COMP3141

Software System Design and Implementation

Lecture 5: Effects, State Management

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Announcements

Assignment 1: due July 2.

Warning

That is a Sunday. But support may be sparse over the weekend. Plan accordingly!

Help sessions

Use the extra help sessions this week:

- Wednesday 10AM-12PM (online)
- Thursday 1-3PM (Quadrangle G045)
- Friday 1-3PM (online)

Midway

It's Week 5. We're halfway through!

What have we accomplished?

- Mastered the rudiments of Haskell programming.
- Learned basic reasoning methods.
- Encountered useful algebraic structures.
- Data transformations and algorithm implementation in mathematically structured programs.

Midway

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- **Control.Lens** (lenses, folds, traversals)

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- New focus: **control** structures.
- An adept Haskell programmer needs to also master:
  - **Control.Monad** (monads)
  - **Control.Lens** (lenses, folds, traversals)
- The remainder of this course will mostly be about **Control.Monad**.

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Example (Non-termination)

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

Example (Control flow)

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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 complete mapping from the domain type `a` to the codomain type `b`.

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

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Equational reasoning *fails* in the presence of impure functions.

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- $x - x = 0$ is true for all integer expressions.
- ...but `getInt() - getInt() == 0` is nonsense. What if I input two different integers?

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Monads are mathematical structures that were introduced by French mathematician **Roger Godement** in 1950. They come from *category theory*, which we're not learning here.

In Oct 1992, **Simon Peyton Jones** and **Philip Wadler** showed how to use monads to do I/O *without* sacrificing purity in Haskell-like languages. The Haskell community went on to apply monads to many other system design problems.

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The next 3 lectures: building up to understand SPJ and PW's solution to the I/O problem.

Scenario I

We will **not** introduce monads in this lecture. However, we will perform some system design tasks that hint at their existence.

Getting stuff from a DB

Imagine we have a database full of employee records:

```
data Employee = Employee
  { idNumber :: ID
  , name :: String
  , supervisor :: Maybe ID
  } deriving (Show, Eq)
```

Each employee has a unique id number, a name, and possibly a supervisor.

Scenario I

We have a search field, where the user can type an ID. When the user presses the `Search` button, the system should output the record of the **supervisor** of the employee with the given ID (if any).


ID: 23

```
Output: The supervisor of employee #23 is ...
```

State Passing

Example (Labeling Nodes)

```haskell
data Tree a = Node a (Tree a) (Tree a) | Leaf
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Given a tree, label each node with an ascending number, by labeling the left subtree first.

```haskell
label :: Tree a -> Tree Integer
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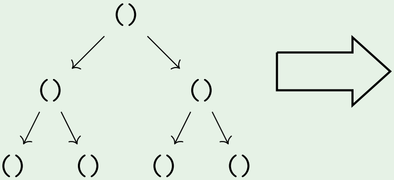

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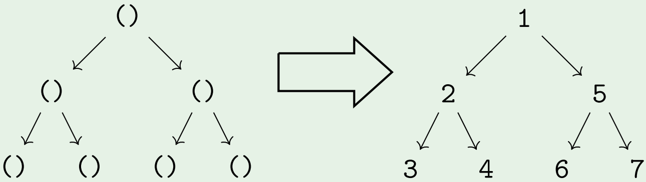

Bind for State

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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Rather than change the state, we return a new copy of the state.

State Implementation

The Haskell standard library has a `State` type that is essentially implemented as the same state-passing we did before! But note that we had a `type` synonym, whereas they have a bona fide `data` type.

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

Caution

In the Haskell standard library `mtl`, the `State` type is actually implemented slightly differently, but the implementation essentially works the same way.

State

State Operations

```
get :: State s s
put :: s -> State s ()
return :: a -> State s a  -- our yield
evalState :: State s a -> s -> a
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Bind

```
-- our bindS is declared infix
(>>=) :: State s a -> (a -> State s b) -> State s b
-- usage (implements the `use` fn):
get         >>= \x ->
put (x+1) >>= \_ ->
return x
```

Higher Kinds

Types and Values

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The type level also has a type system!

Kinds

Just as value-level terms are assigned types, terms on the type level are assigned *kinds*.

The most basic kind is written as $*$.

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- There are binary types etc. But there are also *higher-kinded types* such as `(* -> *) -> *`. We won't deal with them now.

Lists

Suppose we have a function:

```
toString :: Int -> String
```

And we also have a function to give us some numbers:

```
getNumbers :: Seed -> [Int]
```

How can I compose `toString` with `getNumbers` to get a function `f` of type `Seed -> [String]`?

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Answer: we use `map`:

```
f = map toString . getNumbers
```

Maybe

Suppose we have a function:

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And we also have a function that may give us a number:

```
tryNumber :: Seed -> Maybe Int
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How can I compose `toString` with `tryNumber` to get a function `f` of type `Seed -> Maybe String`?

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How can I compose `toString` with `tryNumber` to get a function `f` of type `Seed -> Maybe String`?

We want something like a `map` function but for the Maybe type:

```
f = maybeMap toString . tryNumber
```

Functor

All of these functions are captured by the type class `Functor`.

```haskell
class Functor f where
  fmap :: (a -> b) -> f a -> f b
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Instances for:

- Lists
- `Maybe`
- `Gen` (QuickCheck generators)
- Functions (how?)

...and many more

Functor Laws

The functor type class must obey two laws:

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2. `fmap f (fmap g x) == fmap (f . g) x`

(In Haskell, it's impossible to write a total `fmap` function that satisfies the first law but not the second. This follows from something called *parametricity*, which is beyond the scope of the course.)

FIN

1. **Assignment 1**: due on Sunday, 02 July 2023.
2. Last week's quizzes and exercises are due one Thursday.
3. This week's quizzes and exercises are due **after** flex week.