VMap

a versioned Map implementation

May 2011

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Origin of the Idea

- Driving home from Columbia after visiting son
- Wife sleeping so can't play radio
- Thinking about functional programming
- Thinking about hash tables, a.k.a. maps ← invented in 1953 by Luhn and independently by Amdahl, Boehme, Rochester, Samuel

The Problem

- Thinking about how they conflict
  - FP avoids mutable things
  - maps are mutable
- Want to be able to
  - write functions that take maps as parameters and return a new map that is a modified version of the one passed in
- Is there a way to implement an efficient, immutable hash table?

Ignorance Is Bliss

- Really into Clojure a little over two years ago
- Forgot that Clojure already solved this problem
  - `PersistentHashMap` and `PersistentHashSet`
  - uses wide tries (up to 32 children)
  - from Wikipedia, a trie is "an ordered tree data structure that is used to store an associative array"
  - based on the paper "Ideal Hash Trees" by Phil Bagwell
- So my solution
  - is nothing like the Clojure solution
  - is a variation on the typical hash table implementation

Sets From Maps

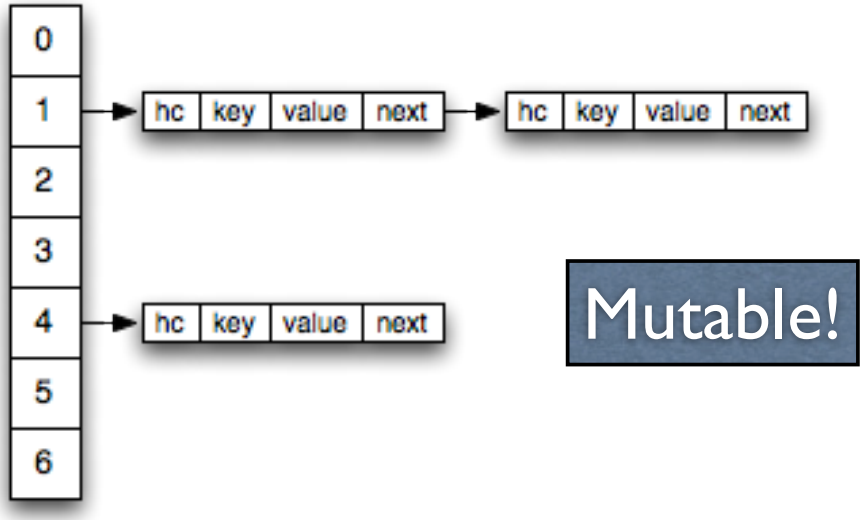
- Can implement sets from maps
- Values are booleans
- Slight optimization by
  - using boolean primitives instead of Boolean objects
  - ignoring values

Simple Approach

- Methods that normally mutate return a mutated copy instead of changing the original
  - add/put
  - delete/remove
- Stupid idea!
  - slow
  - uses too much memory
- Is there a way that one "version" of a map can share memory with another version?

Typical Map Implementation

- Buckets
  - array of chains
- Chains
  - linked list of entry objects
- Entry objects
  - hold hash code of key, reference to key, reference to value and reference to next entry
- Key objects
  - implement a "hashCode" method
    - used to locate the correct bucket
  - implement an "equals" method
    - used in chain searches to find the entry object for a given key



Steps to Add Key/Value

- Compute hash code of key
- Mod hash code by # of buckets
  to select bucket
- Walk entries in chain
  searching for an entry with an equal key
- If found, change value of existing entry
- Otherwise add new entry

In Code

- Ruby
  - `map[key] = value`
- Java
  - `map.put(key, value);`
- Objective-C
  - `[map setObject: value forKey: key];`

Steps to Find Value of a Key

- Compute hash code of key
- Mod hash code by # of buckets
  to select bucket
- Walk entries in chain
  searching for an entry with an equal key
- If found, return value of existing entry
- Otherwise return null

In Code

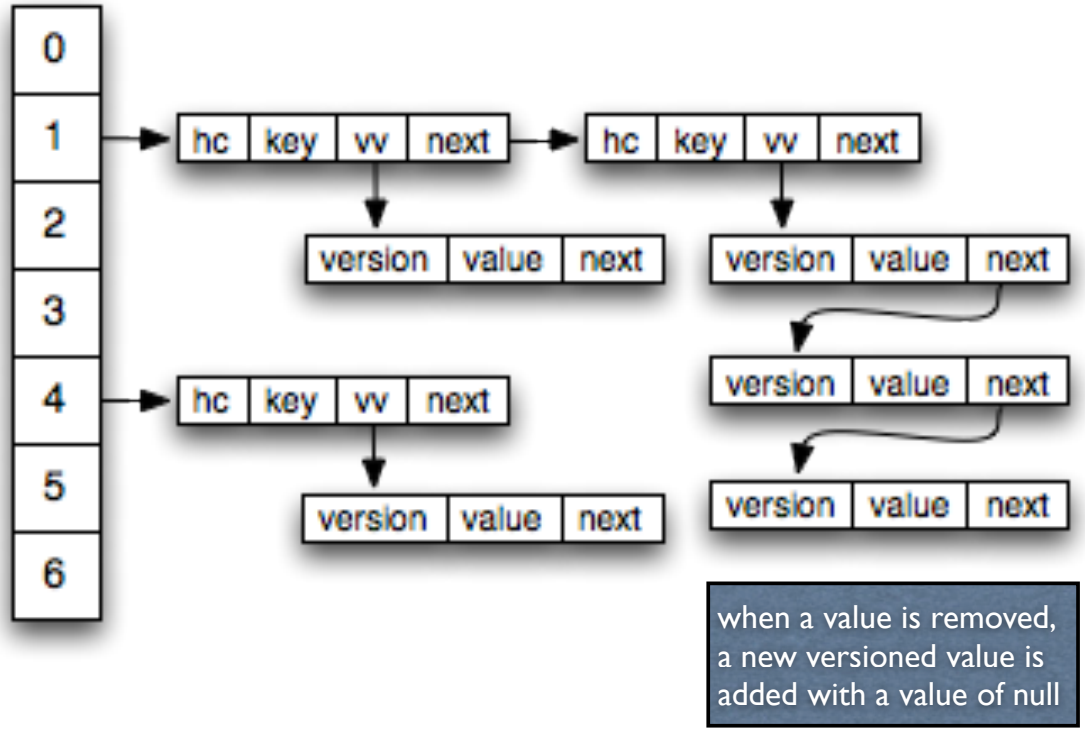
- Ruby
  - `value = map[key]`
- Java
  - `value = map.get(key);`
- Objective-C
  - `value = [map objectForKey: key];`

Rehashing

- As entries are added,
  average length of chains grows
- Lookups take longer due to
  sequential search of chains
- Rehashing fixes this by creating more buckets
  and redistributing entries into new, shorter chains
  - reason why hash codes are saved - avoids recomputing
  - new number of buckets is typically old*2 + 1
  - mod of hash code and new number of buckets locates new chain

How To Share Versions?

- Change entry objects to hold a chain of versioned values!
  - newest values at beginning since more likely to be retrieved



New VMap Instances

- Modifying a VMap creates a new instances
- But each new VMap instance can share an "internal map"
  - picture on previous slide
- Each VMap instance stores
  - version number
  - reference to internal map
  - size - to avoid recomputing each time it is requested

Rehashing Strategy

- Automatically rehash when entry count / bucket count > 0.75
  - means that on average 75% of the buckets contain one entry in their chain
    - of course many will contain more than one entry and many won't contain any entries
- Tries to avoid having many chains containing more than one entry
  - those require sequential searching

Version Limit

- Currently the type of version numbers is **`int`**
- Can't create more than **`2^31 - 1`** versions
  - 2,147,483,647 > 2 billion
- Need more than 2 billion versions?
- Could use **`long`** instead
  - 2^63 - 1 = 9,223,372,036,854,775,807 > 9 quintillion
- Other map implementations don't have a limit
- Is this a deal breaker?

Initial Implementation

- In Java because I felt most confident in getting it right there
  - adding support for generics greatly increased code complexity
- But most Java developers don't care about immutability
  - need to port to functional languages
- Lots of unit tests
- Performance tests compare to
  - Java `HashMap` and `HashSet`
  - Clojure `PersistentHashMap` and `PersistentHashSet`

Simple Example

```
VMap<String, Integer> map0 = new VHashMap<String, Integer>();
VMap<String, Integer> map1 = map0.put("foo", 1);
VMap<String, Integer> map2 = map1.put("bar", 2);
VMap<String, Integer> map3 = map2.delete("foo");
VMap<String, Integer> map4 = map3.put("bar", 3);
VMap<String, Integer> map5 = map4.put("foo", 4);
```

map0 is empty

map0 is still empty.
map1 only contains the key "foo".

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map2 contains the keys "foo" and "bar".

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map4 contains the key "bar",
but with a different value than in map2.

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map3 still only contains the key "bar".
map4 still contains the key "bar",
but with a different value than in map2.
map5 contains the keys "foo" and "bar",
but "foo" has a different value than in map1 and map2.

Multiple Values in a Version

```
// Using a set.
VSet<String> set1 =
    new VHashSet<String>("red", "orange", "yellow");
VSet<String> set2 = set.add("green", "blue", "purple");
```

set2 contains all six colors

```
// Using a map.
VMap<String, Integer> map =
    new VHashMap<String, Integer>();
map.put(
  new Pair<String, Integer>("foo", 1),
  new Pair<String, Integer>("bar", 2),
  new Pair<String, Integer>("baz", 3));
```

there is also a constructor that takes a variable number of `Pair` objects

Which Versioned Values?

- When performing a lookup
  in a particular VMap instance,
  which versioned values should be considered?
- A given VMap instance can use values
  from its ancestor maps
  - lower version number, but not necessarily all lower versions
  - version 6 may derive from version 4 which derives from 1 and 0
  - values are in order from newest to oldest version
  - sequential search, but don't need to search far in the common case
    - tend to want newer values more than older ones
    - tend to not have a large number of values for the same key

Recording Ancestors

- How does a VMap instance record its ancestors?
  - Java implementation using `java.util.BitSet`
  - version numbers are used as indexes
  - uses an array of longs that grows automatically as needed
- BitSets are large when many versions are created
  - 1 million versions => BitSet with 15,625 longs
- But VMap instances can share a BitSet
  - just need to be careful to only check versions of indexes that are <= instance version

Searching Versioned Values

```
VersionValue<V> vv = firstVV; // of an entry
while (vv != null) {
    if (vv.version == version.number) return vv;
    if (vv.version < version.number &&
        version.ancestors.get(vv.version)) {
        return vv;
    }
    vv = vv.next;
}
return null;
```

Thread Safe?

- Lots of synchronized methods
- Performance tests pay the cost for all those locks
- Could use a code review

Performance Tests ...

- Tested using full text of four classic books

Title	Words	Unique
Alice in Wonderland	26,388	3,153
Adventures of Tom Sawyer	70,040	8,761
A Tale of Two Cities	135,820	11,671
War and Peace	562,177	21,843

Map Performance Tests

- Data
  - 1st key is "firstKey"; 1st value is first word in book
  - 2nd key is 1st word in book; 2nd value is 2nd word in book
  - and so on

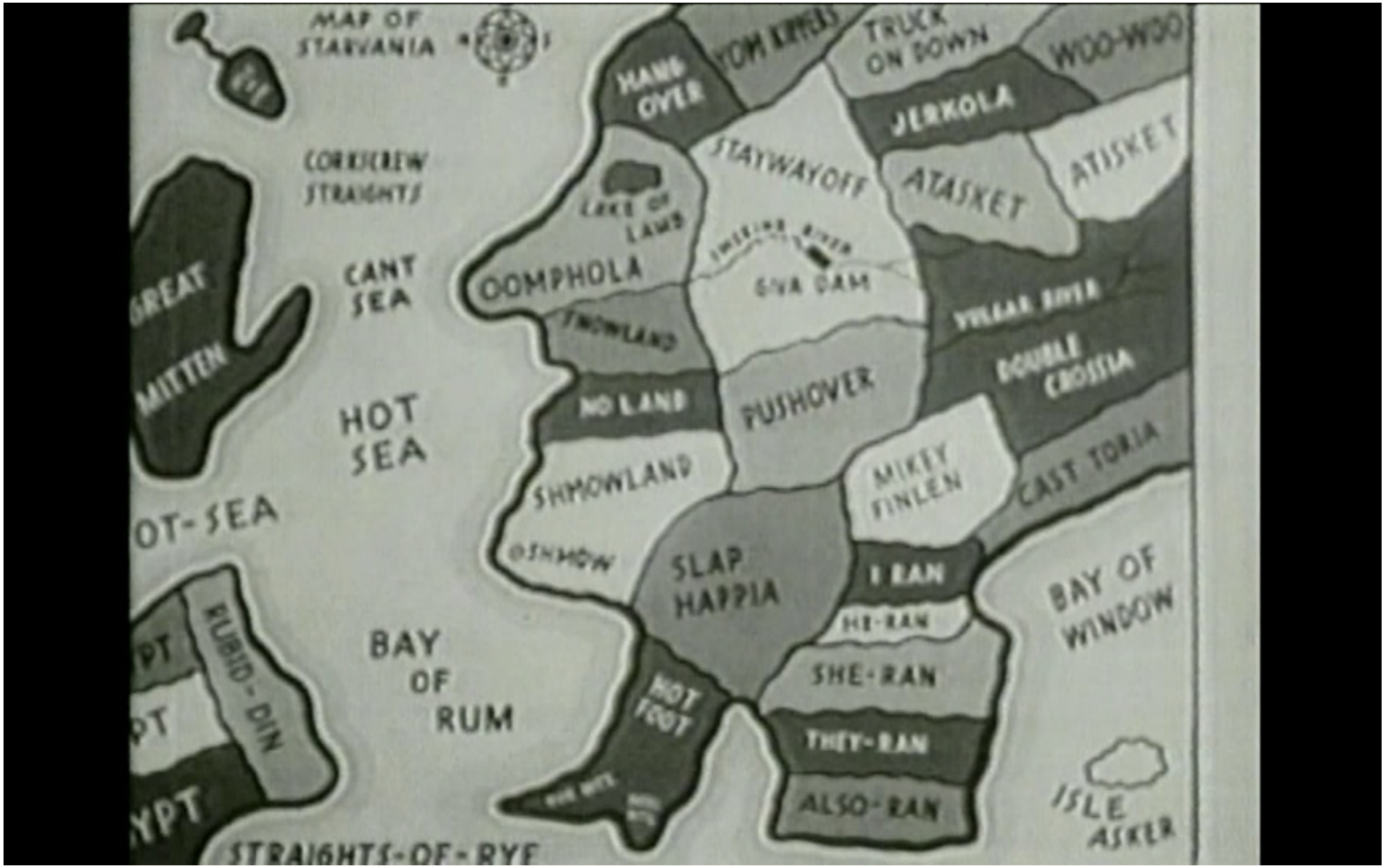
For "War and Peace" this results in 30,762 values for the key "the"!

- Steps
  - get list of key/value pairs (not included in timing)
  - create empty map
  - populate map from pairs
  - retrieve the value for each key (lookup) and verify
- Other details
  - perform a priming run for each map implementation
  - capture time of second run for each map implementation

Set Performance Tests

- Data
  - ordered collection of all words in book
    - not a set, so includes duplicates
- Steps
  - get ordered list of words (not included in timing)
  - create an empty set
  - add each of the words to the set one at a time
  - verify that the set contains each of the words (lookup)
- Other details
  - perform a priming run for each set implementation
  - capture time of second run for each set implementation

Study This Map!



Performance Results

numbers are in milliseconds;
1st is time to **load** data; 2nd is time to **lookup** values; 3rd is **total**

	Alice in Wonderland	Adventures of Tom Sawyer	A Tale of Two Cities	War and Peace
java.util.HashMap	2 1 3	6 1 7	14 4 18	89 6 95
clojure.lang.PersistentHashMap	25 3 28	46 2 48	251 3 254	658 9 667
com.ociweb.collection.VHashMap	10 5 15	24 8 32	51 5 56	271 17 288
java.util.HashSet	8 3 11	17 5 22	34 15 49	91 75 166
clojure.lang.PersistentHashSet	32 3 35	95 7 102	85 22 107	149 110 259
com.ociweb.collection.VHashSet	6 4 10	16 11 27	39 36 75	154 113 267

Conclusions

- Can't compete with java.util versions
  - but those are mutable
- Much faster loading times than Clojure versions
  - but advantage becomes less when number of entries gets very large
- Slower lookup times than Clojure versions
  - but that is a much smaller part of the total than load time
  - not good though since most apps will perform more lookups than loads
- Need to verify thread safety
- Maybe more optimizations can be made

What Do You Think?

- Has a similar idea already been evaluated?
- Is this idea worth pursuing further?
- Do you have ideas for further optimizations?
- What programming language communities would value a port of this?

- On GitHub - https://github.com/mvolkmann/VMap
- Send feedback to mark@ociweb.com
- Thanks for listening!