COMP3141

Software System Design and Implementation

Effects and State

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Example (IO)

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Example (Non-termination)

```
// infinite loop
while (1) {};
```

Example (Control flow)

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// exception effect
throw new Exception();
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Internal vs. External Effects

External Observability

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Are memory effects *external* or *internal*?
Answer: Depends on the scope of the memory being accessed. Global variable accesses are *external*.

Purity

A function with no external effects is called a *pure* function.

Pure functions

A *pure function* is the mathematical notion of a function. That is, a function of type `a -> b` is *fully* specified by a mapping from all elements of the domain type `a` to the codomain type `b`.

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Question: Are Haskell functions pure?

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Despite the impurity of Haskell functions, we can often reason as though they are pure. Hence we call Haskell a purely functional language.

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We can't, in general, reason equationally about effectful programs!

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Typically, a computation involving some state of type `s` and returning a result of type `a` can be expressed as a function:

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Efficiency?

All that copying might seem expensive, but by using tree data structures, we can usually reduce the cost to an $\mathcal{O}(\log n)$ overhead.

State Passing

Example (Labelling Nodes)

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Given a tree, label each node with an ascending number in infix order:

```haskell
label :: Tree () -> Tree Int
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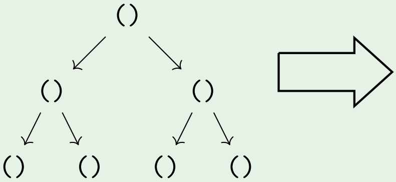

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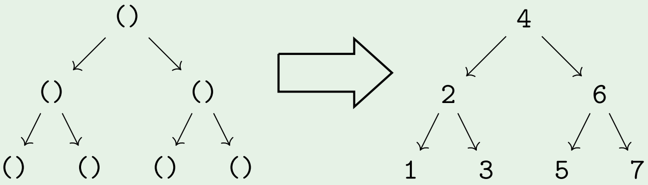

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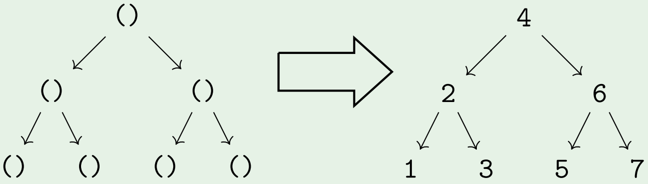

Let's use monads to simplify this!

State Monads

```haskell
newtype State s a = State (s -> (s, a))
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Here we use a monadic interface to simplify the passing of our state around, so that we don't need to manually plumb data around.

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Haskell's approach

Pure by default. Effectful when necessary.

The IO Type

A procedure that performs some side effects, returning a result of type a is written as `IO a`.

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World interpretation

`IO a` is an abstract type. But we can think of it as a function:

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(that's how it's implemented in GHC)

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

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

Infectious IO

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The only function that gets an `a` from an `IO a` is `>>=`:

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(>>=) :: IO a -> (a -> IO b) -> IO b
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But it returns an `IO` procedure as well.

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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!

Haskell Design Strategy

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

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main :: IO ()
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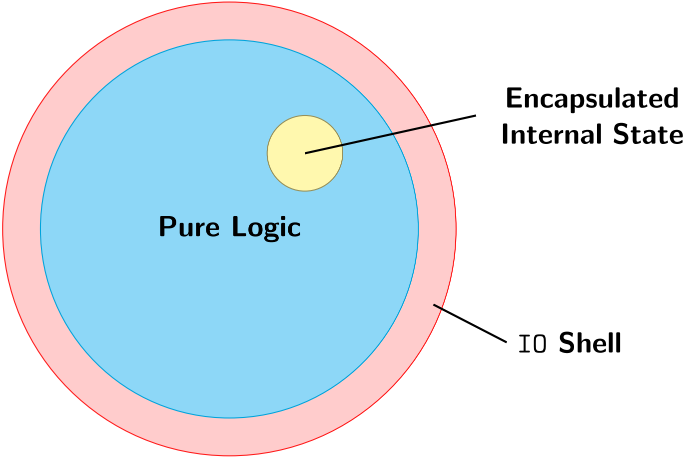

Examples

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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 effects makes type system more informative:
  - A type signatures captures entire interface of the function.
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- Absence of effects makes type system more informative:
  - A type signatures captures entire interface of the function.
  - All dependencies are explicit in the form of data dependencies.
  - All dependencies are typed.
- It is easier to reason about pure code and it 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.

Mutable Variables

We can have honest-to-goodness mutability in Haskell, if we really need it, using `IORef`.

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data IORef a
newIORef :: a -> IO (IORef a)
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Example (Effectful Average)

Average a list of numbers using `IORef`s.

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data STRef s a
newSTRef :: a -> ST (STRef s a)
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runST :: (forall s. ST s a) -> a
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Note

The ST Monad is not assessable in this course, but it is useful sometimes in Haskell programming.

QuickChecking Monads

QuickCheck lets us test IO (and ST) using this special property monad interface:

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monadicIO :: PropertyM IO () -> Property
pre       :: Bool -> PropertyM IO ()
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Example (Testing `gfactor`)

Let's test that the GNU `factor` program works correctly!

Homework

1. New exercise out, due Tuesday next week.
2. Last week's quiz is due on Friday.
3. This week's quiz is due the following Friday.
4. **Note**: Assignment 2 released next week!