An Invitation to Haskell

Emily Pillmore

March 21, 2023

1

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

Ghcup

Cabal

10

Conclusion

2

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).



5

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



Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

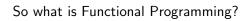
Ghcup

Cabal

IC

Conclusion

7



So what is Functional Programming?

► A collection of features? (lambdas, first class HOF's, static type system...)

9

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)

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?

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

Ghcup

Cabal

10

Conclusion

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

Compositionality! Equational Reasoning! Sound foundational principles!

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

Ghcup

Cabal

10

Conclusion



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

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

Ghcup

Caba

10

Conclusion

▶ It has functions (read: function definitions, lambdas)

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

- ▶ 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

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

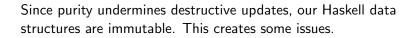
Building Stuff

Ghcup

Cabal

IC

Conclusion



► The amortized complexity theory needed to talk about the best/average/worst case of operations goes out the window (your average case becomes your worst case for many operations).

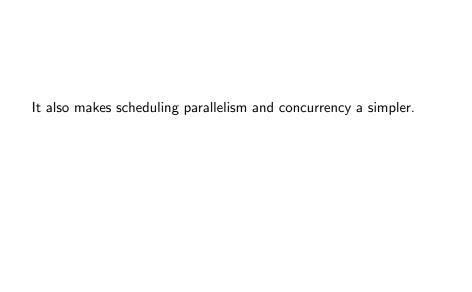
- The amortized analysis (cheap small steps paying off a more expensive larger step) needed to talk about the best/average/worst case of operations goes out the window (your amortized cost becomes your worst case for many operations).
- ► Laziness (a limited form of mutation) turns out to be enough to recover amortized analysis

- 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 (thunk counting techniques etc.) which causes you to think in a whole new paradigm.

- ► 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 (thunk 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.



Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

Ghcup

Cabal

IC

Conclusion

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

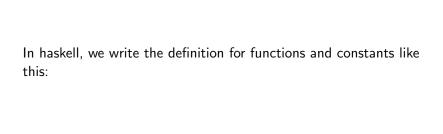
Building Stuff

Ghcup

Caba

IC

Conclusion



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

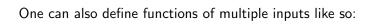
```
-- a function
square :: Int -> Int
square x = x ^ x
```

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:

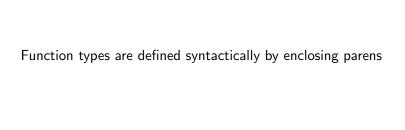
```
-- builtin lists
oneTwoThree :: [Int]
oneTwoThree = [1,2,3]
-- builtin tuples
ab :: a -> b -> (a,b)
ab a b = (a,b)
```



One can also define functions of multiple inputs like so:

```
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

44

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

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

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

Ghcup

Cabal

IC

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
```

47

```
-- data DataType <tyvars>
-- = Case1
-- | Case2
-- / ...
data MyAdt = Thing1 | Thing2
data MyRec = MyRecordName
 { foo :: Int
    -- ^ foo :: MyRecordName -> Int
  , 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!"
```

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

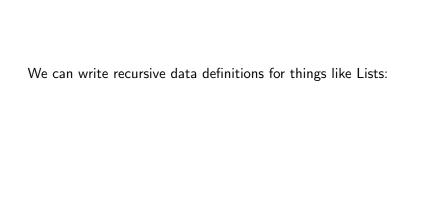
Building Stuff

Ghcup

Cabal

IC

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:

```
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:[]))
```

```
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
```

<code>reduce</code> is commonly referred to as a "fold". In fact, it's a "right fold" in the sense that the values are accumulated thusly: reduce (+) 0 [1,2,3] 1+(2+(3+0))

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

```
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.

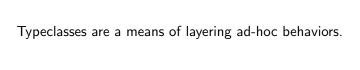
```
sum :: [Int] -> Int
sum 1st = reduce (+) 0 1st
product :: [Int] -> Int
product lst = reduce (*) 1 lst
filter :: (a -> Bool) -> [a] -> [a]
filter p lst = reduce
  (\a acc -> if p a then a:acc else acc)
  [] lst
map :: (a \rightarrow b) \rightarrow [a] \rightarrow [b]
map f lst = reduce
 (\a acc \rightarrow (f a):acc) \sqcap 1st
```

```
-- 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*.



```
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)
```

64

```
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
```

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

Ghcup

Cabal

10

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

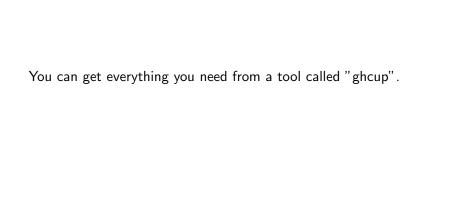
Folds

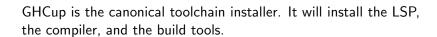
Building Stuff

Ghcup

Cabal

IC





Get it here: get-ghcup

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

Ghcur

Cabal

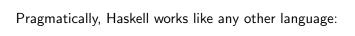
IC

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.



Pragmatically, Haskell works like any other language:

▶ Define a main

Pragmatically, Haskell works like any other language:

- ▶ Define a main
- ► Do stuff in sequence

Pragmatically, Haskell works like any other language:

- ► Define a main
- ► Do stuff in sequence
- ► Exit

Table of Contents

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

Building Stuff

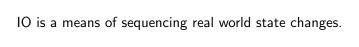
Ghcup

Cabal

10

Conclusion

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





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

Table of Contents

Introduction

Functional Programming

Foundations

Purity

Types

Consequences

Examples

Basics

Data

Folds

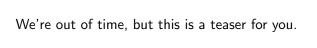
Building Stuff

Ghcup

Cabal

IC

Conclusion



► Laziness + Purity = Performance + Reasoning

- ► Laziness + Purity = Performance + Reasoning
- ► Reasoning + Consistency = Laws

- ► Laziness + Purity = Performance + Reasoning
- ► Reasoning + Consistency = Laws
- ightharpoonup Laws + Types = Fewer Bugs

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

