Functional Programming
Lecture 8: Introduction to Haskell

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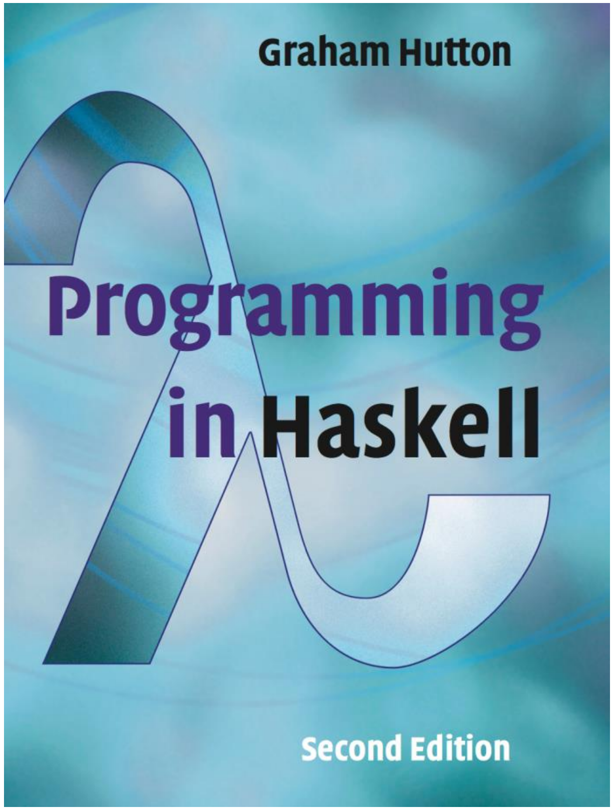
Slides for next few lectures based on slides for the book:



Brief History

- Lambda calculus (1930s)
  - formal theory of computation older than TM
- Lisp = List processor (1950s)
  - early practical programming language
  - second oldest higher level language after Fortran
- ML = Meta language (1970s)
  - Lisp with types, used in compilers
- Haskell = first name of Curry (1990s)
  - standard for functional programming research
- Python, Scala, Java8, C++ 11, ….

Why Haskell?

- Purely functional language
  – promotes understanding the paradigm
- Rich syntactic sugar (contrast to Lisp)
- Most popular functional language
- Fast prototyping of complex systems
- Active user community
  – Haskell platform, packages, search

Main properties

- Purely functional
  - besides necessary exceptions (IO)
- Statically typed
  - types are derived and checked at compile time
  - types can be automatically inferred
- Lazy
  - function argument evaluated only when needed
  - almost everything is initially a thunk

Haskell standard

Haskell is a standardization of ideas in over a dozen of pre-existing lazy functional languages

- Haskell 98
  - first stable standard
- Haskell 2000
  - minor changes based on existing implementations
    - integration with other programming languages
    - hierarchical module names
    - pattern guards

Haskell implementations

- Glasgow Haskell Compiler (GHC)
  - the leading implementation of Haskell
  - comprises a compiler and interpreter
  - written in Haskell
  - is freely available from: www.haskell.org/platform
- Haskell User´s Gofer System (Hugs)
  - small and portable interpreter
  - Windows version with simple GUI called WinHugs
  - unmaintained

Starting GHCi

The interpreter can be started from the terminal command prompt $ by simply typing ghci:

```
$ ghci

GHCi, version X: http://www.haskell.org/ghc/  :? for help

Prelude>
```

The GHCi prompt > means that the interpreter is now ready to evaluate an expression.

Basic interaction

- REPL interaction as in scheme
- Common infix syntax
- Space denotes function application
- Infix operators have priorities
  - function application is first
  - otherwise use brackets
- Left associativity (as in lambda calculus)
- Up arrow recalls the last entered expression

Lists

The basic data structure

- [1,2,3,4,5]
- [1..]
- [1,3,…]

Build by "cons" operator : , ended by the empty list []

Includes all basic functions

- take, length, reverse, ++, head, tail

In addition, you can index by !!

Special commands

Commands to the interpreter start with ":"

- :? for help
- :load <module>
- :reload
- :quit

Can be abbreviated to the first letter

Haskell scripts

- New functions are defined within a script
  - text file comprising a sequence of definitions
- Haskell scripts usually have a .hs suffix
- Can by loaded by
  - ghci <filename>
  - :load <filename>

Defining functions

```
fact1 1 = 1
fact1 n = n * fact1 (n-1)

fact2 n = product [1..n]

power n 0 = 1
power n k = n * power n (k-1)
```

Comments

```
-- Comment until the end of the line

{-
    A long comment
    over multiple
    lines.
-}
```

Naming requirements

Function and argument names must begin with a lower-case letter. For example:

`myFun`   `fun1`   `arg_2`   `x'`

By convention, list arguments usually have an <u>s</u> suffix on their name. For example:

`xs`   `ns`   `nss`

Pattern matching

The first LHS that matches the function call is executed

```
not False = True
not True  = False
```

not maps False to True, and True to False.

Pattern matching

Functions can often be defined in many different ways using pattern matching. For example

```
True  && True  = True
True  && False = False
False && True  = False
False && False = False
```

The underscore symbol _ is a <u>wildcard</u> pattern that matches any argument value.

Pattern matching

Function and can be defined more compactly by

```
and True True = True
and _    _    = False
```

The following definition is more efficient, it avoids evaluating the second argument if the first is False:

```
and True  b = b
and False _ = False
```

Pattern matching

The order of the definitions matters

```
_    && _    = False
True && True = True
```

Patterns may not <u>repeat</u> variables. For example, the following definition gives an error:

```
b && b = b
_ && _ = False
```

List patterns

Functions on lists can be defined using x:xs patterns

```
head (x:_) = x

tail (_:xs) = xs
```

It works similarly for other composite data types

List patterns

x:xs patterns only match <u>non-empty</u> lists:

```
> head []
*** Exception: empty list
```

x:xs patterns must be <u>parenthesised</u>, because application has priority over (:). For example, the following definition gives an error:

```
head x:_ = x
```

Tuples

(1,2)

('a','b')

(1,2,'c',False)

Accessing the elements using pattern matching

```
first (x,_) = x
second (_,y) = y
```

Let / where

```
dist1 (x1,y1) (x2,y2) =
        let d1 = x1-x2
            d2 = y1-y2
        in sqrt(d1^2+d2^2)

dist2 (x1,y1) (x2,y2) = sqrt(d1^2+d2^2)
  where d1 = x1-x2
        d2 = y1-y2
```

The layout rule

In a sequence of definitions, each definition must begin in precisely the same column:

```
a = 10

b = 20

c = 30
```

✓

```
a = 10

 b = 20

c = 30
```

✗

```
 a = 10

b = 20

 c = 30
```

✗

The layout rule

The layout rule avoids the need for explicit syntax to indicate the grouping of definitions.

```
a = b + c
    where
      b = 1
      c = 2
d = a * 2
```

means ⇒

```
a = b + c
    where
      {b = 1;
       c = 2}
 d = a * 2
```

implicit grouping

explicit grouping

The layout rule

Keywords (such as where, let, etc.) start a block

- The first word after the keyword defines the pivot column.
- Lines exactly on the pivot define a new entry in the block.
- Start a line after the pivot to continue an entry from the previous lines.
- Start a line before the pivot to end the block.

Conditional expressions

As in most programming languages, functions can be defined using conditional expressions.

```
abs n = if n ≥ 0 then n else -n
```

Conditional expressions can be nested:

```
signum n = if n < 0 then -1 else
                  if n == 0 then 0 else 1
```

If must always have an else branch

Guarded equations

As an alternative to conditionals, functions can also be defined using <u>guarded equations</u>.

```
abs n | n ≥ 0     = n
      | otherwise = -n
```

Definitions with multiple conditions are easier to read:

```
signum n | n < 0     = -1
         | n == 0    = 0
         | otherwise = 1
```

<u>otherwise</u> is defined in the prelude by otherwise = True

Set comprehensions

In mathematics, the comprehension notation can be used to construct new sets from old sets.

$$\{x^2 \mid x \in \{1...5\}\}$$

The set {1,4,9,16,25} of all numbers x^2 such that x is an element of the set {1...5}.

List comprehensions

In Haskell, a similar comprehension notation can be used to construct new lists from old lists.

```
[x^2 | x ← [1..5]]
```

x ← [1..5] is called a generator

Comprehensions can have multiple generators

```
> [(x,y) | x ← [1,2,3], y ← [4,5]]

[(1,4),(1,5),(2,4),(2,5),(3,4),(3,5)]
```

Generator order

```
> [(x,y) | y ← [4,5], x ← [1,2,3]]

[(1,4),(2,4),(3,4),(1,5),(2,5),(3,5)]
```

x ⟵ [1,2,3] is the last generator, so the value of the x component of each pair changes most frequently.

Generator order

Changing the order of the generators changes the order of the elements in the final list:

```
> [(x,y) | y ← [4,5], x ← [1,2,3]]

[(1,4),(2,4),(3,4),(1,5),(2,5),(3,5)]
```

Multiple generators are like nested loops, with later generators as more deeply nested loops whose variables change value more frequently.

Dependent generators

Later generators can depend on the variables that are introduced by earlier generators.

```
[(x,y) | x ← [1..3], y ← [x..3]]
```

All pairs (x,y) such that x,y are elements of the list [1..3] and y ≥ x.

Using a dependant generator we can define the library function that concatenates a list of lists:

```
concat xss = [x | xs ← xss, x ← xs]
```

Infinite generators

Generators can be infinite (almost everything is lazy)

```
[x^2 | x ← [1..]]
```

The order then matters even more

```
[x^y | x ← [1..], y ←[1,2]]
```

```
[x^y |  y ←[1,2], x ← [1..]]
```

Guards

List comprehensions can use <u>guards</u> to restrict the values produced by earlier generators.

```
[x | x ← [1..10], even x]
```

The list [2,4,6,8,10] of all numbers x such that x is an element of the list [1..10] and x is even.

Using a guard we can define a function that maps a positive integer to its list of <u>factors</u>:

```
factors n =
   [x | x ← [1..n], mod n x == 0]
```

Example: primes

A prime's only factors are 1 and itself

```
prime n = factors n == [1,n]
```

List of all primes

```
[x | x ← [2..], prime x]
```

Example: quicksort

```
qsort [] = []
qsort (x:xs) = qsort [a | a <- xs, a < x]
               ++ [x] ++
               qsort [a | a <- xs, a >= x]
```

Example: quicksort

```
qsort []     = []
qsort (x:xs) = qsort smalls ++ [x] ++
               qsort larges
           where
             smalls = [a | a ← xs, a ≤ x]
             larges = [b | b ← xs, b > x]
```

Summary

- Haskell is the unified standard for FP
  - purely functional, lazy, statically typed
- It has rich 2D syntax to write compactly
- Functions are defined by pattern matching