Non-Volatile Memory Through Customized Key-Value Stores

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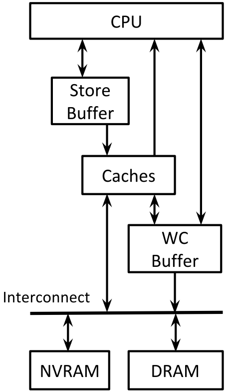
Characteristics of NVM

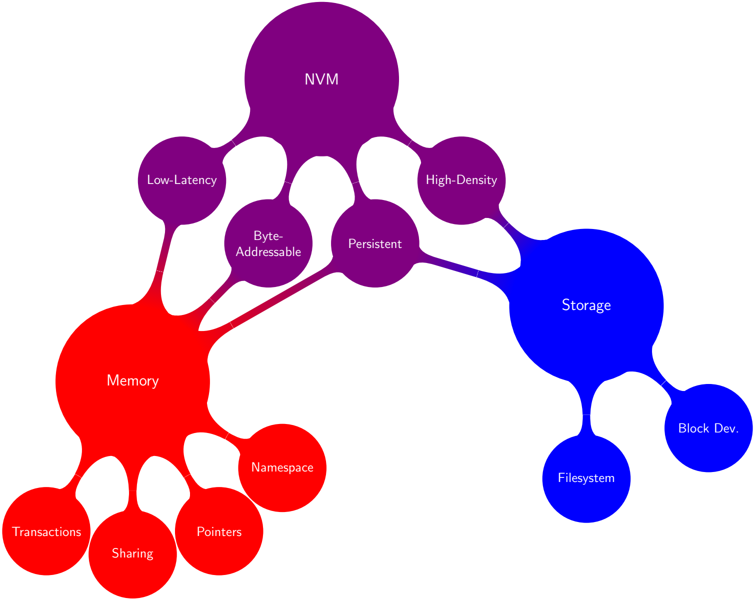
- Non-volatile
  - Memory survives power cycles
  - No need to restore from slow disks or flash
- High density
- Low latency
- Fine granularity updates
  - Operates on individual words
  - Access through `load` and `store` instructions

NVM Challenges

- Non-persistent caching
- Out-of-order flushes
  - write-back caches
- Torn writes
  - Updates bigger than 8 bytes are not atomic
- Complex interfaces
  - flushing cache lines, using memory fences, etc.



Approaches to use NVM

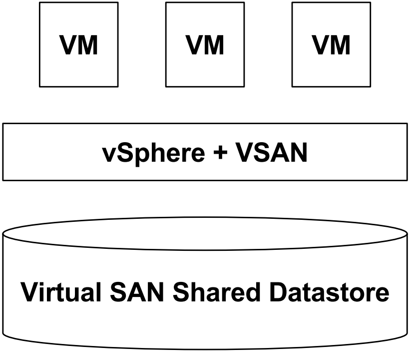


Application Specific Solution

We argue for consuming NVM through a transactional key-value store.

- Flexible
- Simple
- Performant

Case Study: VMware® Virtual San



METRADB: Specialized KV Store for VSAN

- Organizes objects in Containers
- Provides a flat namespace for Containers
- Provides transactional update containers
  - Only one active transaction per container
  - Transactions do not expand to multiple containers
- Provides KV-Store like interface

METRADB API

Operation	Description
$open(name, flags)$	open/create container, get handle
$remove(name)$	remove container
$close(h)$	close a handle
$put(h, k, buf, len)$	put key-value pair
$get(h, k, buf, len)$	get key-value pair
$delete(h, k)$	delete key-value pair
$commit(h)$	commit transaction
$abort(h)$	abort transaction

Transactions: How to do them?

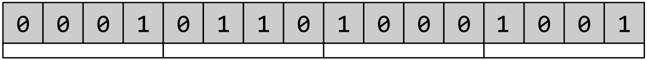
Undo Logging

- Update in-place
- Adds latency to critical path
- No easy way to batch and flush (poor cache locality)
- Data can be read from its original location
- Easy to implement

Redo Logging

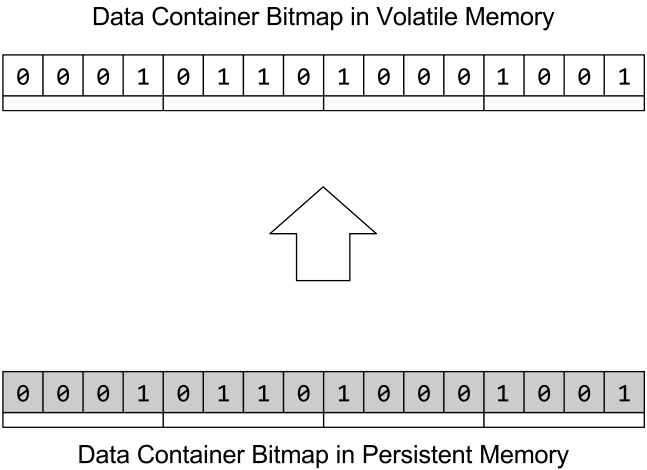
- Updates are buffered and applied at commit
- Batch flushes and sync (better cache locality)
- No latency added to the critical path
- Data may need to be read from the log
- Implementation is more complicated

Shadow Bitmaps: Handling Allocations



Data Container Bitmap in Persistent Memory

Shadow Bitmaps: Handling Allocations



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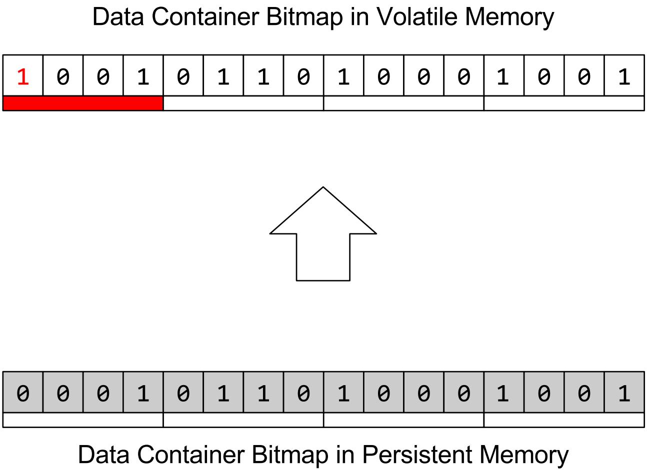

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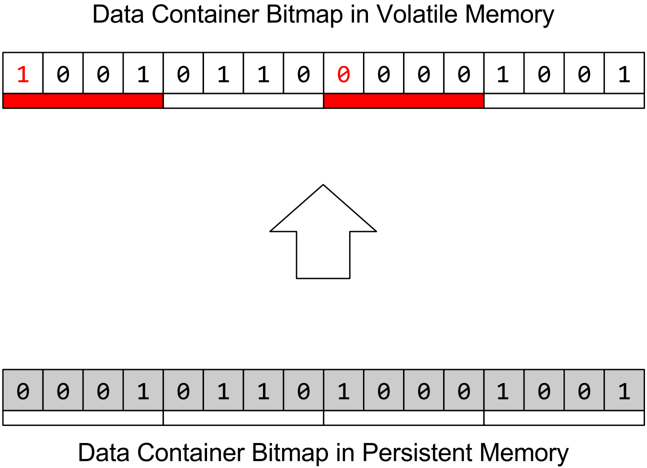

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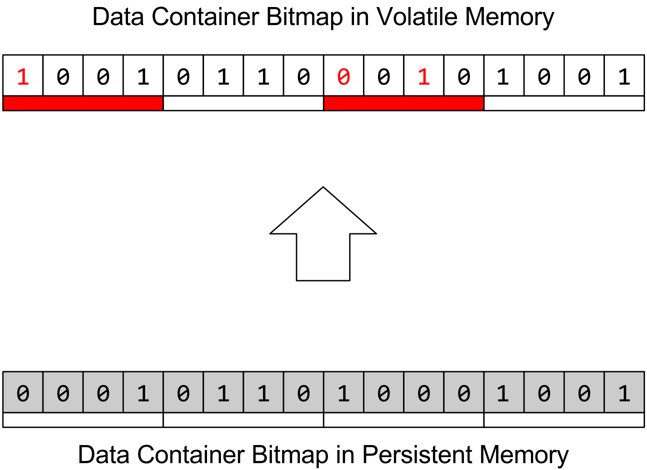

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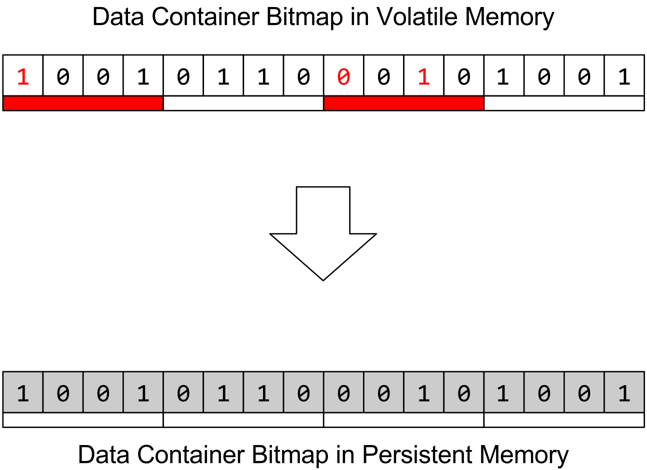

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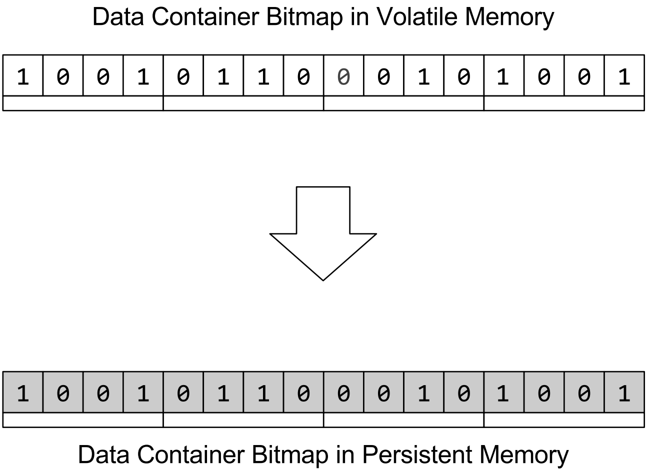


Implementing Transactions

- Redo logging
- Out-of-place updates
- Shadow data structures
- Idempotent commits
  - Volatile metadata can be reconstructed from the logs
- Implicit start transaction
  - Move the state of the KV Store from one consistent state to the next

Indexing: Which data structure to use?

B+ Tree

- Higher latency for average operations
- Higher write amplification
- Predictable performance
- More difficult to implement
- Maintain key order

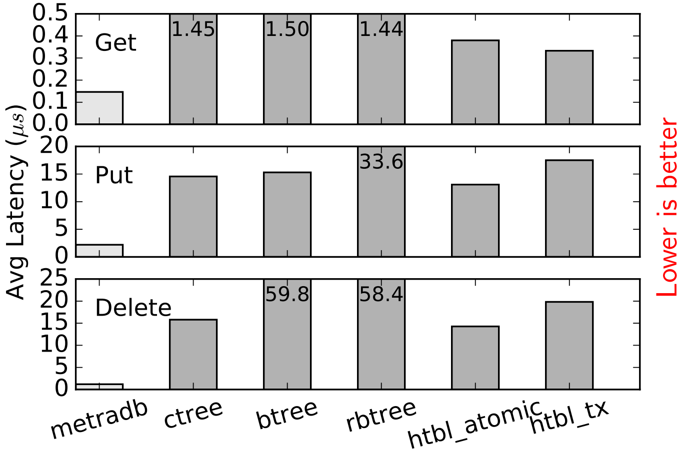
Hash Table

- Low latency for average operation
- Lower write amplification
- Less predictable performance
- Easy to implement
- Does not maintain key order

Experimental Setup

- METRADB is a user space library for GNU/Linux
- Linux Kernel v4.4
- 24 GB of RAM
- Intel XeonE5-2440 v2 1.90GHz CPU
  - 8 cores each with 2 hyper-threads
- NVM was simulated with memory mapped files
  - EXT4 with DAX support

Comparison with NVML



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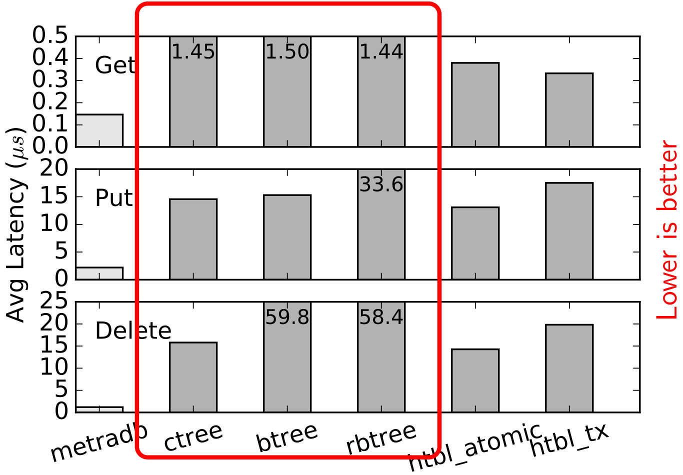

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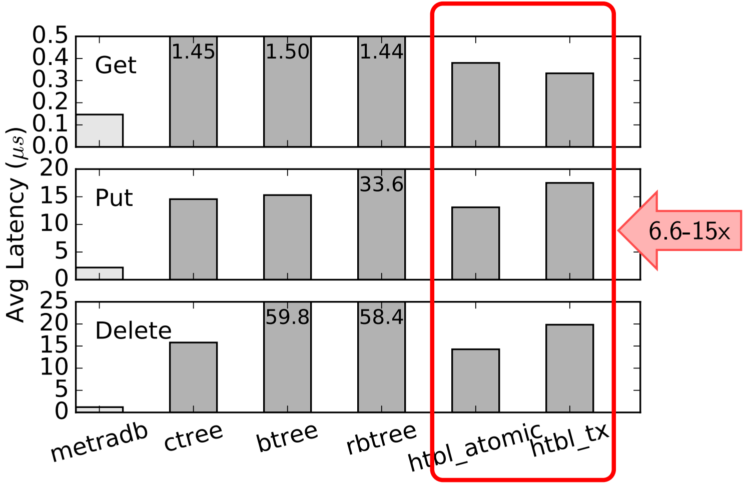

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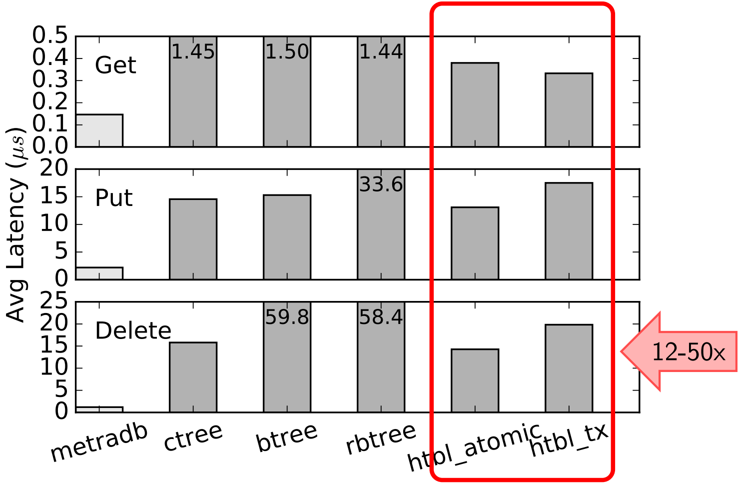

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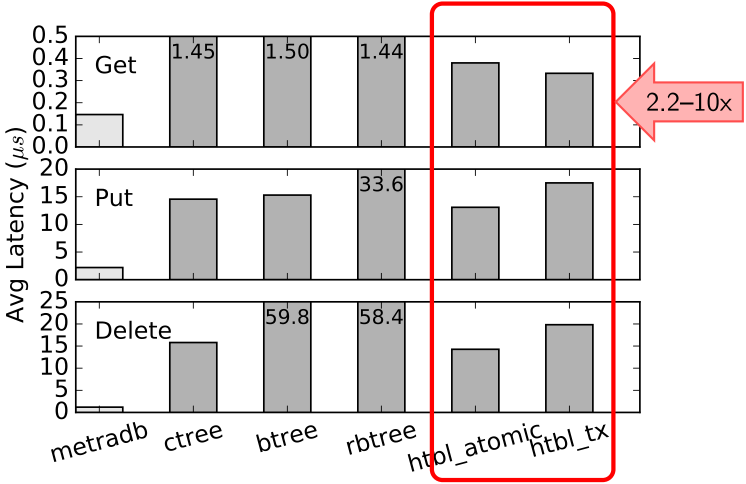
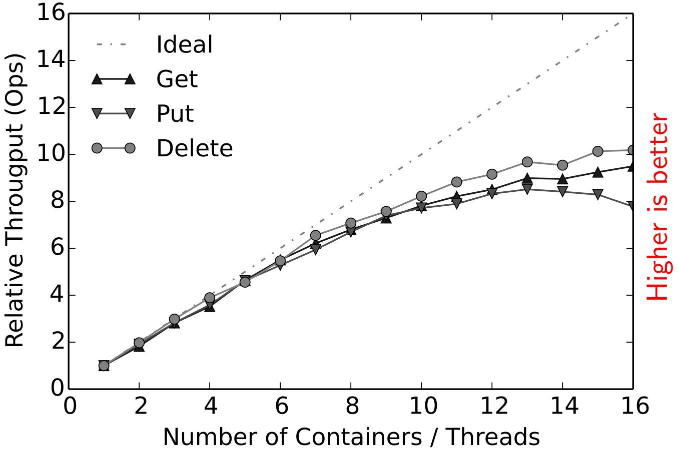


Throughput Scalability of METRADB



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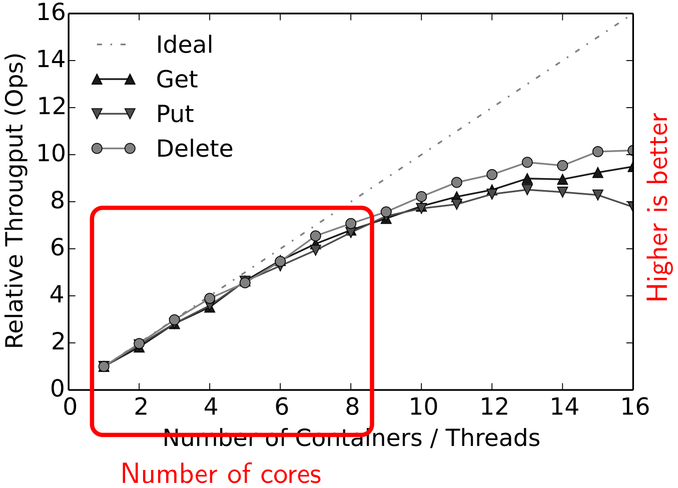

Summary

- We propose application to consume NVM through a middle layer
  - For our application a key-value interface was sufficient
- This approach allows simplicity, easy adoptions of different NVM technologies, and fast development
  - About 2.3K LOC
- Because our solution was tailored to our application, we achieved higher performance than more general solutions

Thank you!

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