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Design and Implementation of HAMM

Haskell Authenticated Modular Maps

Victor Miraldo, Harold Carr, Alex Kogan, Mark Moir, Maurice Herlihy
Oracle Labs
September 21, 2018

Motivation

From a blockchain participant’s perspective:

- To start verifying, it needs a state.
- Traditionally, download and verify all transactions since forever. This data grows large.
- Instead, transfer just the necessary part of the state first.
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2. To verify this *summary* against some obtained hash.
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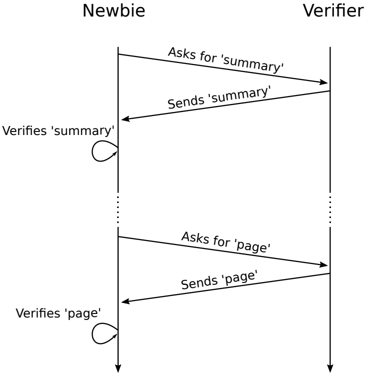
Verifier Comming Online



Merkle Trees
[Merkle,1979]

Verification of the state is not novel. One could use *Merkle Trees* to construct proofs of membership or compare roots.

Merkle Trees
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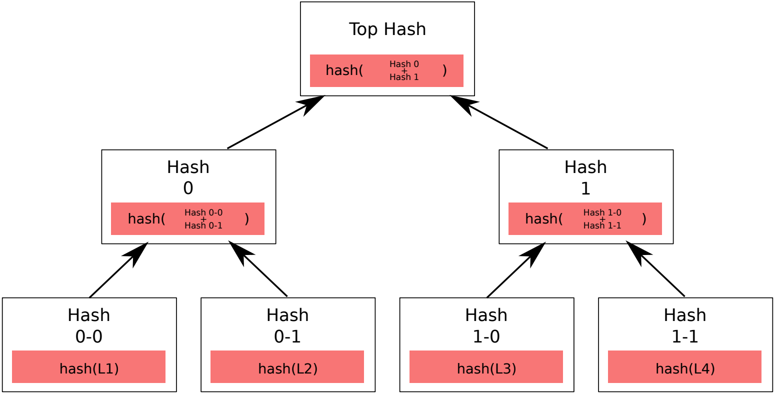
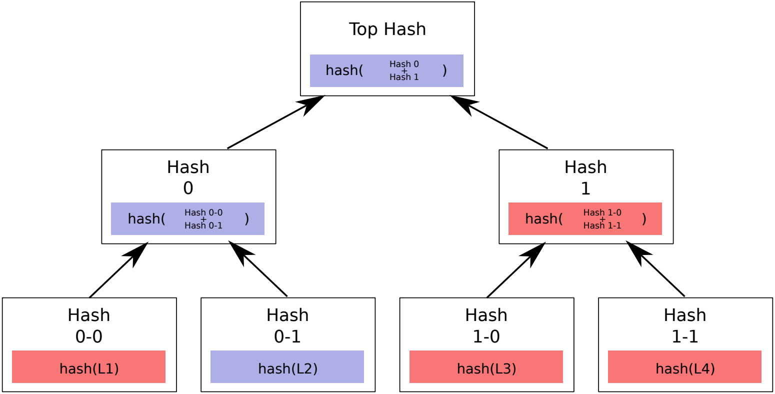


Merkle Root is the *Top Hash*.

Merkle Trees

[Merkle,1979]



Prove L_2 is member: give L_2, $hash\ 0{-}0$ and $hash\ 1$.

HAMM 101

DSL for combining key-value store components.

Quickly study different map architectures, eg:

Different add-ons alter the behavior of base maps.

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```
myMap : BoundedCacheOf b
            (BloomOf h m
               (PagesOf [3, 4, 4]
                  (PartialOf RB)))
          String Int
myMap = fromList [("A", 0), ("X", 10)]
```

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Cooking HAMM from *Data.Map*

Take *Data.Map.lookup* as an example:

$$\begin{aligned} \mathit{lookup} &:: (\mathit{Ord}\ k) \\ &\Rightarrow k \to \mathit{Map}\ k\ v \to \mathit{Maybe}\ v \end{aligned}$$

Cooking HAMM from *Data*.*Map*

Abstract away *Map* for a type variable $c :: * \to * \to *$

$$\begin{aligned} &lookup :: (Ord\ k) \\ &\qquad \Rightarrow k \to c\ k\ v \to Maybe\ v \end{aligned}$$

Cooking HAMM from *Data.Map*

Abstract away *Ord* by a type family

$$\begin{aligned} &\mathit{lookup} :: (\mathit{IsMapCnstr}\ c\ k\ v) \\ &\qquad \Rightarrow k \rightarrow c\ k\ v \rightarrow \mathit{Maybe}\ v \end{aligned}$$

Cooking HAMM from *Data.Map*

Allow for arbitrary errors

$$\begin{aligned} &\mathit{lookup} :: (\mathit{IsMapCnstr}\ c\ k\ v) \\ &\qquad \Rightarrow k \to c\ k\ v \to \mathit{Except}\ (\mathit{Err}\ c)\ (\mathit{Maybe}\ v) \end{aligned}$$

Cooking HAMM from *Data.Map*

Parametrize everything with a Monad

$$\begin{aligned} &\mathit{lookup} :: (\mathit{IsMapCnstr}\ m\ c\ k\ v, \mathit{Monad}\ m) \\ &\qquad \Rightarrow k \to c\ k\ v \to \mathit{ExceptT}\ (\mathit{Err}\ c)\ m\ (\mathit{Maybe}\ v) \end{aligned}$$

Cooking HAMM from *Data.Map*

Wrap it in a typeclass

```
class IsMap (c :: * → * → *) where
  type Err          c        :: *
  type IsMapCnstr m c k v :: Constraint
  lookup :: (Monad m, IsMapCnstr m c k v)
         ⇒ k → c k v → ExceptT (Err c) m (Maybe v)
  ...
```

Add-ons

- Have kind $(* \to * \to *) \to * \to * \to *$

- *add-ons* $\approx$ *monad transformer*

- Alter the implementation under same API

```
instance (IsMap c) ⇒ IsMap (BloomOf h m c) where
  lookup k (BloomOf blf c)
      | bloomMember k blf = lookup k c
      | otherwise         = return Nothing
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Meet the Add-ons

BloomOf h m Adds a bloom-filter with *h* hash functions and *m* machine words.

PartialOf Allows for the argument map to be absent.

PagesOf l Replicates the argument map on a tree structure following *l*.

CacheOf c p Adds a cache *c* with eviction policy *p*.

BoundedCacheOf b c p Forces the size of the cache to never exceed *b*.

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- Type-classes provide access to properties satsified by certain combinations of add-ons.

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Properties: Partitioned

Combination of add-ons containing *PagesOf*: supports notion of “page” or “partition”.

```
class (IsMap c) ⇒ Partitioned c where
  type Partition c :: ∗ → ∗ → ∗
  getPartition :: (IsMapCnstr m c k v)
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               → c k v
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Properties: Cached

Combination of add-ons containing *CacheOf*: supports a lookup that alters the structure of the map, maintaining the eviction policy.

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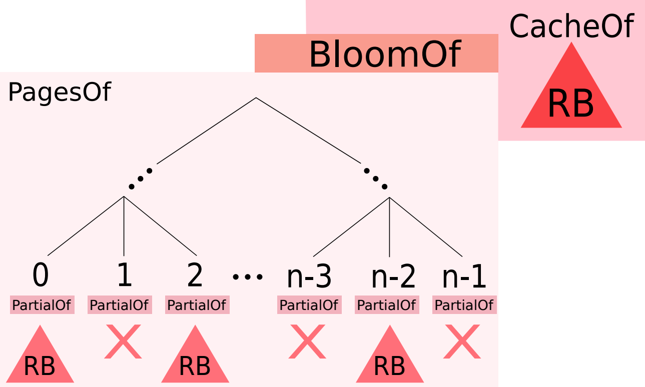
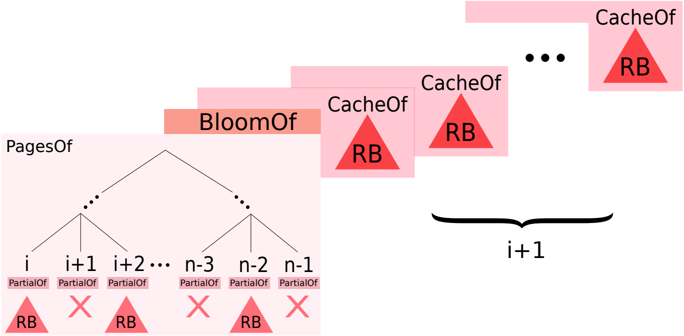
Examples
PWB_1BC



A *authenticated* tree, with possibly absent individual pages, and a cache acting as a *summary*.

Examples

PWB_Cascache



A fixed-point-like construction of just the *summary* of the previous state. Different eviction policies might show interesting differences.

The Authenticated Interface

- `hamm` supports proofs-of-membership

```
class (IsMap c) ⇒ IsAuthMap c where
   type Ev c :: ∗

   vlookup :: (IsMapCnstr m c k v)
           ⇒ k → c k v → ExceptT (Err c) m
                                  (Maybe (v, Ev c))

   rebuild  :: (IsMapCnstr m c k v)
           ⇒ Proxy c → Ev c → k → v → Digest
```

Upon seing a successufl *vlookup*, we can *rebuild* a digest and check it matches the merkle root of the map.

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The Authenticated Interface

Example Instance

```
data PartialOf c k v = Missing Digest
                     | Present   (c k v)

instance IsAuthMap c ⇒ IsAuthMap (PartialOf c) where
  type Ev (PartialOf c) = Ev c

  vlookup k (Missing _) = throwError ErrOnMissing
  vlookup k (Present c) = withExceptT ErrOnPresent
    $ vlookup k c

  rebuild _ = rebuild (Proxy :: Proxy c)
```

Experiment: Routine

- Insert 200000 keys in a map.

- Simulate transfering the “summary”.

- Perform *n createOrUpdate* operations, serving and counting page misses as they arise.
  - Draw keys according to uniform and geometric distributions (99.99%)

- We assume 14ms latency and 16Mbps transfer speed.

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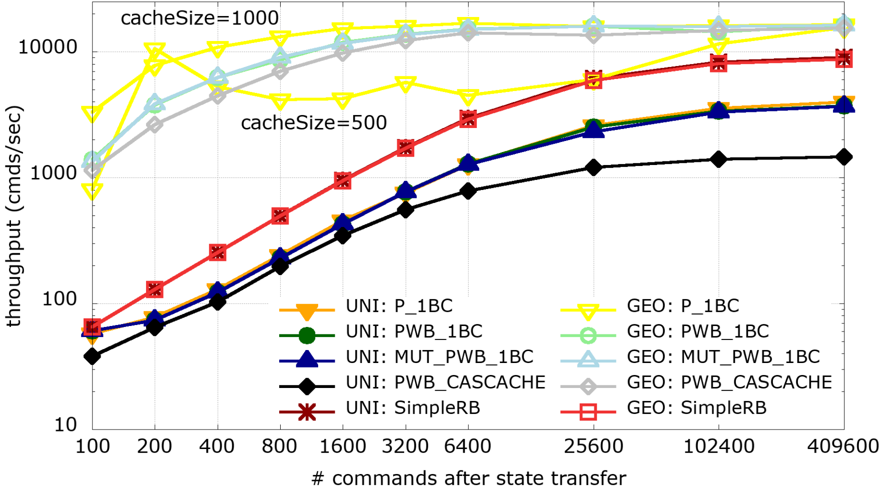

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Bloom Filter

- Seemed like a great idea! Prevent unecessary page fetches.
- Turns out its not so great:
  - Either too big to be transfered efficiently
  - Or fills up quite fast and produces false positives.
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