Monads: Safe Side-effects in Functional Programs

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Pure Functional Programming

- Biggest advantage: No side effects
  - Easier debugging
  - Lazy evaluation

Pure Functional Programming

- Biggest disadvantage: No side effects
  - Input and output are side effects
  - Some algorithms require global or local state

Applications of Haskell

- GHC: most popular Haskell compiler
- xmonad: tiling window manager
- Darcs: distributed version control system
- List of ~50 companies using Haskell:
  - http://haskell.org/haskellwiki/Haskell_in_industry
  - Examples: Bank of America, Facebook, Google
- *Real World Haskell*
  - Examples: barcode recognition, JSON parser

Source: O'Sullivan, Bryan, et.al.

Monads

- Motivation
  - First use in computer science
  - Early attempts at functional I/O
- Use in functional I/O
  - Abstraction
  - Advantages
- Use in state management
  - Abstraction
  - Implementation
  - Advantages

Original Motivation

- Original idea presented in (Moggi, 1991)
- Formal reasoning about programs
  - Trivial without side effects
  - Most programs have side-effects
  - Solution: monads/category theory
- Says nothing about implementation

Goal of Functional I/O

- `f :: Int -> Int`
  - Cannot perform I/O, access network, access anything in the universe except for its Int argument
- `f :: Int -> ____ Int`
  - Add something else that gives access to perform I/O

Functional I/O: Dialogue

```
type Dialogue = [Response] -> [Request]
```

- Based on lists and recursion
  - Function returns I/O requests
  - Responses given in argument
- Problems
  - hard to synchronize
  - hard to compose multiple I/O actions in one function

Source: Jones and Wadler

Functional I/O: Continuations

```
main :: Result -> Result
```

- I/O function
  - Takes continuation function as argument
  - Performs I/O
  - Calls continuation function after completion
- Problem: every function is aware of this model

Source: Jones and Wadler

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What is a monad?

- Monads provide a context for actions
  - Examples: getLine, print
- When performed, an action
  - Possibly uses some side effect
  - Returns value
- Actions may be composed (combined)

Source: Jones and Wadler

Input/Output in Haskell

```haskell
main :: IO ()
main = do
  name <- getLine
  print $ "Hello, " ++ name
```

Goal of Functional I/O

- `f :: Int -> Int`
  - Cannot perform I/O, access network, access anything in the universe except for its Int argument
- `f :: IO Int -> Int`
  - Function in IO monad can perform I/O

Monads: unit/return function

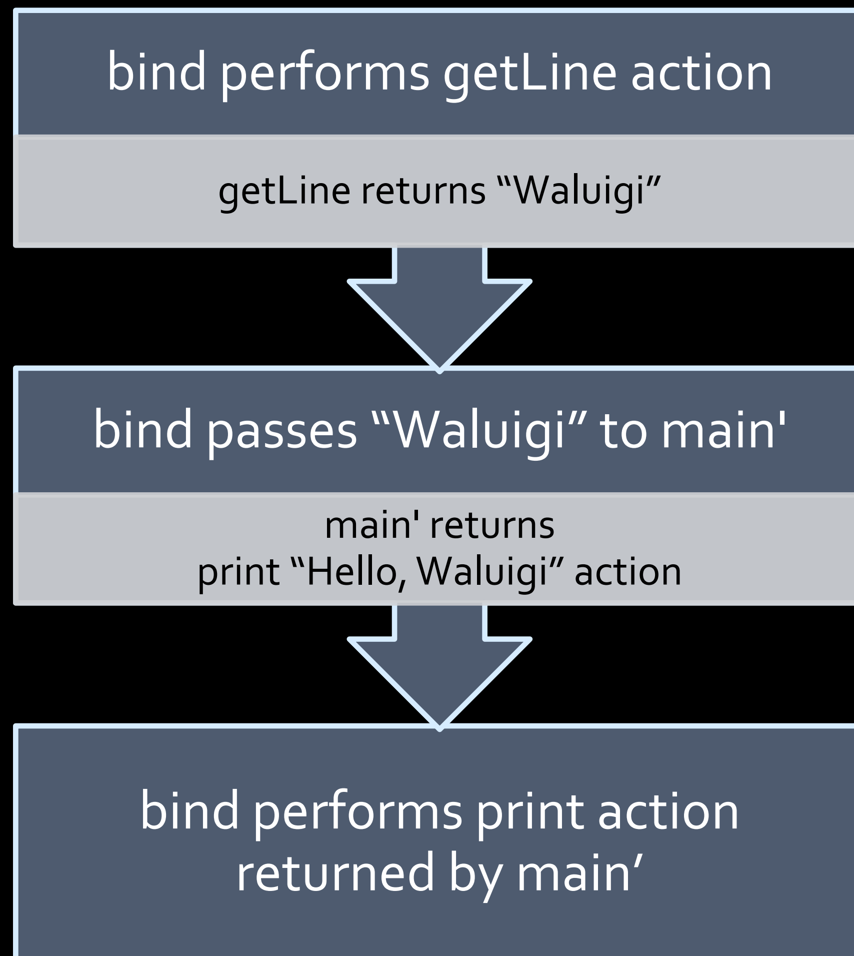
```
someAction :: IO String
someAction = do
  x <- getLine
  return $ "Hello, " ++ x
```

Source: Jones and Wadler

Monads: bind (>>=) function

```haskell
main :: IO ()
main =
  getLine >>= main'

main' :: String -> IO ()
main' name =
  print
    $ "Hello, " ++ name
```



Source: Jones and Wadler

Monad advantages

- Functional in nature
- Built into type system
  - Cannot perform IO action outside an IO function
  - Side effects are controlled
- Opaque
  - Internals of IO hidden from user
- Eliminates boilerplate
  - `Bind` absorb "continuation" code

Monads

- Motivation
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State monad

- Allows hidden local state management
- Examples:
  - Parser state: remaining text and line number
  - Random number generator: seed

Source: O'Sullivan, Bryan, et.al.

Motivation: Random Numbers

```
pureRNG :: Int -> Int

-- Make two random numbers
main =
  let x = pureRNG initSeed
      y = pureRNG x
  in print $ show x ++ "," ++ show y
```

Source: O'Sullivan, Bryan, et.al.

Better Random Numbers

```
nextRandom :: RNG Int

getTwoRandoms = do
  x <- nextRandom
  y <- nextRandom
  return (x, y)
```

Source: O'Sullivan, Bryan, et.al.

Better Random Numbers

```
nextRandom :: RNG Int
twoRandoms :: RNG (Int, Int)

main =
  let (x, y) = evalRNG twoRandoms initSeed
  in print $ show x ++ "," ++ show y
```

Source: O'Sullivan, Bryan, et.al.

General State: Two issues

- How to transport state
  - Usual monadic functions
  - bind “glue” code
- How to transform state
  - Actions: get and put

Source: O’Sullivan, Bryan, et.al.

State transformation

```
transform :: b -> (s -> (a, s))
```

- This function is curried
  - Can separate into two functions
  - Separate state transformation from computation

Source: O'Sullivan, Bryan, et.al.

State transportation

```
type State s a = s -> (a, s)

return x = \s -> (x, s)

m >>= f = \s -> let (x, s') = m s
  in (f x) s'
```

Source: O'Sullivan, Bryan, et.al.

Initial State: runState

- Input
  - action m
  - initial state s
- Output
  - final state
  - output data

```
runState ::
    State s a
 -> s
 -> (a, s)
runState m s = m s
```

Source: O'Sullivan, Bryan, et.al.

State transformation

- `get`: returns state as value

`put`: sets state to passed-in state

```
get :: State s s
get = \s -> (s, s)
```

```
put :: s -> State s ()
put s = \_ -> ((), s)
```

Source: O'Sullivan, Bryan, et.al.

Monad advantages

- Built into type system
  - Cannot perform state action outside context
  - Side effects are controlled
- Opaque
  - Internals of state mechanism hidden from user
- Eliminates boilerplate
  - `bind` absorbs state management code

Conclusion

- Side effects essential to programming
  - I/O is primary example
  - Painful to debug
- Monads provide the solution
  - Provide context for actions with side effects
  - Allow composing actions
  - Side effects cannot escape monadic context

References

"Haskell in Industry." *The Haskell Programming Language .* http://haskell.org/haskellwiki/index.php?title=Haskell_in_industry&oldid=38782

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Questions?