COMP3141

Software System Design and Implementation

Lecture 7: Monads, IO

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Announcements

As of yesterday, Assignment 2 is out!
Due 02 Aug 2022

- It involves monads. Lots of 'em.
- A full solution will require you to write approximately 200 lines of Haskell code, and you'll have to do quite a bit of independent thinking. Start early!

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  - `List`: List comprehensions

NB: Haskell allowed us to abstract away repetitive code.

The Monad Type Class

All of these (seemingly different) things are instances of the same abstract concept: a *monad*.

```
class Monad m where
  return :: a -> m a
  (>>=) :: m a -> (a -> m b) -> m b
```

The Haskell community used monads to solve many system design problems in functional programming. There are many applications we haven't seen: e.g. writing parsers using monads is a breeze. Async via futures and promises is another example.

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While monads are abstract, once you grok them they make many systen design tasks easy.

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Monadic I/O

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We still haven't done any I/O!

Now that we know a few examples of monads, we'll be able to understand how to use monads to do input/output, and what problems this solves.

Monads

Recall how two weeks ago we defined our own `State` type and monad using

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

State Operations

```
get :: State s s
put :: s -> State s ()
return :: a -> State s a
(>>=) :: State s a -> (a -> State s b) -> State s b
evalState :: State s a -> s -> a
```

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We need to perform I/O, to communicate with the user and with the hardware. A `State`-like monad will allow us to do this.

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`IO a` will be an abstract type. But what if we thought of it as a function:

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RealWorld -> (RealWorld, a)
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We can! This was Jones' and Wadler's original idea. And if we do, we get a monad. (that's close to how it's implemented in GHC)

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```
(>>=) :: IO a -> (a -> IO b) -> IO b
return  :: a -> IO a

getChar :: IO Char
readLine :: IO String
putStrLn :: String -> IO ()
```

Infectious IO

But what about the `RealWorld` type? That type is purely abstract. You can't get We can convert values to procedures with `return`:

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return :: a -> IO a
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This is just the procedure that returns the value, and does nothing else.

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Conclusion

The moment you use an `IO` procedure in a function, `IO` shows up in the types, and you can't get rid of it!

If a function makes use of `IO` effects directly or indirectly, it will have `IO` in its type!

Equational Reasoning

Demo: Hello World

Equational Reasoning

Demo: Hello World Demo: Referential Transparency, Equational Reasoning

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Haskell Design Strategy

We ultimately "run" `IO` procedures by calling them from `main`:

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main :: IO ()
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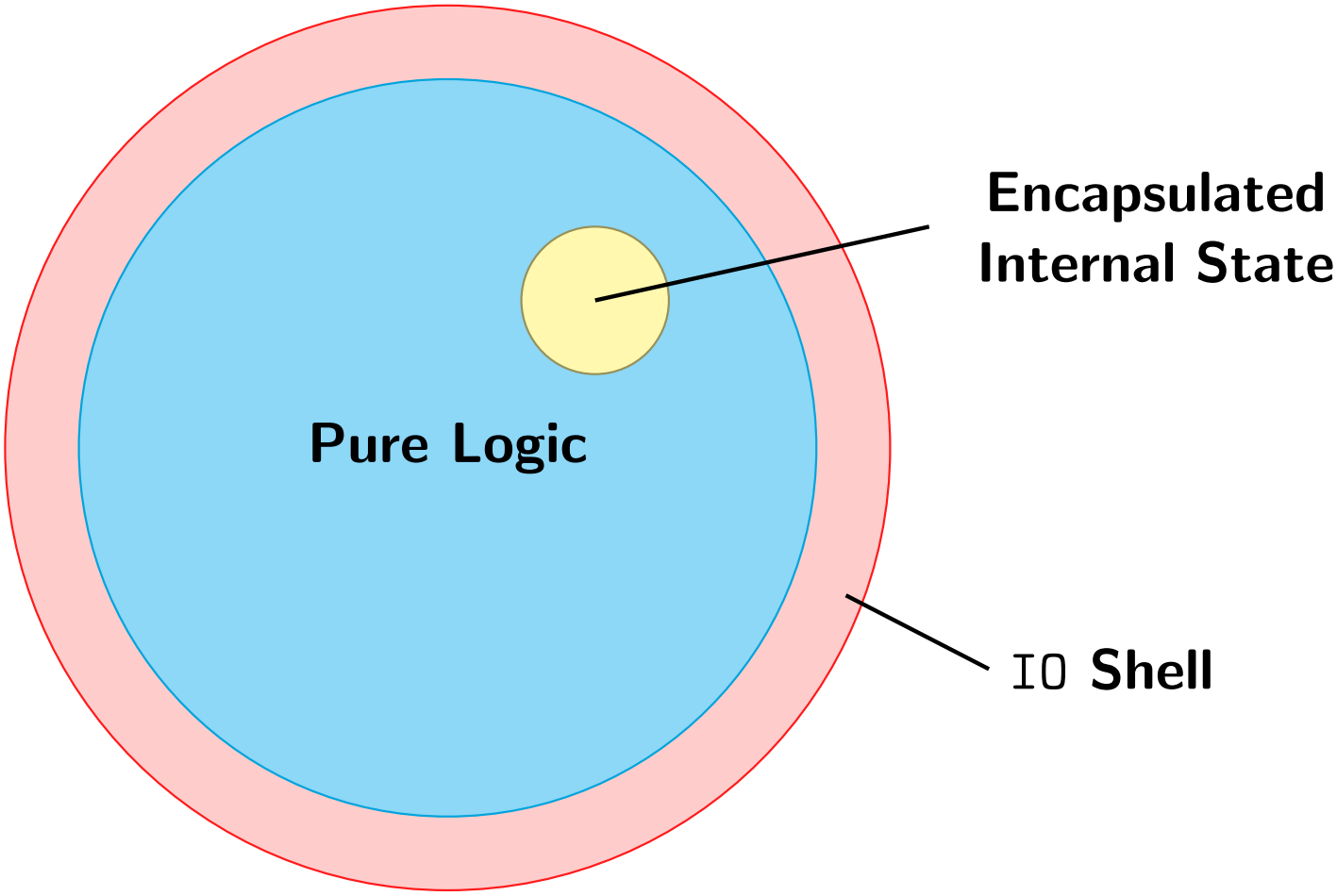

Examples

Example (Triangles)

Given an input number n, print a triangle of $*$ characters of base width n.

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Example (Maze Game)

Design a game that reads in a $n \times n$ maze from a file. The player starts at position $(0, 0)$ and must reach position $(n-1, n-1)$ to win. The game accepts keyboard input to move the player around the maze.

Benefits of an IO Type

- Absence of undeclared effects (i.e. side effects) makes type system more informative:
  - A type signatures captures entire interface of the function.
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  - All dependencies are typed.
- Equational reasoning works, and code is easier to test:
  - Testing is local, doesn't require complex set-up and tear-down.
  - Reasoning is local, doesn't require state invariants.
  - Type checking leads to strong guarantees.

The Either Monad

```
data Either a b = Left a | Right b
```

The `Either` type represents values with two possibilities: a value of type `Either a b` is either `Left a` or `Right b`.

This type is sometimes used to represent a value which is either correct or an error; by convention, the `Left` constructor is used to hold an error value and the `Right` constructor is used to hold a correct value (mnemonic: "right" also means "correct"). **Demo**

FIN

1. **Thanks!**
2. The quiz is due 23:59 Thursday, 21 July 2022.
3. The exercise is due 09:10 Thursday, 21 June 2022.
4. Check out the assignment.