Basic Function Definitions

Stephen A. Edwards

Columbia University

Fall 2019
Patterns

You can define a function with patterns.

Patterns may include literals, variables, and `_ "wildcard"`

```haskell
badCount :: Integral a => a -> String
badCount 1 = "One"
badCount 2 = "Two"
badCount _ = "Many"
```

Patterns are tested in order; put specific first:

```haskell
factorial :: (Eq a, Num a) => a -> a
factorial 0 = 1
factorial n = n * factorial (n - 1)
```
Pattern Matching May Fail

Prelude> :{
  Prelude|   foo 'a' = "Alpha"
  Prelude|   foo 'b' = "Bravo"
  Prelude|   foo 'c' = "Charlie"
  Prelude| :}
Prelude> :t foo
foo :: Char -> [Char]
Prelude> foo 'a'
"Alpha"
Prelude> foo 'd'
"*** Exception: <interactive>:(23,1)-(25,19): Non-exhaustive patterns in function foo"
Let the Compiler Check for Missing Cases

Much better to get a compile-time error than a runtime error:

```
Prelude> :set -Wall
Prelude> :{
Prelude| foo 'a' = "Alpha"
Prelude| foo 'b' = "Bravo"
Prelude| :}

<interactive>:32:1: warning: [-Wincomplete-patterns]
  Pattern match(es) are non-exhaustive
  In an equation for 'foo':
    Patterns not matched: p where p is not one of {'b', 'a'}

Prelude> :set -Wincomplete-patterns
```
Pattern Matching on Tuples

A tuple in a pattern lets you dismantle the tuple. E.g., to implement \textit{fst},

\begin{verbatim}
Prelude> fst' (x,_) = x
Prelude> :t fst'
fst' :: (a, b) -> a
Prelude> fst' (42,28)
42
Prelude> fst' ("hello",42)
"hello"
\end{verbatim}

\begin{verbatim}
Prelude> addv (x1,y1) (x2,y2) = (x1 + x2, y1 + y2)
Prelude> :t addv
addv :: (Num a, Num b) => (a, b) -> (a, b) -> (a, b)
Prelude> addv (1,10) (7,3)
(8,13)
\end{verbatim}
Patterns in List Comprehensions

Usually, where you can bind a name, you can use a pattern, e.g., in a list comprehension:

```
Prelude> :set +m
Prelude> pts = [ (a,b,c) | c <- [1..20], b <- [1..c], a <- [1..b], a^2 + b^2 == c^2 ]
Prelude> pts
[(3,4,5),(6,8,10),(5,12,13),(9,12,15),(8,15,17),(12,16,20)]
Prelude> perimeters = [ a + b + c | (a,b,c) <- pts ]
Prelude> perimeters
[12,24,30,36,40,48]
```
Pattern Matching On Lists

You can use : and [, , , ]-style expressions in patterns

Like \texttt{fst}, \texttt{head} is implemented with pattern-matching

\begin{verbatim}
Prelude> :{
Prelude|  head' (x:_) = x
Prelude|  head' [] = error "empty list"
Prelude|  :}

Prelude> :t head'
head' :: [p] -> p

Prelude> head' "Hello"
'H'
\end{verbatim}
Pattern Matching On Lists

```
Prelude> :{
Prelude| dumbLength [] = "empty"
Prelude| dumbLength [_] = "singleton"
Prelude| dumbLength [_,_] = "pair"
Prelude| dumbLength [_,_,_] = "triple"
Prelude| dumbLength _ = "four or more"
Prelude| :}

Prelude> :t dumbLength
dumbLength :: [a] -> [Char]
Prelude> dumbLength []
"empty"
Prelude> dumbLength [1,2,3]
"triple"
Prelude> dumbLength (replicate 10 ' ')
"four or more"
```
List Pattern Matching Is Useful on Strings

Prelude> :{
Prelude|    notin ('i':'n':xs) = xs
Prelude|    notin xs = "in" ++ xs
Prelude|    :}

Prelude> notin "inconceivable!"
"conceivable!"
Prelude> notin "credible"
"incredible"
Pattern Matching On Lists with Recursion

```haskell
Prelude> :{
Prelude| length' [] = 0
Prelude| length' (_:xs) = 1 + length' xs
Prelude| :}
Prelude> :t length'
length' :: Num p => [a] -> p
Prelude> length' "Hello"
5

Prelude> :{
Prelude| sum' [] = 0
Prelude| sum' (x:xs) = x + sum' xs
Prelude| :}
Prelude> sum' [1,20,300,4000]
4321
```
The “As Pattern” Names Bigger Parts

Syntax: <name>@<pattern>

```haskell
Prelude> :{
  Prelude| initial "" = "Nothing"
  Prelude| initial all@(x:_) = "The first letter of " ++ all ++ " is " ++ [x]
  Prelude| }

Prelude> :t initial
initial :: [Char] -> [Char]
Prelude> initial ""
"Nothing"
Prelude> initial "Stephen"
"The first letter of Stephen is S"
```
Guards: Boolean constraints

Patterns match structure; guards (Boolean expressions after a \(|\) match value

Prelude> :{
Prelude| heightEval h
Prelude|   | h < 150 = "You're short"
Prelude|   | h < 180 = "You're average"
Prelude|   | otherwise = "You're tall" -- otherwise = True
Prelude| :}

Prelude> heightEval 149
"You're short"
Prelude> heightEval 150
"You're average"
Prelude> heightEval 180
"You're tall"
**Filter: Keep List Elements That Satisfy a Predicate**

`odd` and `filter` are Standard Prelude functions

```haskell
odd n = n `rem` 2 == 1

filter :: (a -> Bool) -> [a] -> [a]
filter p [] = []
filter p (x:xs) | p x = x : filter p xs
                | otherwise = filter p xs

Prelude> filter odd [1..10]
[1,3,5,7,9]
```
Compare: Returns LT, EQ, or GT

Another Standard Prelude function

```haskell
x `compare` y
  | x < y    = LT
  | x == y   = EQ
  | otherwise = GT

Prelude> :t compare
compare :: Ord a => a -> a -> Ordering
Prelude> compare 5 3
GT
Prelude> compare 5 5
EQ
Prelude> compare 5 7
LT
Prelude> 41 `compare` 42
LT
```
triangle :: Int -> Int -> Int -> String
triangle a b c
  | a + b < c || b + c < a || a + c < b = "Impossible"
  | a + b == c || a + c == b || b + c == a = "Flat"
  | right = "Right"
  | acute = "Acute"
  | otherwise = "Obtuse"
where
  right = aa + bb == cc || aa + cc == bb || bb + cc == aa
  acute = aa + bb > cc && aa + cc > bb && bb + cc > aa
  sqr x = x * x
  (aa, bb, cc) = (sqr a, sqr b, sqr c)

Order of the where clauses does not matter

Indentation of the where clauses must be consistent

Where blocks are attached to declarations
The Primes Example

```haskell
primes = filterPrime [2..]
    where filterPrime (p:xs) =
        p : filterPrime [x | x <- xs, x `mod` p /= 0]
```

[2..]  The infinite list [2,3,4,...]
where filterPrime  Where clause defining filterPrime
(p:xs)  Pattern matching on head and tail of list
p : filterPrime ...  Recursive function application
[x | x <- xs, x `mod` p /= 0]  List comprehension: everything in xs not divisible by p
Haskell Layout Syntax

Internally, the Haskell compiler interprets

\[
a = b + c
\]

where

\[
\begin{align*}
b &= 3 \\
c &= 2
\end{align*}
\]

as

\[
a = b + c \quad \text{where} \; \{ \; b = 3 \; ; \; c = 2 \; \}
\]

The only effect of layout is to insert \{ ; \} tokens.
Manually inserting \{ ; \} overrides the layout rules
Haskell Layout Syntax

- Layout blocks begin after `let`, `where`, `do`, and `of` unless there’s a `{`.
- The first token after the keyword sets the indentation of the block.
- Every following line at that indentation gets a leading `;`.
- Every line indented more is part of the previous line.
- The block ends (an implicit `}`) when anything is indented less.

```
a = b + c  where
  b = 2
  c = 3

a = b + c  where
  b = 3
  + 2
  c = 3

a = b + c
  where
    b = 2
    + 2  -- No
    c = 3

a = b + c
  where
    b = 2
    c = 3  -- No
```
Let Bindings: Naming Things In an Expression

\[
\text{let } <\text{bindings}> \text{ in } <\text{expression}>
\]

cylinder :: RealFloat a => a -> a -> a
\[
cylinder \ r \ h = \text{let sideArea} = 2 * \pi * r * h
\]
\[
\text{topArea} = \pi * r^2
\]
\[
in \text{sideArea} + 2 * \text{topArea}
\]

This example can be written "more mathematically" with \textit{where}

cylinder :: RealFloat a => a -> a -> a
cylinder \ r \ h = \text{sideArea} + 2 * \text{topArea} 
\[
\text{where sideArea} = 2 * \pi * r * h
\]
\[
\text{topArea} = \pi * r^2
\]

Semantically equivalent; \textit{let...in} is an expression; \textit{where} only comes after bindings. Only \textit{where} works across guards.
let...in Is an Expression and More Local

A contrived example:

```haskell
f a = a + let a = 3 in a
```

This is the “add 3” function. The scope of \( a = 3 \) is limited to the `let...in`

`let` bindings are recursive. E.g.,

```haskell
let a = a + 1 in a
```

does not terminate because all the \( a \)’s refer to the same thing: \( a + 1 \)

This can be used to define infinite lists

```haskell
Prelude> take 5 (let x = 1 : 2 : x in x)
[1,2,1,2,1]
```

but is mostly for defining recursive functions. There’s no non-recursive `let`
Let Can Also Be Used in List Comprehensions

Prelude> handshakes n = [ handshake | a <- [1..n-1], b <- [a+1..n], let handshake = (a,b) ]
Prelude> handshakes 3
[(1,2),(1,3),(2,3)]

Its scope includes everything after the let and the result expression
Defining a function with patterns is syntactic sugar for `case...of`

```plaintext
badCount 1 = "One"
badCount 2 = "Two"
badCount _ = "Many"
```

is equivalent to

```plaintext
badCount x = case x of
  1 -> "One"
  2 -> "Two"
  _ -> "Many"
```

But, like `let`, `case...of` is an expression and may be used as such:

```plaintext
describeList :: [a] -> String
describeList xs = "The list is " ++ case xs of
  [] -> "empty"
  [x] -> "a singleton"
  _ -> "two or more"
```