AC21007: Haskell Lecture 4
Higher order functions, map, folds

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Recapitulation

- Data type tuple `(a, b)`
- Non-strict semantics:
  - expressions evaluated on-demand
  - allows infinite data structures (lists)

Anonymous (lambda) functions

- Functions without a name
- Syntax:

  ```
  \<var₁> ... <varₙ> -> <expr>
  ```

  Variables var_1 to var_n in scope in the expression *expr*
- Anonymous functions:
  - can be applied to an argument:
    `(\x -> 2 + x) 3 ==> 5`
  - can be passed as an argument
    ...anonymous functions **are** values
- E.g.:

```
      2 + 3 ::  Int
\x -> 2 + x ::  Int -> Int
   Not in scope:  `x`
```

Anonymous (lambda) functions (cont.)

- `filter`, applied to a predicate and a list, returns the list of those elements that satisfy the predicate

```
filter :: (a -> Bool) -> [a] -> [a]
filter _    []      = []
filter pred (x:xs) = if (pred x)
    then x : filter pred xs
    else filter pred xs
```

- E.g:

```
filter (\x -> x `mod` 2 == 1) [1, 2, 3, 4, 5, 6]
    ==> [1, 3, 5]

filter (\x -> x `mod` 2 == 0) [1, 2, 3, 4, 5, 6]
    ==> [2, 4, 6]
```

First-class functions

- All functions can be passed as an argument, e.g standard functions `even` and `odd`:

```
filter odd [1, 2, 3, 4, 5, 6]
     ==> [1, 3, 5]

filter even [1, 2, 3, 4, 5, 6]
     ==> [2, 4, 6]
```

- All functions are just values
- We will call functions that take a function as an argument *higher order functions*

Some useful higher order functions

- `map` - applies a function to each element of a list

```
    map :: (a -> b) -> [a] -> [b]
    map _ []       = []
    map f (x:xs) = f x : map f xs

map (\x -> 2 * x)) [1, 2, 3, 4]
    ==> [2, 4, 6, 8]
```

- `zipWith` - generalises `zip`, combines list elements with the function in its first argument, truncates the longer list

```
    zipWith :: (a -> b -> c) -> [a] -> [b] -> [c]
    zipWith _ []     _      = []
    zipWith _ _      []     = []
    zipWith f (a:as) (b:bs) = f a b : zipWith f as bs

zipWith (+) [2, 3, 4] [5, 6, 7]
    [7, 9, 11]
```

First-class functions (cont)

- Function type `a -> b` (right-associative)
- Values of this type are constructed by:
  - the usual function definitions
  - lambda constructions
- The following definitions of `max` are equivalent:

```
   max ::  (Int -> (Int -> Int))
-- max x y = if x > y then x else y
-- max x = \y -> if x > y then x else y
   max = \x y -> if x > y then x else y
```

- Haskell compiler will figure out types from LHS patterns and type of RHS expression
- Note: In a function definition all equations must have the same number of LHS patterns

Currying

- **currying** - translating the evaluation of a function that takes multiple arguments (a tuple of arguments) into evaluating a sequence of (higher-order) functions, each with a single argument
- A variant of `max`:

  ```
  max' :: (d, d) -> d
  max' (x, y) = if x > y then ...
  ```

- We can express this translation as higher-order function:

  ```
  curry :: ((a, b) -> c) -> a -> b -> c
  curry f x y = f (x, y)
  ```

- There is also the reverse translation:

  ```
  uncurry :: (a -> b -> c) -> (a, b) -> c
  uncurry f (x, y) = f x y
  ```

Function manipulation

- Composition
  - The usual $(f.g)(x) = f(g(x))$
  - Operator `(.)`, higher order function:

    ```
    (.) :: (b -> c) -> (a -> b) -> a -> c
    f . g = \ x -> f (g x)
    ```

  - E.g.:

    ```
    filter even . (filter (\ x -> x `mod` 3 == 0))
    ```

- Partial application
  - We can provide function only with first n arguments
  - Result is a partially applied function - a new function taking the rest of arguments
  - E.g: `max 5`, `(1 +)`, `(2 *)`

List folding

- Let's compare two recursive functions on lists:
  - Function `sum`:

```
sum :: [Integer] -> Integer
sum []          = 0
sum (x : xs)    = x + sum xs
```

  - Function `maximum`:

```
maximum :: [Integer] -> Integer
maximum []       = error "empty list"
maximum (x : []) = x
maximum (x : xs) = max x (maximum xs)
```

- Recursive case has the same structure:

$$recf \quad (x : xs) \quad = \quad f \quad x \quad (recf \quad xs)$$

List folding

- Let's compare two recursive functions on lists:
  - Function `sum`:

```
sum :: [Integer] -> Integer
sum []          = 0
sum (x : xs)    = (+) x (sum xs)
```

  - Function `maximum`:

```
maximum :: [Integer] -> Integer
maximum []       = error "empty list"
maximum (x : []) = x
maximum (x : xs) = max x (maximum xs)
```

- Recursive case has the same structure:

$$recf \quad (x : xs) \quad = \quad f \quad x \quad (recf \quad xs)$$

- Base case is different . . .

List folding (cont.)

- Let's slightly modify our two functions:
- Function `sum`:

```
sum ::  (Int -> Int -> Int) ->
     Int -> [Int] -> Int
sum      _ val []         = 0val
sum      f val (x :  xs) = f(+) x (sum f val xs)
```

```
  sum (+) 0 [1, 2, 3, 4, 5]
```

- Function `maximum`:

```
maximum ::  (Int -> Int -> Int) ->
     Int -> [Int] -> Int
maximum _ val []         = val
maximum f val (x :  xs) = fmax x (maximum f val xs)
```

```
  maximum max 3 [ 2, 5, 4, 2]
```

List folding - foldr and foldl

- One generic function `foldr` for right-associative recursion:

```
foldr :: (a -> b -> b) -> b -> [a] -> b
foldr _ z []         = z
foldr f z (x : xs) = f x (foldr f z)
```

- The structure of recursion is

  $\texttt{foldr f z [}x_1\texttt{, }x_2\texttt{, ..., }x_n\texttt{]}$

  $\quad\texttt{==> f }x_1\texttt{ (f }x_2\texttt{ ...(f }x_1\texttt{)...)}$

- There is also function

  `foldl ::  (b -> a -> b) -> b -> [a] -> b`

  for left-associative recursion, i.e.:

  $\texttt{foldl f z [}x_1\texttt{, }x_2\texttt{, ..., }x_n\texttt{]}$

  $\quad\texttt{==> f }x_n\texttt{ (...(f }x_2\texttt{ (f }x_1\texttt{)...)}$

List folding - examples

- Our `sum` and `maximum` as folds:

```
sum :: [Int] -> Int
sum xs = foldr (+) 0 xs

maximum :: [Int] -> Int
maximum []     = error "empty list"
maximum (x:xs) = foldr max x xs
```

- A fold where `a` and `b` are different:

```
length :: [a] -> Integer
length xs = foldr f 0 xs
    where
        -- f :: a -> Integer -> Integer
        f _ b = 1 + b
```

Next time

- Monday the the 8th of February, 2-3PM, Dalhousie 3G05 LT2
- Sorting algorithms on lists
  - Selection Sort
  - Insertion Sort
  - Bubble Sort