The State of Haskell in Ethereum

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Introduction

- What is Ethereum? Where does it fit?
- What makes Ethereum development "difficult"?
- What off the shelf haskell libraries can help?

Blockchain vs Cryptocurrency

- Cryptocurrency ~ programmable money
  - access control
  - specified utility
  - scarcity
- Blockchain ~ âŠ¥
  - process digital assets[1]
  - cryptographic[2]
  - distributed

[1] This is currently the primary use case, but all work is leading towards more general use cases, e.g. governance.

[2] In the sense of cryptographic hash functions.

Blockchains in Production

- Existing: Bitcoin, Ethereum
- Nascent: Kadena, Cardano SL, RChain

Ethereum Today

- Only public, permissionless, 2nd generation blockchain in production
- Largest developer community
- Will be here for a while...

Example Applications

- Tokenized Assets
  - Digital Art -- SuperRare, CryptoKitties
  - Intellectual Property / Licensing
- Digital Registries
  - Ad Tech -- ad chain
  - Geospatial Data -- FOAM

Data Access and Streaming

(An Ethereum Node's point of view)

The Problem

- Node's primary concern is block production, propogation, and verification
- Query performance and expression are not primary concerns.

Solution: Wherever applicable, use production grade databases as a history cache (e.g. Postgres, Elasticsearch).

Access Model

Libraries give the appearance of a high level interface:

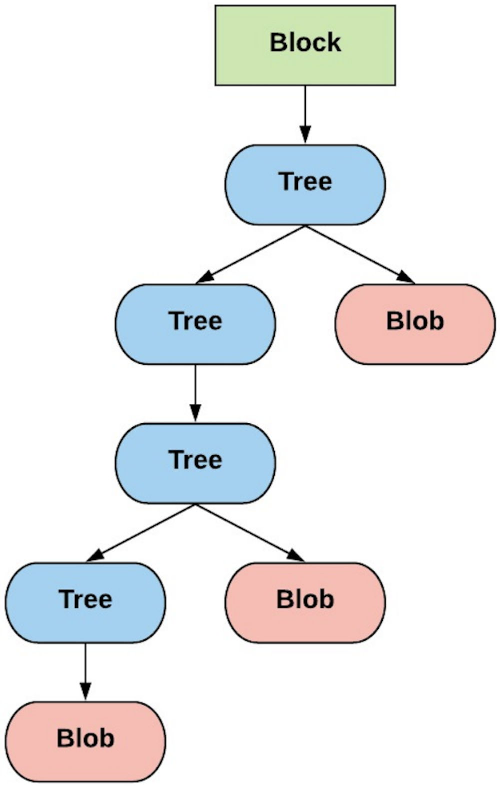
```
-- | Get the token balance for a user
balanceOf
  :: ContractAddress
  -> BlockNumber
  -> UserAddress
  -> Web3 TokenBalance
balanceOf = ...
```

Internally, the low level interface is key value storage:

```
getValue :: ByteString -> Maybe ByteString
```

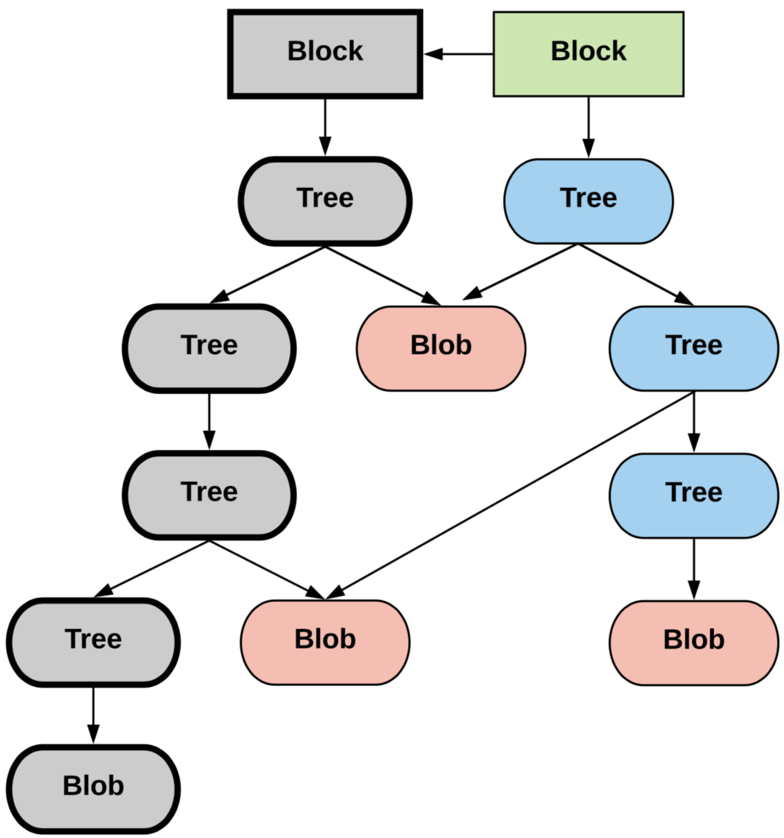
Ethereum Storage

- Internal storage model is cryptographic (Merkle) tree, not meant for Enterpiseâ„¢ data access.
- Each block contains a different index into this tree, indicating the current state.



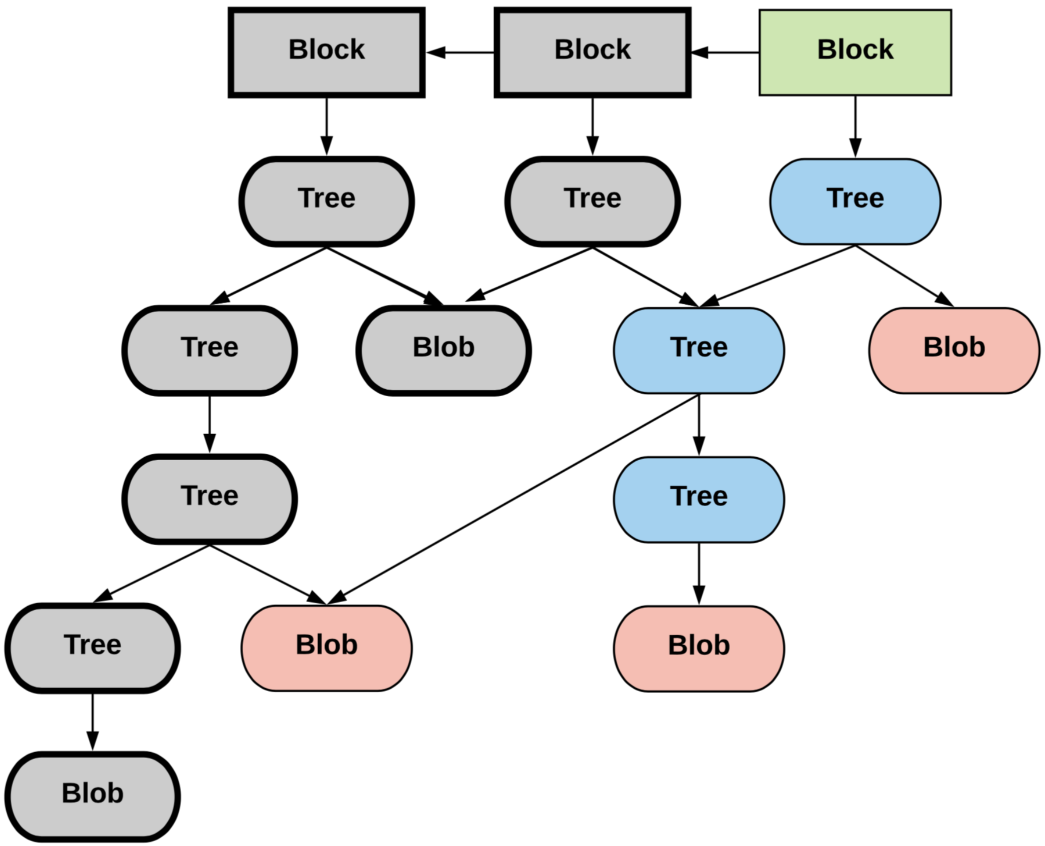
Ethereum Block Progression

- Storage is never overwritten.
- Block progression gives a series of indices into storage, i.e. Ethereum is a *time-indexed database*.



Ethereum Block Progression

- Smart Contract state changes *could* be inferred via tree diffs.
- *Events* are the mechanism to observe and react to state changes for external applications.



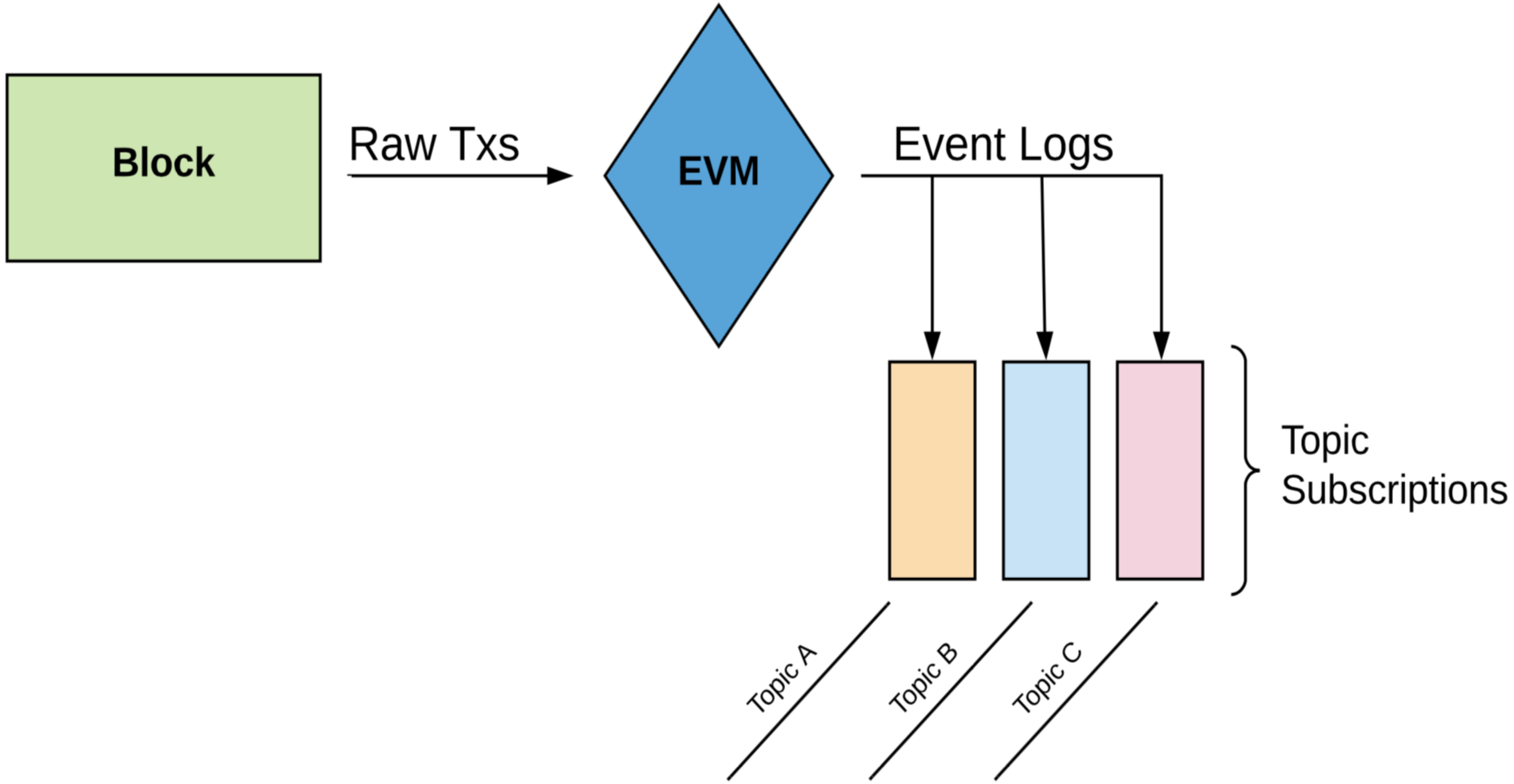
What Are These *Event Logs* Precisely? (Example)

Example:

- Alice transfers Bob a token.
- Their balances in contract storage change (new state tree index).
- This act of exchange `Transfer(Alice, Bob, 1)` is not stored in the contract-- it isn't even accessable.
- Outside world notified via contract's *Transfer* topic.

What Are These *Event Logs* Precisely? (Illustration)

```
processBlock
  :: Block
  -> StateT StateTree (Writer EventLog) ()
```



Functional Tools

Minimal web3 Library Requirements

- stream relevant Smart Contract updates, i.e. *events*
- access state history (e.g. indexing, auditing, replaying)
- submit transactions to update the blockchain

Core Functional Ethereum Libraries

- **hs-web3**
- purescript-web3 - similar design to hs-web3.
- chanterelle - smart contract build/deploy/test.

Interacting with Smart Contracts

- Ethereum smart contracts expose an interface
- Example: ERC20 standard

The ERC20 Token Standard Interface

Following is an interface contract declaring the required functions and events to meet the ERC20 standard:

```
// ----------------------------------------------------------------------------
// ERC Token Standard #20 Interface
// https://github.com/ethereum/EIPs/blob/master/EIPS/eip-20-token-standard.md
// ----------------------------------------------------------------------------
contract ERC20Interface {
    function totalSupply() public constant returns (uint);
    function balanceOf(address tokenOwner) public constant returns (uint balance);
    function allowance(address tokenOwner, address spender) public constant returns (uint remaining);
    function transfer(address to, uint tokens) public returns (bool success);
    function approve(address spender, uint tokens) public returns (bool success);
    function transferFrom(address from, address to, uint tokens) public returns (bool success);

    event Transfer(address indexed from, address indexed to, uint tokens);
    event Approval(address indexed tokenOwner, address indexed spender, uint tokens);
}
```

Interacting with Smart Contracts (ABI)

- Compliation artifact called ABI (application binary interface)
- JSON object specifying interface:
  - function calls
  - events / topics
- minimum data about contract required to generate FFI in any language (ps, haskell).

Interacting with Smart Contracts (QuasiQuoter)

```
[abiFrom|".abis/ERC20.json"]
```

```
...
-- | Transfer a quantity of tokens to an address.
transfer :: Call -> Address -> UIntN 256 -> Web3 Hash

-- | Represents a 'Transfer' event log.
data Transfer =
  Transfer { transferFrom :: Address
           , transferTo :: Address
           , transferValue :: UIntN 256
           } deriving (Show, Eq, Ord, Generic)
...
```

Interacting with Smart Contracts (Encodings)

- Ethereum has its own binary encoding schema (ABI-codecs)
  - transactions are serialized *closures* (function + args)
  - events / topics
- codecs derived generically (`generics-sop`)
- all other required instances declared in QQ

Conclusion:

All datatypes and FFI needed to interact with *any* Smart Contract can be generated from the QuasiQuoter and used natively in any application.

Streaming Logs

Machines - *Ceci n'est pas une pipe*

- similar libraries:
  - *conduit*
  - *purescript-coroutines*
  - *pipes*
- Idea: build up data processing machines[1], compose them, join them, split them.
- Useful for cases when streaming from one IO source to another with intermediate processing phases.

1. Usually build something called a *Plan*, which is a DSL describing what the machine should do and how to terminate.

Analogous Problem

You want to stream all photos uploaded to some api by a user.

- API supports `GET /photos/user_id`.
- supports ws notifactions for new photos from a `user_id` after time `t`.

1. Break up the http requests into intervals, use a cursor.
2. Whenever you've caught up to the current time, start the ws.

This is what the SuperRare monitor is doing with Ethereum + IPFS.

Filter Type Description

We send out a description of what we want to monitor.

```
-- | Filter has a phantom type for the specific event.
data Filter e =
  Filter { address   :: [Address]
         -- ^ contract addresses for event origin.
         , fromBlock :: ChainCursor
         , toBlock   :: ChainCursor
         , topics    :: [Maybe ByteString]
         -- ^ Bloom filter to narrow this event filter.
         }
```

Each match that comes back looks like this:

```
data FilterChange e =
  FilterChange { rawChange :: Change
               -- ^ event metadata (e.g. tx hash)
               , event     :: e
               -- ^ particular event (e.g. Transfer)
               }
```

Filter Machines (slightly simplified)

There's an internal distinction between folding over past blocks and subscribing to current events (think of example problem).

Folding over past events:

```
-- | Take a filter and split it into smaller intervals.
filterStream
  :: FilterStreamState e
  -> MachineT Web3 k (Filter e)

-- | Stream past events until you are caught up to
-- the end of the filter's interval.
playLogs
  :: DecodeEvent i ni e
  => FilterStreamState e
  -> MachineT Web3 k (FilterChange e)
```

Weirdly, all web3 machines are polymorphic in `k`

Filter Machines (slightly simplified)

Subscribing to current events:

```haskell
-- | Poll the filter until a given block number
-- TODO: support ws
pollFilter
  :: forall i ni e k .
     DecodeEvent i ni e
  => Filter e
  -> MachineT Web3 k (FilterChange e)
```

Reduce a machine by running it:

```haskell
data EventAction = Continue | Terminate

-- | run while 'mapM_'ing with the given handler.
-- return conditions of termination.
reduceEventStream
  :: Monad m
  => MachineT m k (FilterChange e)
  -> (e -> ReaderT Change m EventAction)
  -> m (Maybe (EventAction, BlockNumber))
```

High level functions

There are also high level functions that don't require you to interface with machines.

```haskell
-- | Subscribe to the given filter, processing a number
-- | of blocks at a time with the handler until
-- | possibly transitioning to polling or exiting.
eventMany
  :: DecodeEvent i ni e
  => Filter e
  -> WindowSize
  -> (e -> ReaderT Change Web3 EventAction)
  -> Web3 ()
```

Ironically, I usually use this to feed a `Conduit` in all the data processing work that I do.

Querying Data

Haxl Interlude

What is Haxl?

- Originally developed at Facebook, led by Simon Marlow
- Kind of like a scheduler for monadic computation
  - input "sequential", IO bound, monadic computation
  - will optimally[1] rewrite to parallalelize
  - sophisticated caching
- Really great for time indexed databases where you really don't want to do more work than you have to.

[1] Uses `{-# LANGUAGE ApplicativeDo #-}`. Not actually optimal (couldn't be anyway), uses heuristics to avoid slow compile times and still get good results.

Example Computation

Suppose we have these functions:

```haskell
-- | Core logic generated by QuasiQuoter,
--   queries web3 api.
balanceOf
  :: MonadWeb3 m
  => BlockNumber
  -> Address
  -> m (UIntN 256)
...

-- | Uses our stored history of all token transfers.
getTraders
  :: MonadPg m
  => BlockNumber
  -> Address
  -> m [Address]
...
```

Example Computation (*continued*)

Let **Neighbor** be a relations with **Neighbor(A,B)** if address A has traded with address B, where B currently has nonzero token balance.

```
-- | Gets the 10 Neighbors with the highest token
--   balances
getRichestNeighbors
  :: ( MonadWeb3 m
     , MonadPg m
     )
  => BlockNumber
  -> Address
  -> m [(Address, UIntN 256)]
getRichestNeighbors bn userAddress = do
  traders <- getTraders userAddress
  pairs <- forM traders $ \trader -> do
    bal <- balanceOf bn trader
    pure (trader, bal)
  let pairs' = filter ((> 0) . snd) pairs
  pure . take 10 . sortOn (Down . snd) $ pairs'
```

Example Computation (*continued*)

Introduce another parameter `k` with **Neighbor'(A, B, k)** if there exists A_1 ..., A_{i-1} with `i <= k` and **Neighbor(A, A_1)** ... **Neighbor(A_{i-1}, B)**.

In other words, A and B are at most `k` `Neighbor` pairs apart.

Example Computation: Naive Approach

```haskell
getRichestNeighborsK
  :: (MonadWeb3 m, MonadPg m)
  => BlockNumber
  -> Int
  -> Address
  -> m [(Address, UIntN 256)]
getRichestNeighborsK bn k userAddress = do
  traders <- getAllNs bn k userAddress
  pure . take 10 . sortOn (Down . down) $ pairs'
  where
    getAllNs _ 0 _ = pure []
    getAllNs bn k userAddress = do
      traders <- getTraders userAddress
      pairs <- forM traders $ \t -> do
        bal <- balanceOf bn t
        pure (t, bal)
      let pairs' = filter ((> 0) . snd) pairs
          addrs = map fst pairs'
      rest <- concat <$> mapM (getAllNs bn (k-1)) addrs
      pure $ pairs' <> rest
```

Example Computation: Problems

- `balanceOf` is possibly called multiple times per address.
- `getTraders` is possibly called multiple times per address.
- any time we used `mapM` (equivalently `forM`), we could be concurrently running each operation.

Bad Solutions

- Run computation in `State` monad holding `MVar` with maps
  - `traders :: Map Address [Address]`
  - `balances :: Map Address (UIntN 256)`
- Use combination of `par` strategies and `async` / `wait`.

Building custom concurrency like this is tedious, fragile, and not always composible.

Good Solutions

- Don't do anything at all.
- Let the compiler and libraries work for you.

Haxl Solution

The analogy is:

- `Memory Management` is to `Garbage Collection` as `Concurrency` is to `Haxl`[1]

You might be able to do better with custom concurrency controls, but unlikely. Also, it's probably not the actual problem you're trying to solve at the moment.

[1] Simon Marlow [StrangeLoop 2017]

Haxl Scheduler Diagram

Not an AST!
This represents a dependency graph where
sequential dependencies are marked with `(>>=)` and syncrhonization points with `(<*>)`.