

An Invitation to Haskell

Emily Pillmore

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My name is Emily Pillmore.

I am a programmer, and a math enthusiast.

- ▶ Author/Maintainer of more than 30 packages, some bigger than others
- ▶ Served on the Haskell Core Libraries and .Org committees
- ▶ Twitter ([@yandereidiot](#))
- ▶ Meetups in NYC: NY Homotopy Type Theory, NY Category Theory, and the NY Haskell User Group.
- ▶ All of my slides, general scribbles, research, and meetup content are hosted at [cohomolo.gy](#).

If you ever want to talk math or programming, I'm around.

I helped start the [Haskell Foundation](#) and served on the executive leadership team as a duo (CTO) with Andrew Boardman (ED).



I now work at a company called **Kadena**, as the lead of the language, its ecosystem, and its execution layers.



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- ▶ A programming style? (emphasis on recursion, "math", small static combinators, shunting as many errors to the compiler as possible)

So what is Functional Programming?

- ▶ A collection of features? (lambdas, first class HOF's, static type system...)
- ▶ A programming style? (emphasis on recursion, "math", small static combinators, shunting as many errors to the compiler as possible)
- ▶ A cult?

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In 1977, John Backus wrote everything we needed to know about FP.

Compositionality! Equational Reasoning! Sound foundational principles!

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Haskell builds a equational foundation on **purity**.

This means that functions may not have *side effects*. In conjunction with not allowing side effects anywhere, this allows expressions to be completely deterministic, and therefore *referentially transparent*.

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- ▶ It has functions (read: function definitions, lambdas)
- ▶ It has builtins (integers, IEEE floating points, machine words, characters etc.)
- ▶ It has generics

Haskell has a global notion of parametricity everywhere you want it which may be reasoned about equationally, and therefore free theorems you can reason about.

It has a form of ad-hoc polymorphism for generics called "Typeclasses".

For more, see:

- ▶ Wadler - [Theorems for Free](#)
- ▶ My talk - [Type Arithmetic](#)

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- ▶ Laziness (a limited form of mutation) turns out to be enough to recover amortized analysis

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- ▶ Laziness (a limited form of mutation) turns out to be enough to recover amortized analysis.
- ▶ This requires a different take on analysis (think counting techniques etc.) which causes you to think in a whole new paradigm.

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- ▶ The amortized analysis (cheap small steps paying off a more expensive larger step) needed to talk about the best/average/worst case of operations goes out the window (your amortized cost becomes your worst case for many operations).
- ▶ Laziness (a limited form of mutation) turns out to be enough to recover amortized analysis.
- ▶ This requires a different take on analysis (think counting techniques etc.) which causes some tension.

Immutability + Laziness, though, is a super power. Friedman-Wise posed an important question back in 1976.

Inherently easy to spread about on multiple cores. With commutative, associative, and unital (see: commutative monoidal) functions, map-reduce is possible.

It also makes scheduling parallelism and concurrency a simpler.

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In haskell, we write the definition for functions and constants like this:

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```
-- a function  
square :: Int -> Int  
square x = x ^ x
```

In haskell, we write the definition for functions and constants like this:

```
-- a function
square :: Int -> Int -- a type signature
square x = x ^ x

-- Constants
pi_trunc :: Double
pi_trunc = 3.14159265359

charizard :: Char
charizard = 'c'

stringy :: String
stringy = "Hi, SEMIBUG!"
```

In haskell, we write the definition for functions and constants like this:

```
-- builtin lists
oneTwoThree :: [Int]
oneTwoThree = [1,2,3]
```

```
-- builtin tuples
ab :: a -> b -> (a,b)
ab a b = (a,b)
```


One can also define functions of multiple inputs like so:

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```
plus :: Int -> Int -> Int
plus x y = x + y

-- Int -> Int -> Int is the
-- same as Int -> (Int -> Int)
plus' :: Int -> Int -> Int
plus' x = \y -> x + y
```

Function types are defined syntactically by enclosing parens

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```
apply :: (a -> b) -> a -> b
-- apply = id
apply f a = f a
```

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

Defining infix notation is easy as well (not pictured: fixity):

```
(^+) :: Int -> Int -> Int  
(^+) x y = x + y  
-- usage: x ^+ y
```

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We can define data as follows:

```
-- data DataType <tyvars>
--   = Case1
--   / Case2
--   / ...
data MyAdt = Thing1 | Thing2

data MyRec = MyRecordName
  { foo :: Int
    -- ^ foo :: MyRecordName -> Int
  , bar :: String
    -- ^ bar :: MyRecordName -> String
  }
```

```
-- data DataType <tyvars>
--   = Case1
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data MyAdt = Thing1 | Thing2

data MyRec = MyRecordName
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  , bar :: String
    -- ^ bar :: MyRecordName -> String
  }
```


Pattern matching is the means by which one destructs sum types.

```
let
  x :: MyDataType
  x = Case1

in case x of
  Case1 -> "hi!"
  Case2 -> "Death!"
```

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As mentioned in the beginning of the talk, immutable data structures let us achieve some remarkable properties.

We can write recursive data definitions for things like Lists:

We can write recursive data definitions for things like Lists:

```
data List a = Nil | Cons a (List a)
-- builtin: data [a] = [] | (:) a [a]
-- usage: Cons 1 (Cons 2 (Cons 3 Nil))
-- usage: [1,2,3] := 1:(2:(3:[]))
```

Noodle baker: why does this work?

```
-- List(a) = 1 + a * List(a)
-- List(a) - a*List(a) = 1
-- List(a)(1 - a) = 1
-- List(a) = 1 / (1 - a)
-- List(a) = 1 + a + a^2 + a^3 ...
```

```
reduce :: (a -> b -> b) -> b -> [a] -> b
reduce step accum lst = case lst of
  [] -> accum
  first:rest ->
    let stepped = step first accum
    in reduce step stepped rest
```

reduce is commonly referred to as a "fold". In fact, it's a "*right fold*" in the sense that the values are accumulated thusly:

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```
reduce (+) 0 [1,2,3]
-- ~ reduce (+) 0 (1:(2:(3:[])))
-- ~ 1 + reduce (+) 0 (2:(3:[]))
-- ~ 1 + (2 + (reduce (+) 0 (3:[])))
-- ~ 1 + (2 + (3 + reduce (+) 0 []))
-- ~ 1 + (2 + (3 + 0))
-- ~ 1 + (2 + 3)
-- ~ 1 + 5
-- ~ 6
```

Claim: this function corresponds with a kind of "canonical way to reduce a list recursively". As a result, one may define many interesting properties of a list in terms of this formulation.

```
sum :: [Int] -> Int
sum lst = reduce (+) 0 lst
```

```
product :: [Int] -> Int
product lst = reduce (*) 1 lst
```

```
filter :: (a -> Bool) -> [a] -> [a]
filter p lst = reduce
  (\a acc -> if p a then a:acc else acc)
  [] lst
```

```
map :: (a -> b) -> [a] -> [b]
map f lst = reduce
  (\a acc -> (f a):acc) [] lst
```

```
-- data Bool = True / False
all :: [Bool] -> Bool
all bs = reduce (&&) True bs

any :: [Bool] -> Bool
any bs = reduce (||) False bs
```

Graham Hutton's paper [A tutorial on the universality and expressiveness of fold](#) is a great resource on the subject.

These are definable in any language for any list. But in haskell, with the right foundation, they're understandable one-liners.

Further, we have laziness. This implies a thing called *shortcircuiting*.

Typeclasses are a means of layering ad-hoc behaviors.


```
class Functor (f :: Type -> Type) where
    fmap :: (a -> b) -> f a -> f b

instance Functor List where
    -- fmap :: (a -> b) -> List a -> List b
    fmap f Nil = Nil
    fmap f (Cons h t) = Cons (f h) (fmap f h)
```

```
functorFloor :: Functor f => f Double -> f Int
functorFloor dubs = fmap floor dubs

-- class Show a where show :: a -> String
stringify :: [Int] -> [String]
stringify = fmap show
```

```
-- instances:
-- Int, <> = +, <> = *, etc.
class Semigroup a where
  (<>) :: a -> a -> a

-- instances:
-- Int, unit = 0, unit = 1
class Semigroup a => Monoid a where
  unit :: a
```

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You can get everything you need from a tool called "ghcup".

GHCup is the canonical toolchain installer. It will install the LSP, the compiler, and the build tools.

Get it here: [get-ghcup](#)

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Cabal is the Haskell project structure spec (as well as other tools), and cabal-install is the tool we use to build Haskell projects.

Useful commands:

- ▶ `init`
- ▶ `build`
- ▶ `repl`
- ▶ `test`
- ▶ `run`
- ▶ `publish`

Dependencies are located by default in a community service called "Hackage". Cabal-install knows how to talk to this service.

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- ▶ Define a main

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- ▶ Exit

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Without spending too much on the dreaded "m-word" (it's monad), we have a monad called "IO".

IO is a means of sequencing real world state changes.

In fact, it is "just" a state monad, for the curious reader.

```
main :: IO ()  
main = putStrLn "Hello, World!"
```

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We're out of time, but this is a teaser for you.

Takeaways:

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- ▶ Laziness + Purity = Performance + Reasoning

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- ▶ Reasoning + Consistency = Laws

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- ▶ Laziness + Purity = Performance + Reasoning
- ▶ Reasoning + Consistency = Laws
- ▶ Laws + Types = Fewer Bugs
- ▶ Fewer Bugs = Less Stressful Programs

Haskell: lose your hair *before* you run the program.

...and then probably after too (it's still programming).