Functional Programming

Lecture 10: Other Haskell Language Features

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Example: Arithmetic Expressions

Recursive typed can represent tree structures, such as <u>expressions</u> from numbers, plus, multiplication.

```
data Expr = Val Int
          | Add Expr Expr
          | Mul Expr Expr
```

$$1 + 2 * 3$$

```
Add (Val 1) (Mul (Val 2) (Val 3))
```

Using recursion, it is now easy to define functions that process expressions. For example:

```
size :: Expr → Int
size (Val n)   = 1
size (Add x y) = size x + size y
size (Mul x y) = size x + size y

eval :: Expr → Int
eval (Val n)   = n
eval (Add x y) = eval x + eval y
eval (Mul x y) = eval x * eval y
```

Type Classes

Functions required by a class can be accessed by

:info <classname>

:info Eq -- produces the following

```
class Eq a where
  (==) :: a -> a -> Bool
  (/=) :: a -> a -> Bool
```

Functions can often be implemented based on other

only minimal complete definition is required

(one of the above)

Show Class

A class values convertible to a readable string

```
class Show a where
  showsPrec :: Int -> a -> ShowS
  show :: a -> String
  showList :: [a] -> ShowS
```

```
type ShowS = String -> String
```

This allows constant-time concatenation of results using function composition (optimization)

Minimal complete definition: showsPrec | show

Instance of a Class

A new instance can be added to a class by

```
instance Show Nat where
  show n = "N" ++ show (nat2int n)
```

```
instance Show Expr where
  show (Val n) = show n
  show (Add e1 e2) = "(+ " ++ show e1 ++ " "
                          ++ show e2  ++ ")"
  show (Mul e1 e2) = "(* " ++ show e1 ++ " "
                          ++ show e2  ++ ")"
```

Class Contexts

Remember the definition

```
data Maybe a = Nothing | Just a
```

To make `Maybe` an instance of `Eq`, `a` has to be in `Eq`

```
instance Eq a => Eq (Maybe a) where
    Nothing == Nothing = True
    (Just x) == (Just x') = x == x'
```

Deriving Classes

Obvious definition of instances are automated

```
data Shape = Circle Float
           | Rect Float Float
           deriving (Show, Eq)
```

Defining Classes

The implemented function bodies determine the minimum required functions

```
class Eq a where
    (==) :: a -> a -> Bool
    (/=) :: a -> a -> Bool
    x == y = not (x /= y)
    x /= y = not (x == y)
```

Functor Class

Class of structures you can map over

```
class Mapable f where
    mmap :: (a -> b) -> f a -> f b
```

```
instance Mapable[] where
    mmap = map

instance Mapable Maybe where
    mmap f (Just x) = Just (f x)
    mmap f Nothing = Nothing
```

Kinds

Types of types

- *   A specific type
- * -> *   A type that given a type creates a type
- :k

Types Summary

- Everything has a type known in compile time
  - basic values
  - functions
  - data structures
- Types are key for data structures in Haskell
- Types can be instances of classes
  - polymorphic functions
- "Types" of types are kinds

Higher Order Functions

The same functions as in scheme are available

```
map :: (a → b) → [a] → [b]
```

```
filter :: (a → Bool) → [a] → [a]
```

```
map f xs = [f x | x ← xs]
```

```
filter p xs = [x | x ← xs, p x]
```

Foldr

```
foldr :: (a → b → b) → b → [a] → b
```

```
  sum [1,2,3]
=
  foldr (+) 0 [1,2,3]
=
  foldr (+) 0 (1:(2:(3:[])))
=
  1+(2+(3+0))
=
  6
```

Replace each (:)
by (+) and [] by 0.

Lambda Expressions

Functions can be constructed without naming the functions by using lambda expressions.

$$\boxed{\lambda x \;\rightarrow\; x \;+\; x}$$

The symbol λ is typed as a backslash \.

In mathematics, nameless functions are usually denoted using the $\rightarrow$ symbol, as in $x \rightarrow x + x$.

As in scheme,

$$\boxed{\texttt{add x y = x + y}}$$

means

$$\boxed{\texttt{add} = \lambda\texttt{x} \rightarrow (\lambda\texttt{y} \rightarrow \texttt{x + y})}$$

We also have the automated currying

$$\boxed{\texttt{add} = \lambda\texttt{x y} \rightarrow \texttt{x + y}}$$

We can use lambda expressions and local functions interchangeably

```
odds n = map f [0..n-1]
         where
            f x = x*2 + 1
```

can be simplified to

```
odds n = map (λx → x*2 + 1) [0..n-1]
```

The earlier may be better if the local function has a natural name

Operator Sections

An <u>infix</u> operator can be converted into a curried <u>prefix</u> function by using parentheses.

```
> (+) 1 2
3
```

This convention also allows one of the arguments of the operator to be included in the parentheses.

```
> (1+) 2
3
> (+2) 1
3
```

If $\oplus$ is an operator then $(\oplus)$, $(x\oplus)$ and $(\oplus y)$ are called <u>sections</u>.

Infix Operators

Any (prefix) function can become infix using ` `

```
`mod`, `elem`
```

Names with only special symbols are infix

```
++++,  +/+,  %-
```

Precedence/asociativity of infix operators set by

```
prefixr <0-9> <name>
prefixl <0-9> <name>
prefix <0-9> <name>
```

Custom infix data constructors begin with :

:#, :+, :::

Infix Operators

Information about associativity and precedence

`:info`

Interesting infix operators

`.` `$` unary -

Modules

Haskell program is a collection of modules

- name spaces, abstract data declarations
- module names start with upper-cased character
- filenames must match module names in GHC

```
module <name> ( <exported>, <symbols> ) where
```

- without exported symbols, everything is exported
- data constructors exported with type name
  - Tree(Leaf,Branch), can be abbreviated to Tree(..)

Example Module

```
module Tree ( Tree(Leaf,Branch), fringe ) where

data Tree a = Leaf a | Branch (Tree a) (Tree a)

fringe :: Tree a -> [a]
fringe (Leaf x)            = [x]
fringe (Branch left right) =
                      fringe left ++ fringe right
```

Importing Modules

Imports must be at the beginning of a module

Prelude module is loaded by default

We can choose names to import and hide

```
import Tree
```

```
import Tree hiding (tree1)
```

```
import Tree (tree1, fringe)
```

```
import qualified Tree as T hiding (tree1)
```

```
:m + Tree
```

Summary

- Type and type classes essential for Haskell
- Unnecessary, but pleasant Haskell features
  - higher order functions
  - lambda functions
  - infix operators and their sections
  - modules