Haskell: Higher Order Functions (Part II)

Principles of Programming Languages
Colorado School of Mines

https://lambda.mines.edu
Haskell has an infix function: $. Here is how it's defined:

\[(\$) :: (a \to b) \to a \to b\]

\[f \; \$ \; x = f \; x\]
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What the heck is this worthless function? It’s a function applicator: it takes a function on the left and an argument on the right, and applies the function to the argument.
The $ Function

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\[f \ $ \ x = f \ x\]

What the heck is this worthless function? It’s a function applicator: it takes a function on the left and an argument on the right, and applies the function to the argument.

So it’s still worthless, right? What if I told you that it has the lowest precedence and is right-associative?
Function application using spaces is left-associative and high precedence, so \( f \ a \ b \ c \) is equivalent to \(((f \ a) b) c\).

What if \( a \) and \( b \) were functions and we wanted \( f (a (b c)) \) instead? We had to add lots of parentheses and it gets messy fast.
Using $ to reduce parentheses

Function application using spaces is left-associative and high precedence, so $ f a b c$ is equivalent to $$(((f a) b) c)$$.

What if $a$ and $b$ were functions and we wanted $f (a (b c))$ instead? We had to add lots of parentheses and it gets messy fast.

Let’s use $ to fix this:

```markdown
-- The following two expressions are equivalent
f (a (b c))
f $ a $ b c
```
Reducing Parentheses: More Examples

- length (filter odd [1..10])
Reducing Parentheses: More Examples

- length (filter odd [1..10])
- length $ \text{filter odd [1..10]}$
Reducing Parentheses: More Examples

- length (filter odd [1..10])
- length $ filter odd [1..10]

- sum (map sqrt (filter even [1..100]))
Reducing Parentheses: More Examples

- \text{length (filter odd [1..10])}
- \text{length $ \text{filter odd [1..10]}$}

- \text{sum (map sqrt (filter even [1..100]))}
- \text{sum $ \text{map sqrt $ \text{filter even [1..100]}$}$}
Reducing Parentheses: More Examples

- \text{length (filter odd [1..10])}
- \text{length \$ filter odd [1..10]}

- \text{sum (map sqrt (filter even [1..100]))}
- \text{sum \$ map sqrt \$ filter even [1..100]}

More examples:

- What does \text{sqrt 3 + 4 + 5} compute?
- What does \text{sqrt \$ 3 + 4 + 5} compute?
-- This function takes a list of functions and applies
-- [1..10] to each
onCountToTen = map ($ [1..10])

-- For example:
-- onCountToTen [filter even, filter odd, map (*2)]
-- [[2,4,6,8,10],[1,3,5,7,9],[2,4,6,8,10,12,14,16,18,20]]
How to interpret an expression which uses $$

How to use $ to reduce parentheses

How to use a partial application of $ to apply an argument to a list of functions
$: What I expect you to know

- How to **interpret** an expression which uses $.
- How to **use** $ to reduce parentheses.
- How to **use** a partial application of $ to apply an argument to a list of functions.

Understanding the definition of the $ function and it’s precedence is optional, but I think it’s helpful to figure out the above.
In mathematics, if we have a function $f(x)$ and $g(x)$, we can rewrite $f(g(x))$ as:

$$(f \circ g)(x)$$
In mathematics, if we have a function \( f(x) \) and \( g(x) \), we can rewrite \( f(g(x)) \) as:

\[(f \circ g)(x)\]

In Haskell, this \( \circ \) can equivalently be written as .:

\[
\text{sumOfSquares} = \text{sum} \ . \ (^2)
\]
Which do you choose?

-- All of these are equivalent, which would you write?

crazy x y = floor (negate (tan (sin (max x y))))
crazy x y = floor $ \neg \tan \sin \max x y$
crazy = floor . negate . tan . sin . max
A **reduction function** is a function which takes a list and reduces the elements in the list to a single value. For example, `sum` and `product` are reduction functions:

```
GHCi> sum [1..10]
55
GHCi> product [1..10]
3628800
```
A reduction function is a function which takes a list and reduces the elements in the list to a single value. For example, sum and product are reduction functions:

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```

What if we had a generalized reduction function which took a function and applied it across a sequence to obtain a result? Something like this:

```
reduce(f, seq) = f(f(f(seq[0], seq[1]), seq[2]), ...)
```
Haskell has a function called `foldr`, which takes a function, an initial value, and a list, and applies the function to each element in the list, recursively calling fold for the right value.

\[
\begin{align*}
\text{foldr} \ f \ z \ [] & = z \\
\text{foldr} \ f \ z \ (x:xs) & = f \ x \ (\text{foldr} \ f \ z \ xs)
\end{align*}
\]
Haskell has a function called `foldl`, which takes a function, an initial value, and a list. It recurses immediately, making the new initial value the result of calling the function on the initial value and the current element.

\[
\begin{align*}
\text{foldl } f \ z \ [\] &= z \\
\text{foldl } f \ z \ (x:xs) &= \text{foldl } f \ (f \ z \ x) \ xs
\end{align*}
\]
Examples: Folding

-- sum using foldl
sum' = foldl (+) 0

-- sum using foldr
sum' = foldr (+) 0

-- product
product' = foldl (*) 1
Quiz Prep Time

With your new learning groups, take some time preparing for the quiz using whatever study mechanism you wish.

Topics covered:

- Pattern Matching and Recursion
- Let, Where, Case, Guards