construct

```
fact :: Int -> Int
fact n = if n==0 then 1
         else n * (fact (n-1))
```

-- written using pattern-matching

```
fact1 :: Int -> Int
fact1 0 = 1
fact1 n = n * fact1 (n-1)
```

```
-- Int denotes bounded integer (with possible overflow)
*Main> fact 20
2432902008176640000
*Main> fact 30
-8764578968847253504
```

Example - Haskell Program

- Factorial with Infinite Precision

-- Integer denotes integer of arbitrary precision

```
fact2 :: Integer -> Integer
fact2 0 = 1
fact2 n = n * fact2(n-1)
```

-- No more overflows

```
*Main> fact2 20
2432902008176640000
*Main> fact2 30
265252859812191058636308480000000
*Main> fact2 40
815915283247897734345611269596115894272000000000
```

Example - Haskell Program

- Mixed Precision

```
fact3 :: Int -> Integer
fact3 0 = 1
fact3 n = n * fact3(n-1)
```

-- However, we get a type error. Why?

```
lec1.hs:16:11:
    Couldn't match expected type `Integer' with actual type `Int'
    In the first argument of `(*)', namely `n'
    In the expression: n * fact3 (n - 1)
    In an equation for `fact3': fact3 n = n * fact3 (n - 1)
```

Example - Haskell Program

- Fix problem using type conversion

```
-- fromIntegral :: Int -> Integer

fact3 :: Int -> Integer
fact3 0 = 1
fact3 n = (fromIntegral n) * fact2(n-1)
```

-- Type in Haskell is actually much more general …more details later.

```
*Main> :t fromIntegral
fromIntegral :: (Integral a, Num b) => a -> b
```

-- For example, can also convert to floating point numbers …

```
*Main> (fact 20)
2432902008176640000
*Main> (fromIntegral (fact 20))::Double
2.43290200817664e18
```

Example - Haskell Program

- Finite and infinite lists.

a type variable

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

finite_list :: List Int
finite_list  = Cons 1 (Cons 2 (Cons 3 Nil))
```

finite list of three elements

```
infint :: Int -> List Int
infint n = Cons n (infint (n+1))
```

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

Local Binding

- Binders are a special class of constructs which declare new identifiers and their possible values.
- Each binder has some lexical scope where the identifier is visible.
- Values of the binders may be either *immutable* or *mutable*.
- Examples of name binders
  - Local declarations
  - Method declaration (parameters)
  - Pattern-Matching

Local Binder in Haskell

- Local variable binders in Haskell are immutable

```
let x = 3::Integer
in x*2
```

- where x is a local immutable variable denoting a value with a fixed scope.

- In general:

```
let v = e1
in e2
```

For Haskell, scope of **`v`** is in both **`e1`** and **`e2`**.

Local Binder in Haskell

- Let binding in Haskell is recursive

```
let x = 1:x in
in x
```

which is an infinite list of `[1,1,1,1,..]`

- Can write recursive function:

```
let f = \ n ->
 if n==0 then 1
 else n * (f (n-1))
in f
```

- Be careful to avoid infinite loop:

```
let x = 1+x
in x*2
```

Local Binder in OCaml

- Let binder in OCaml is non-recursive by default

```
let x = 1
 in let x = x+2
    in x
```

  which will return 3.

- For OCaml:

```
let v = e1
in e2
```

  The scope of **`v`** is only in **`e2`**.

- Recursive let requires an extra keyword :

```
let rec v = e1
in e2
```

  The scope of **`v`** is now in both **`e1`** and **`e2`**.

Local Binder in C

- Local binder in C is *mutable* and *non-recursive*

scope of local variable

```
{ …;
 <type> <id>;
 …
}
```

- Declare variable without a value. Assign variable to a new value with the assignment statement.

```
{ …;
 int x;
 x = 1;
 x = x + 3
 …
}
```

- Here, red `x` denotes previous value of `x`

Binders (in C)

- Block Declaration

names

```
{ …;
  <type> <id>;
  …
}
```

scope of
local variable

- Method Declaration

```
<type> <id>((<type> <id>)*)
  {
        …
  }
```

scope of
parameters

Typeful Programming in Haskell

- Every expression has a type.
- We use ascription `(e::t)` to force an expression `e` to have a given type `t`

```
let x = 3::Integer

let y = [1,2,3,4]::[Int]

let t = ("Tom", 2, 4.5)
 -- type of t above will be inferred
 -- as ([Char],Integer,Double)
```

Typing Comparison

- Typeful programming also in OCaml which has both object and module types, but lack type classes mechanism of Haskell.
- Both type inference and type checking possible.
- Weak typing in C with unsafe casting.
- Dynamic typing in Javascript and Python

Functions

- Functions are also values

```
let add x y = x + y
    double x = (add x x)
    quad x = (double x)+(double x)
```

- Layout rule supports multiple and recursive declarations
- Declarations may be nested:

```
let quad x =
      let add x y = x + y
          double x = add x x
      in (double x)+(double x)
```

Here, `add` and `double` are local functions, while `quad` is a global declaration.

Layout Rule

- Haskell uses two dimensional syntax to help reduce syntactic separators where declarations are "aligned"

```
let  y     = a+b
     f x   = (x+y)/y
in f c + f d
```

is being parsed as:

```
let  { y   = a+b
     ; f x = (x+y)/y }
in f c + f d
```

- Rule : Next character after keywords `where`/`let`/`of`/`do` determines the starting columns for declarations. Starting *after* this point continues a declaration, while starting *before* this point terminates a declaration.

- See https://en.wikibooks.org/wiki/Haskell/Indentation

Recursive Functions in Haskell

- Declarations are mutual recursive by default.

```
let fact n =
     if n=1 then 1
     else n * fact(n-1)
```

- Mutual-recursive functions can be defined and are aligned based on the layout rule

```
let foo n =
      if n<=1 then 1
      else foo(n-1) + goo(n-2)
    goo n =
      if n<=1 then 1
      else goo(n-1) + foo(n-2)
```

alignment

- Note that **`goo n-1`** is parsed as **`(goo n)-1`**

Recursive Methods in OCaml

- Declarations are *non-recursive* by default. Add `rec` keyword to capture recursive declaration.

```
let rec fact n =
     if n=1 then 1
     else n * fact(n-1);;
```

- Mutual-recursive functions can be defined simultaneously with the help of the `and` keyword

```
let rec foo n =
  if n<=1 then 1
  else foo(n-1) + goo(n-2)

and goo n =
  if n<=1 then 1
  else goo(n-1) + foo(n-2);;
```

- Note that `goo n-1` is parsed as `(goo n)-1`