Minimally Ordered Durable Datastructures for Persistent Memory

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Executive Summary

Persistent memory enables recoverable applications

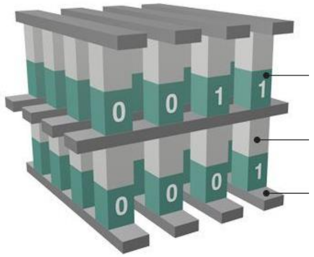
Analysis on Intel Optane memory reveals:

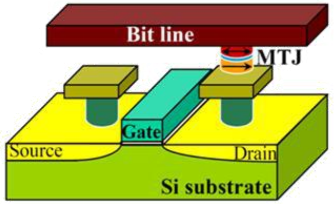
- ~73% of runtime is overhead: mostly flushing data to PM
- Overlapping flushes reduces flush costs by 75%

Minimally Ordered Durable (MOD) Datastructures:

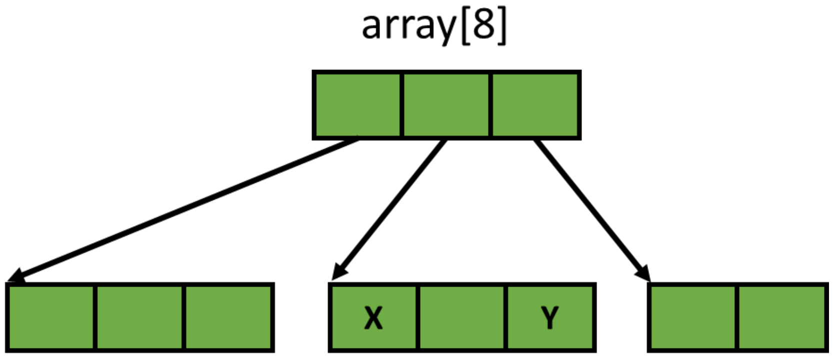
- C++ datastructures: easy to use & good performance
- Increases flush overlap with techniques from functional datastructures
- ~40% speedup compared to PMDK-STM
- Code at https://zenodo.org/record/3563186

Outline

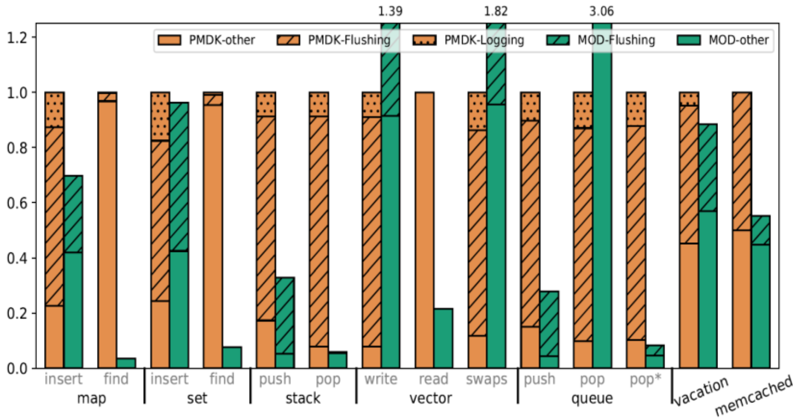




BACKGROUND

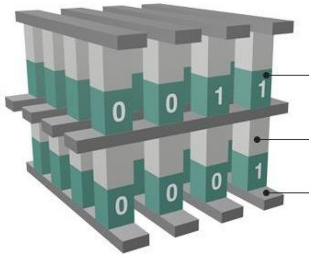


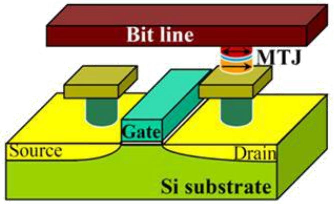
MOD DATASTRUCTURES



EVALUATION

Outline





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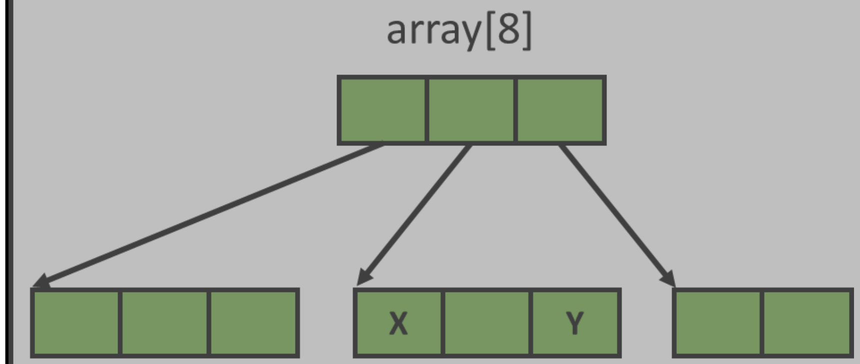

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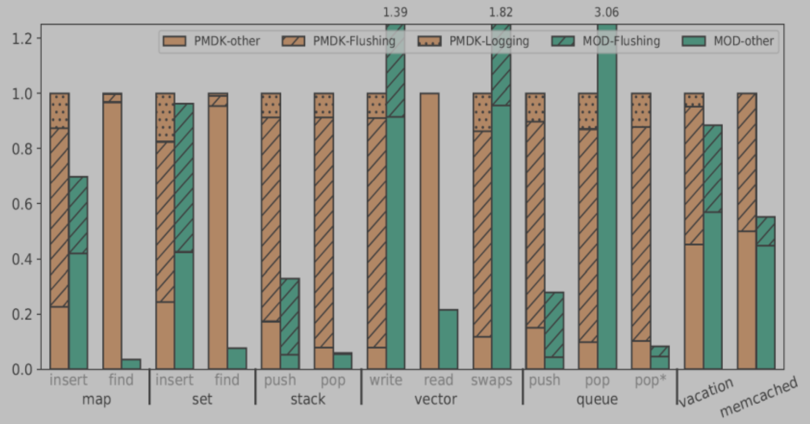
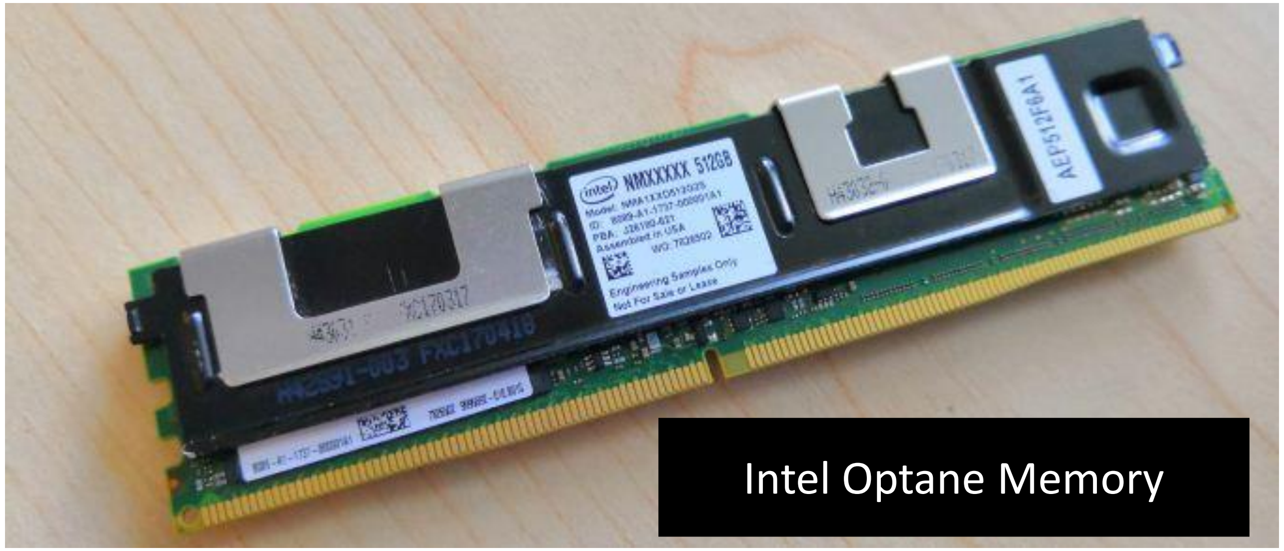


EVALUATION

Persistent Memory is Here!

User-space access to non-volatile memory

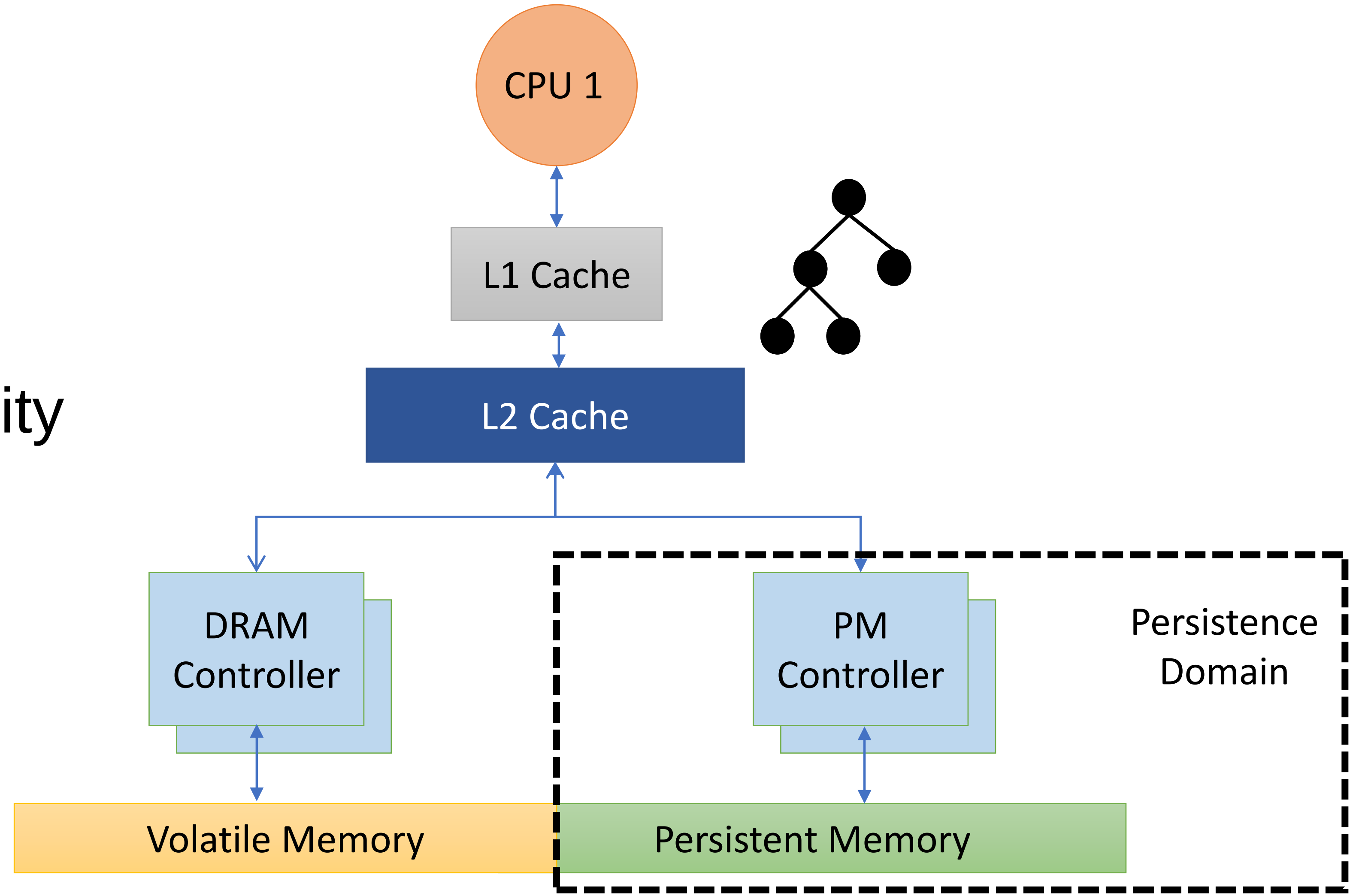
Enables recoverable applications with durable in-memory data



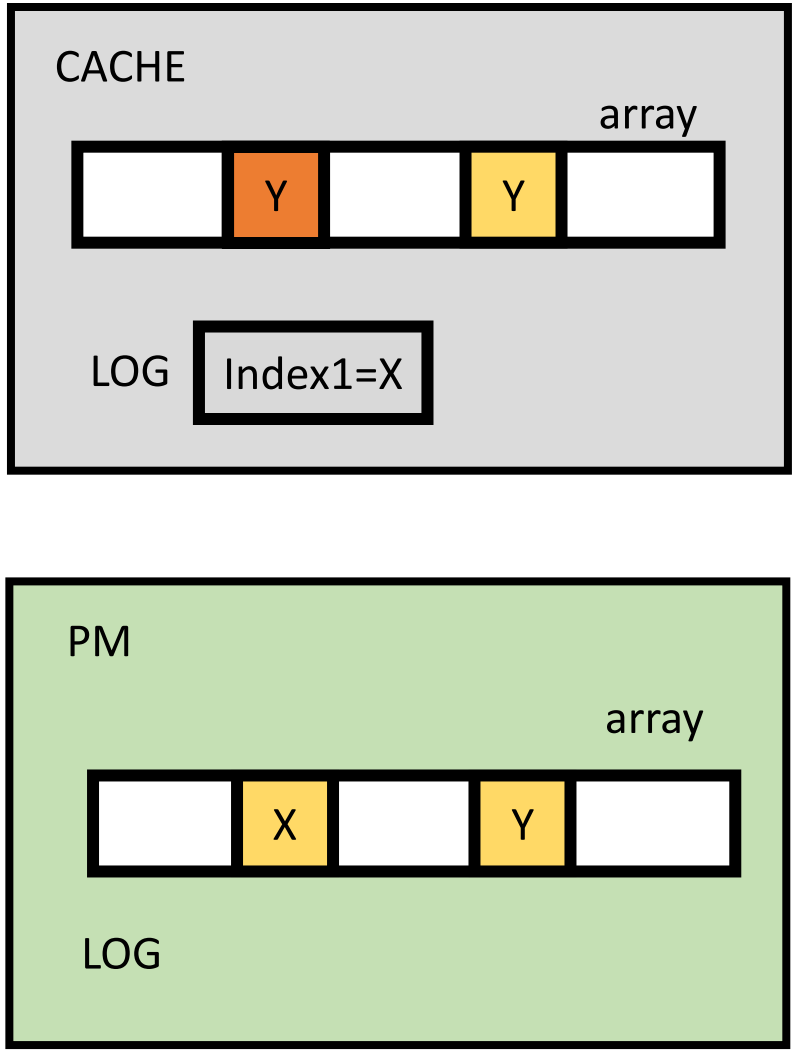
Intel Optane Memory

Programming Challenges

1. Durability
2. Failure Atomicity



Background: Software Transactional Memory



FLUSH LOG

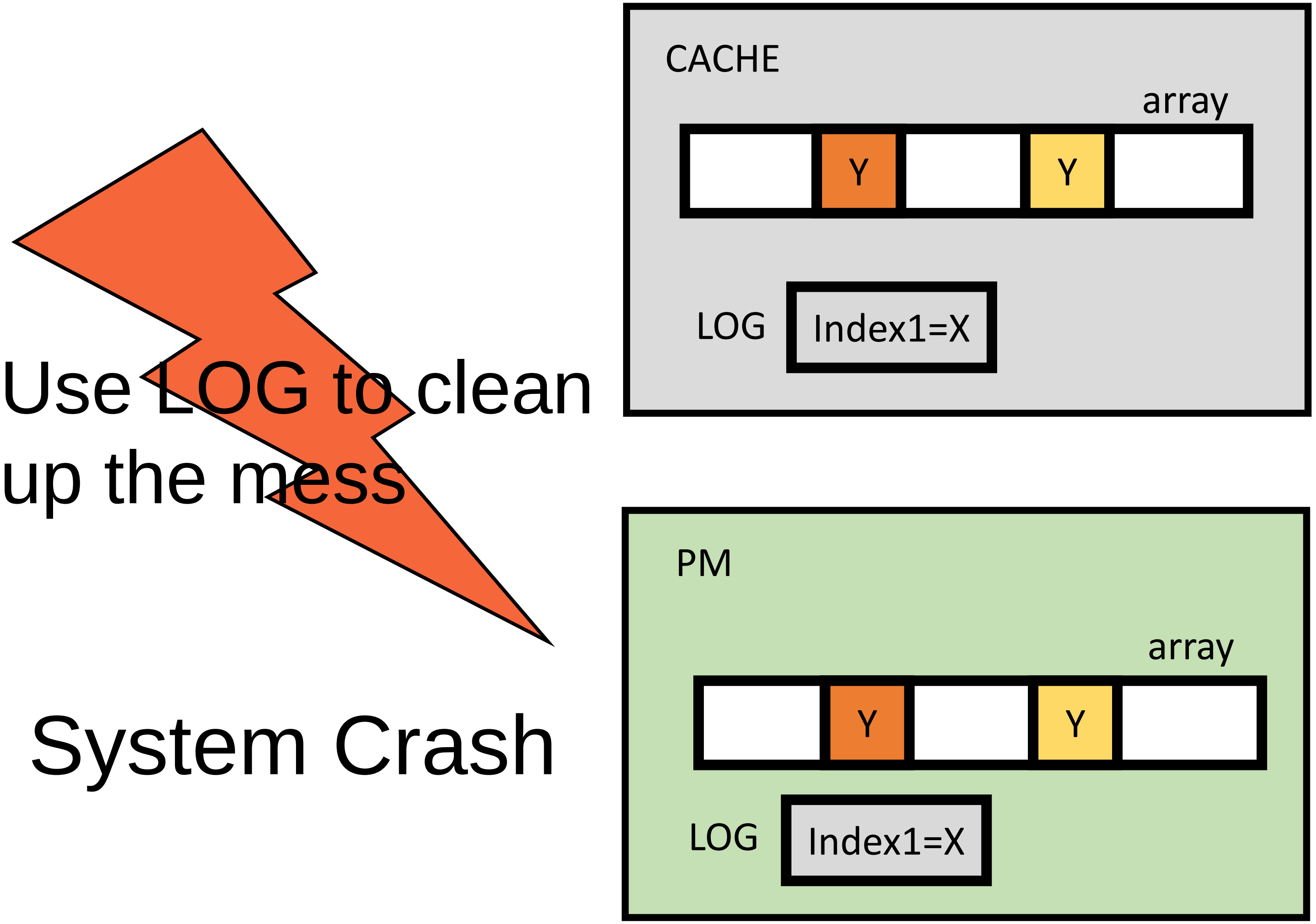
FENCE: LOG DURABLE!

FLUSH DATA

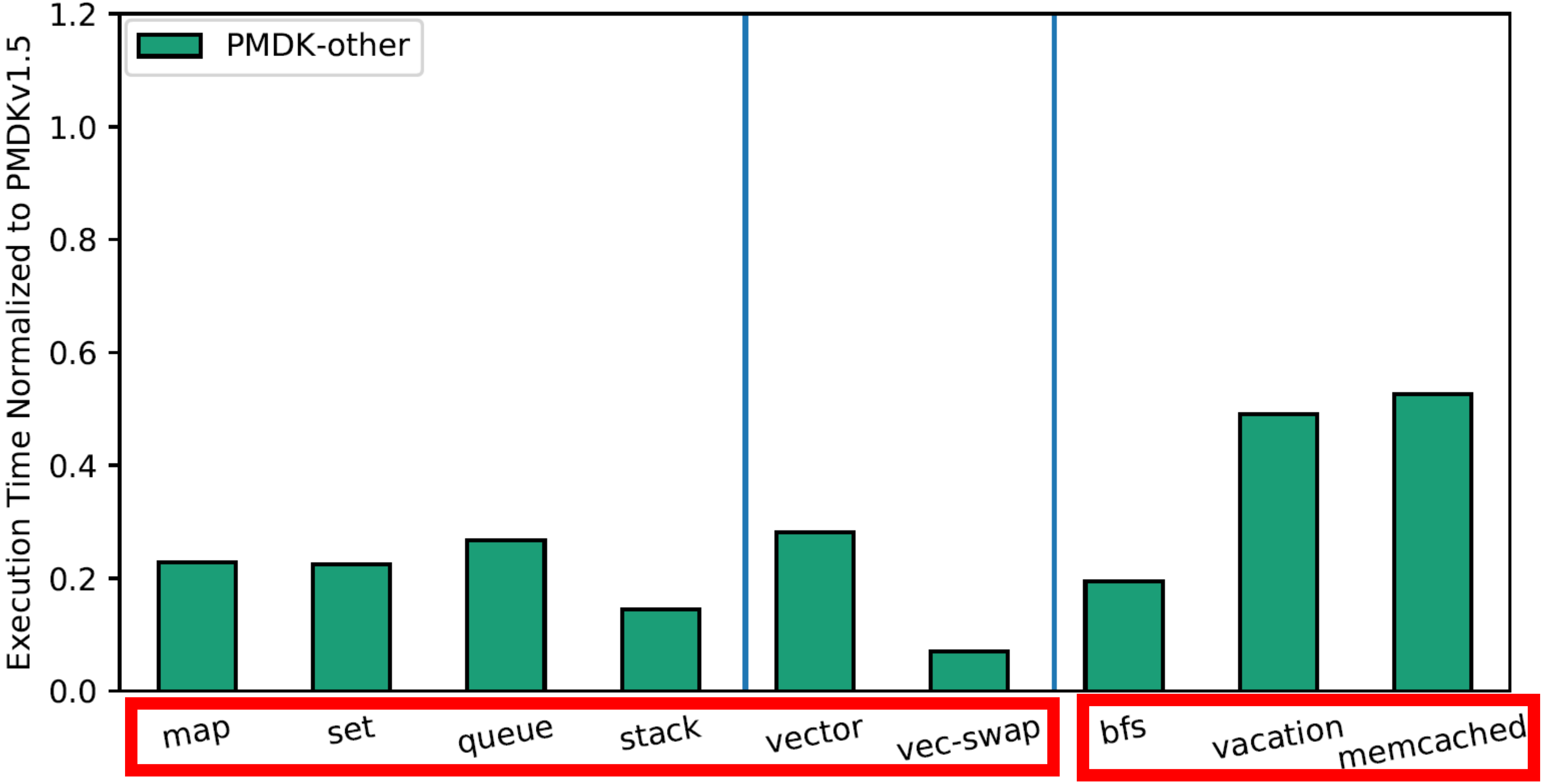
Background: Software Transactional Memory

Use LOG to clean up the mess

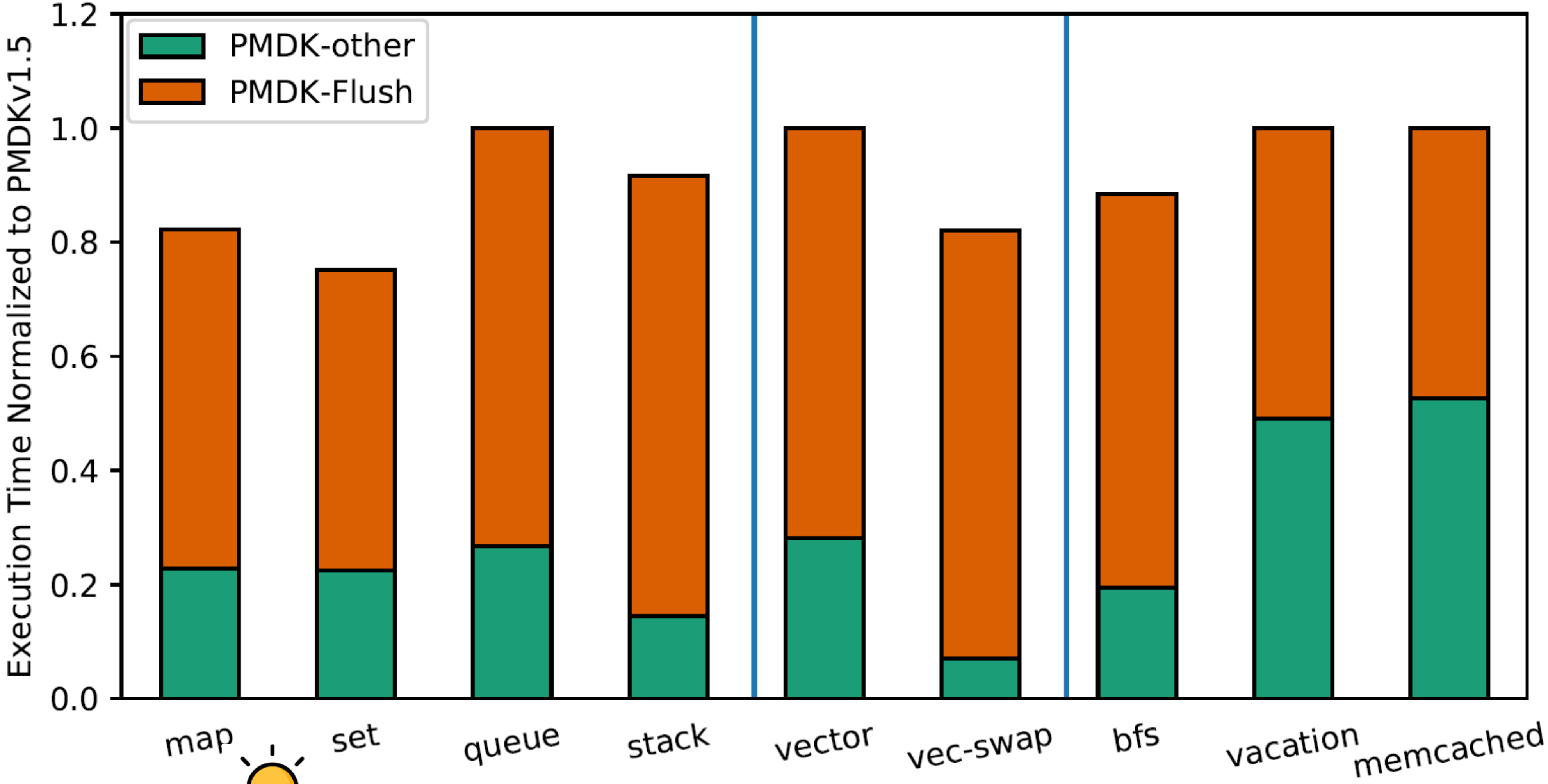
System Crash



PMDK-STM performance on Optane

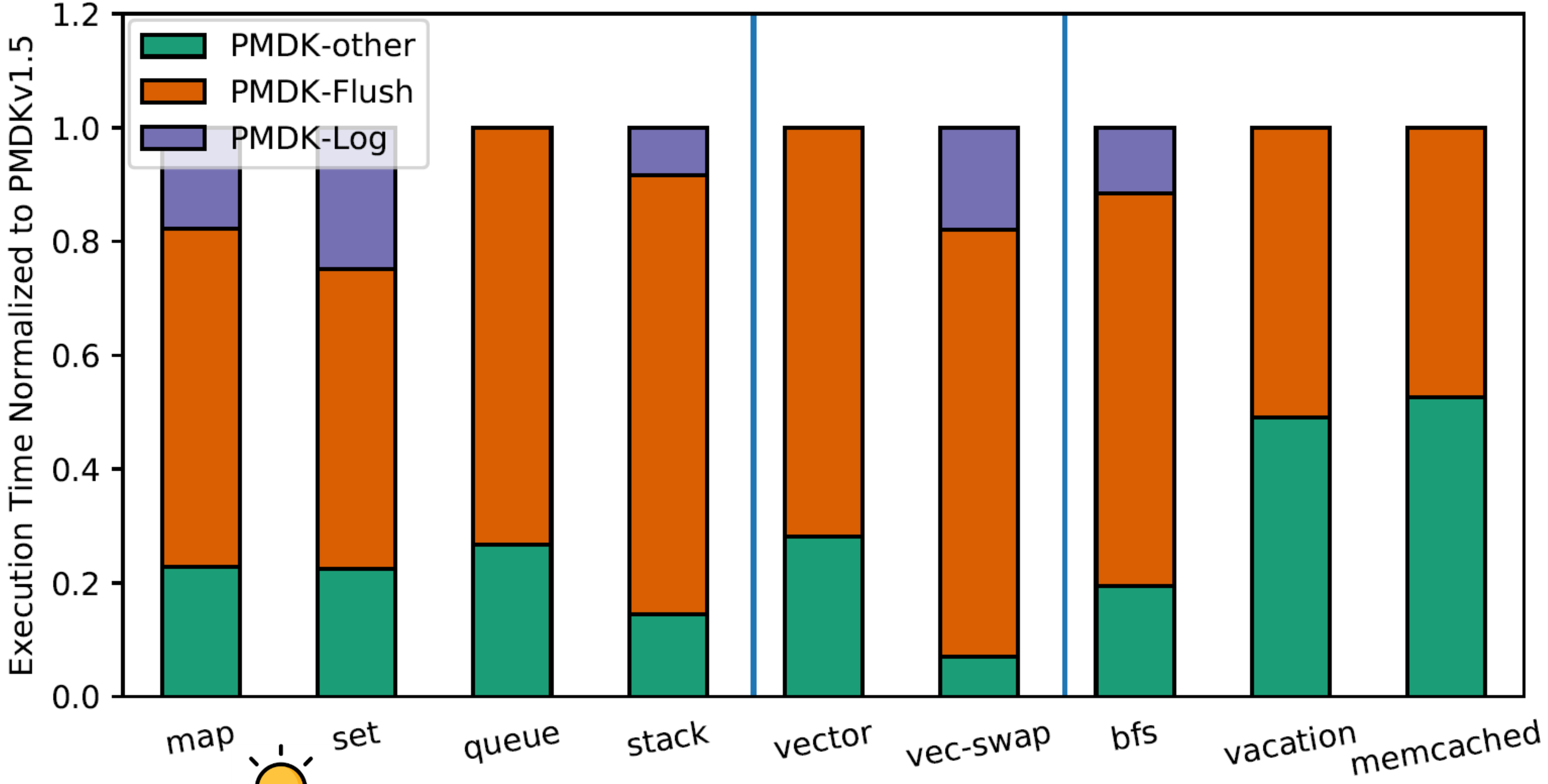


PMDK-STM performance on Optane



~73% of STM runtime is overhead, mostly from flushing

PMDK-STM performance on Optane



~73% of STM runtime is overhead, mostly from flushing

Flush (CLWB) Overheads on Optane

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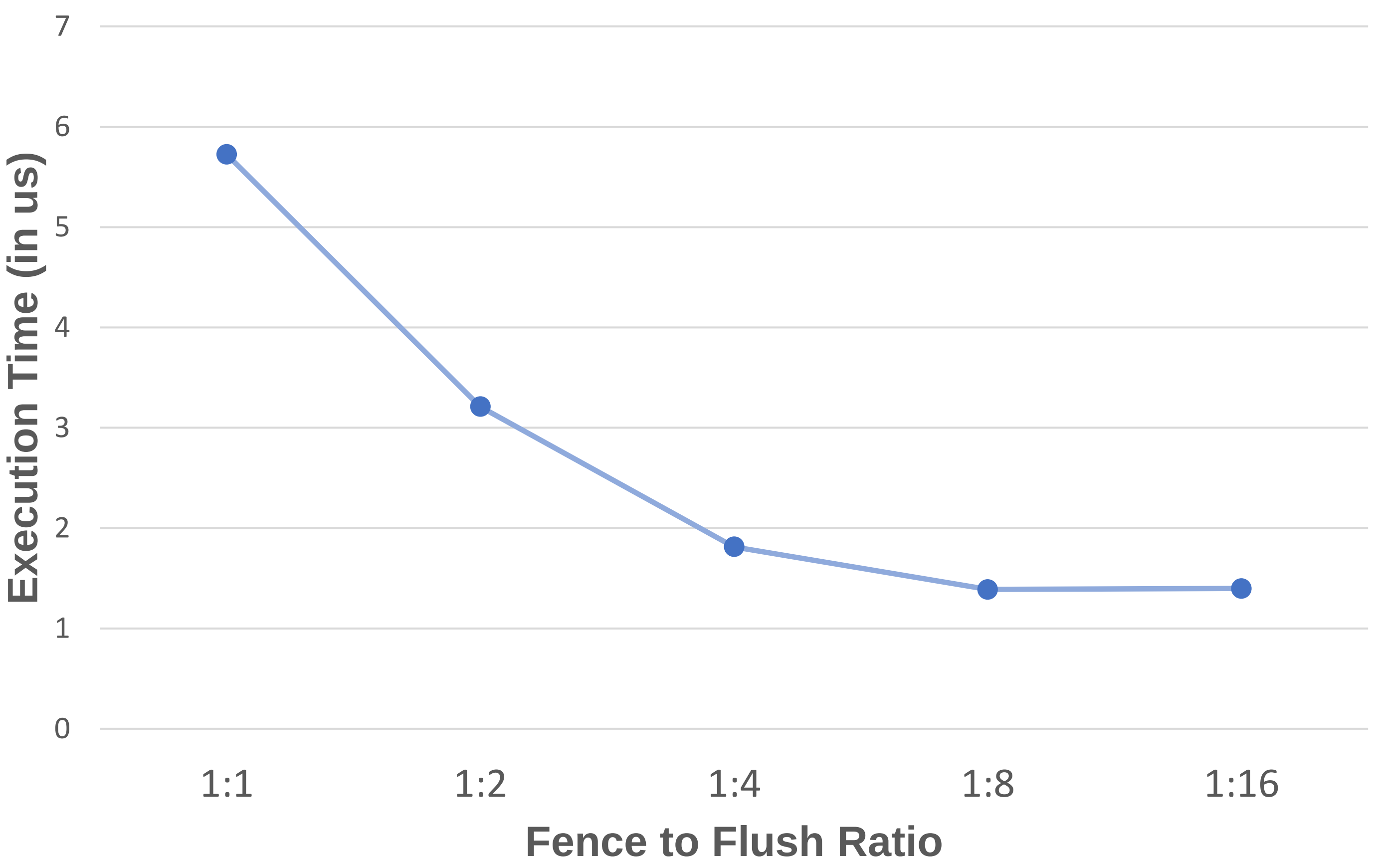

Flushing overhead falls with overlap (following Amdahl's Law)

Flush (CLWB) Overheads on Optane

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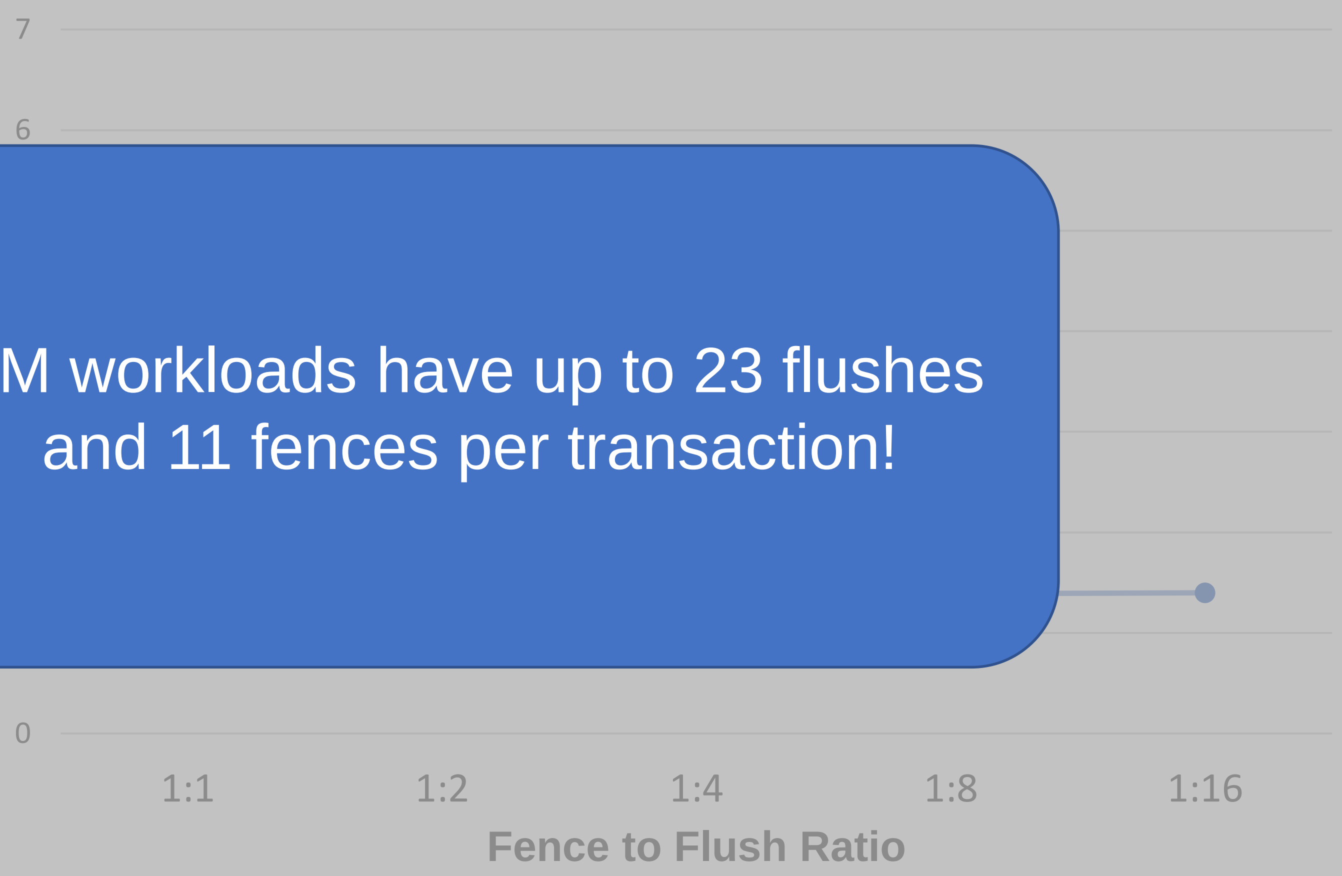
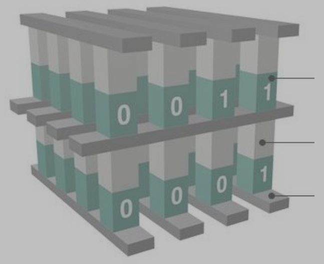
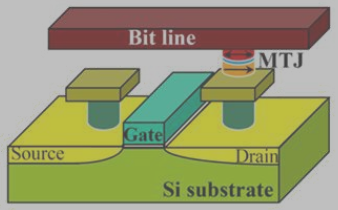


PM workloads have up to 23 flushes and 11 fences per transaction!

Flushing overhead falls with overlap (following Amdahl's Law)

Outline





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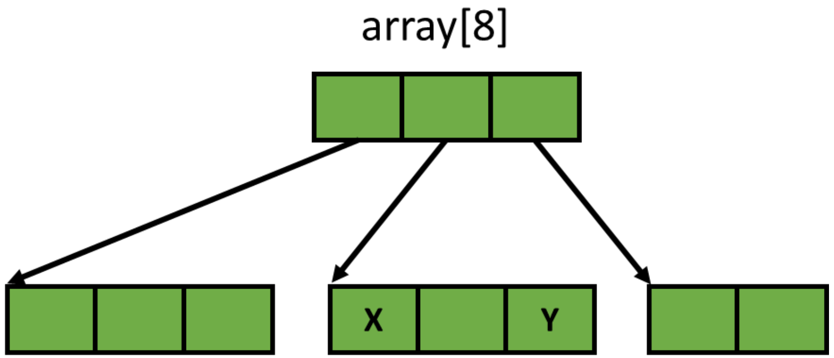
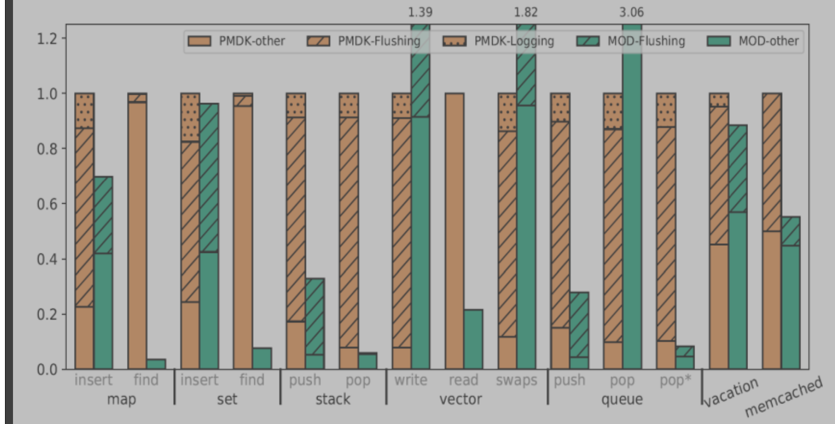


MOD DATASTRUCTURES



EVALUATION

Goal: Minimize Ordering!

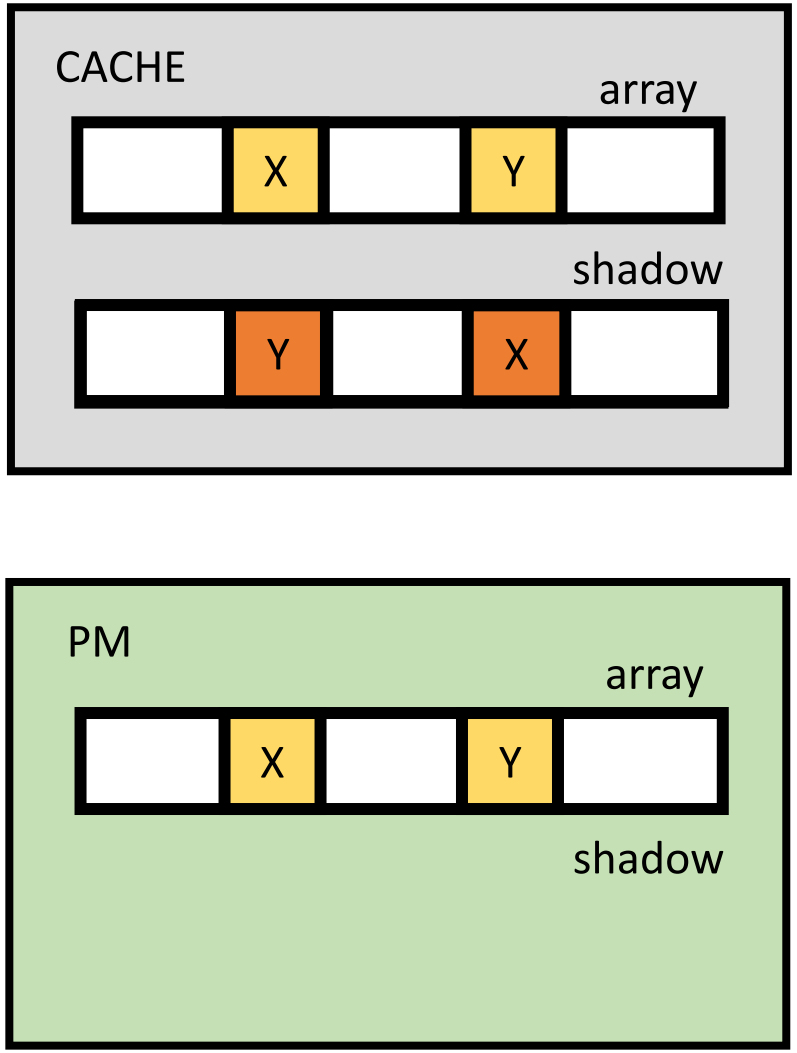
Reduce FENCEs (ordering), even if extra computation required

How to provide failure-atomicity with minimal ordering?

Shadow Paging: Out-of-place updates instead of overwriting data

Background: Shadow Paging

shadow = array // Create shadow copy
shadow[index1] = X
shadow[index2] = Y
FLUSH (shadow)
FENCE
// Application uses shadow subsequently
array = shadow

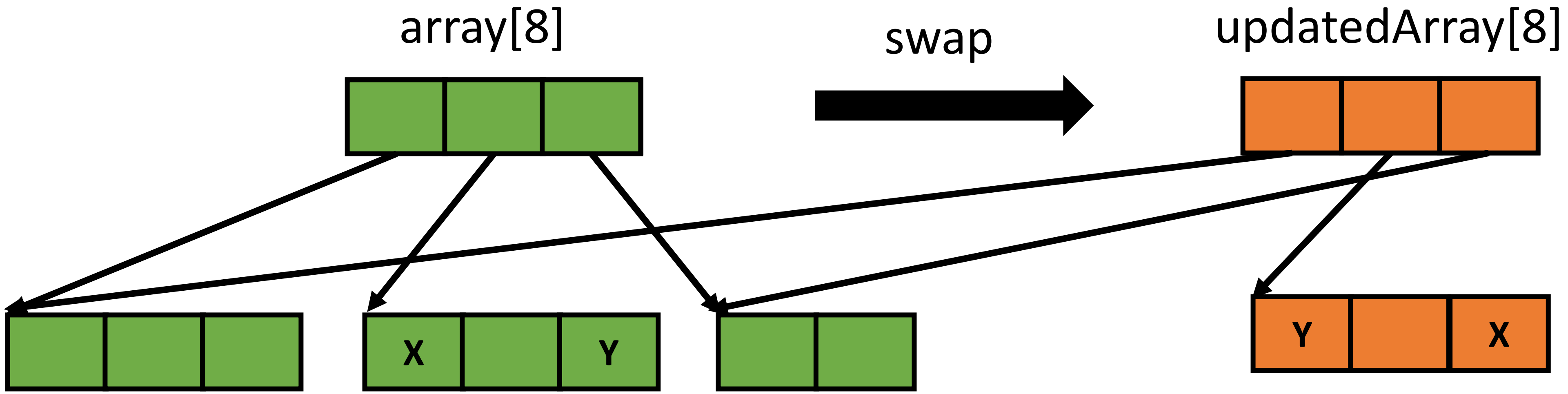


Cue Functional Datastructures!

Purely Functional datastructures are immutable

Implemented as efficient trees: Hash Array Mapped trie, RRBTree

Copying overheads reduced by *structural sharing*



Minimally Ordered Durable Datastructures

Recoverable datastructures adapted from existing functional ones

Durability: PM allocator + Flushes

Failure-Atomicity: Fences + out-of-place updates

Leverage 20+ years of work from functional programming community

Read/Write APIs that hides flushes, fences, out-of-place updates

Atomic Update of Single Datastructure

```
Update(arrayPtr, index, value) // Atomic, Durable w/ 1 FENCE
```

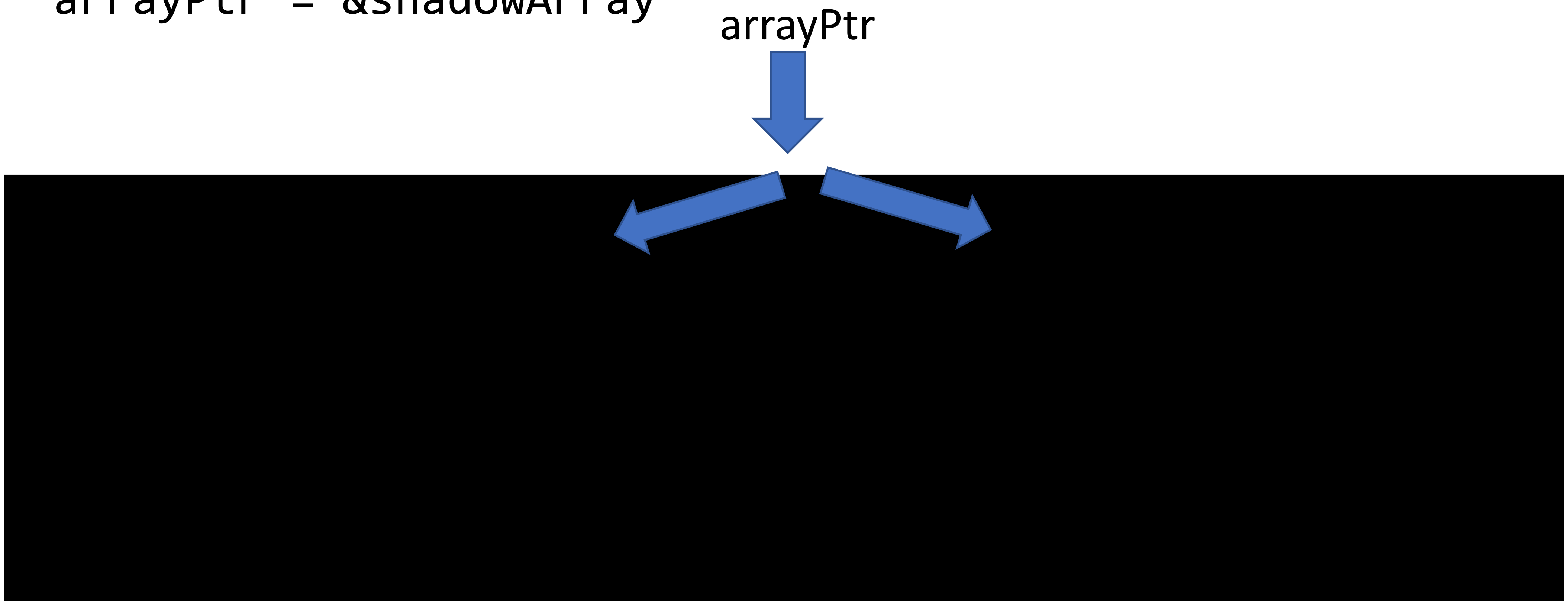
arrayPtr

[redacted]

Atomic Update of Single Datastructure

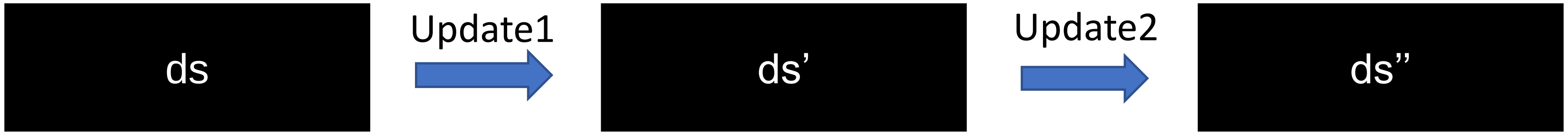
```
shadowArray = arrayPtr->Update(updateParams)
FENCE
arrayPtr = &shadowArray
```

Overlapped Flushes



Advanced MOD usages

Multiple Atomic Updates to One Datastructure (in the paper)



Atomically Updating Multiple Datastructures

3: Updating Multiple Datastructures

```
ds1PtrShadow = ds1Ptr->Update1(updateParams1)
ds2PtrShadow = ds2Ptr->Update2(updateParams2)
...
FENCE
Commit (ds1Ptr, ds1PtrShadow,
        ds2Ptr, ds2PtrShadow, ...)
Begin-TX {
          ds1Ptr = ds1PtrShadow
          ds2Ptr = ds2PtrShadow
          ...
} End-TX
```

All Flushes Overlapped

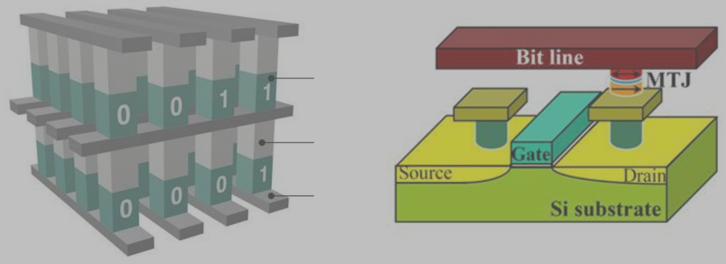
More ordering points but short transaction

3: Updating Multiple Datastructures

```
ds1PtrShadow = ds1Ptr->Update1(updateParams1)
ds2PtrShadow = ds2Ptr->Update2(updateParams2)
...
FENCE
Begin-TX {
          ds1P      trShadow
          ds2Pt      PtrShadow
          ...
} End-TX
```

Paper describes alternate method w/o transactions that handles many such cases

Outline



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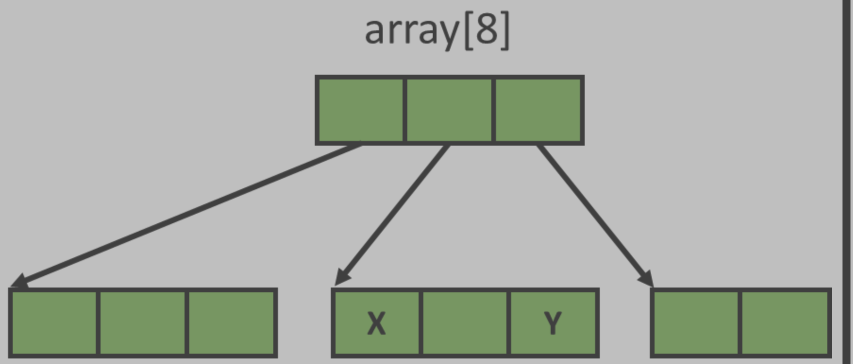

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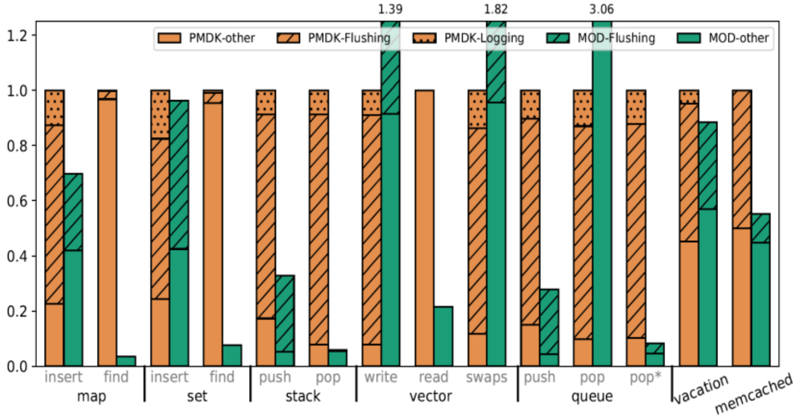


EVALUATION

Evaluation Methodology

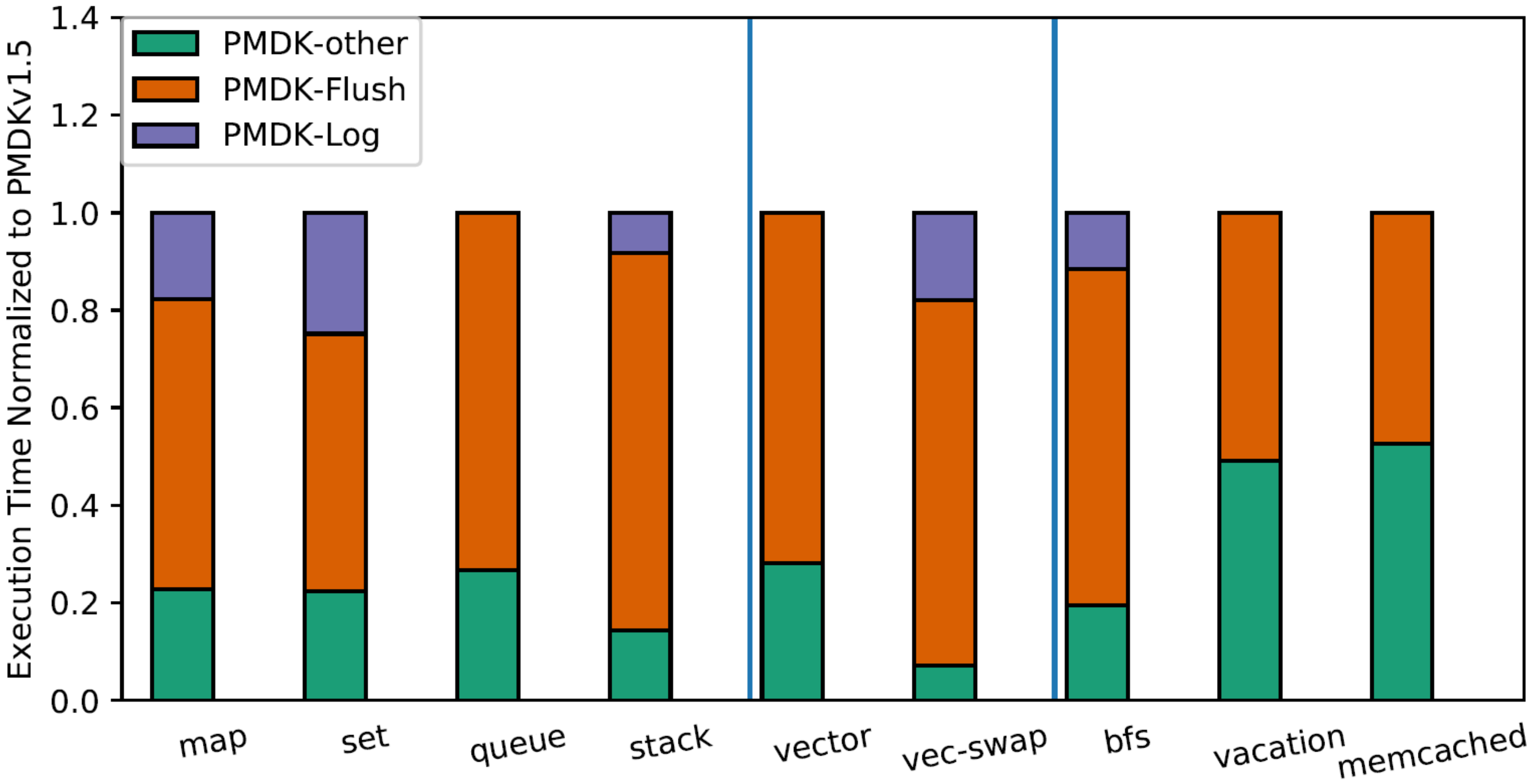
Used C++ library of functional datastructures:
https://github.com/arximboldi/immer

Used off-the-shelf persistent memory allocator:
https://github.com/hyrise/nvm_malloc.git

MOD library released at:
https://zenodo.org/record/3563186

Compared against Intel PMDK v1.5 (hybrid undo-redo logging):
https://github.com/pmem/pmdk

Performance Comparison on Optane



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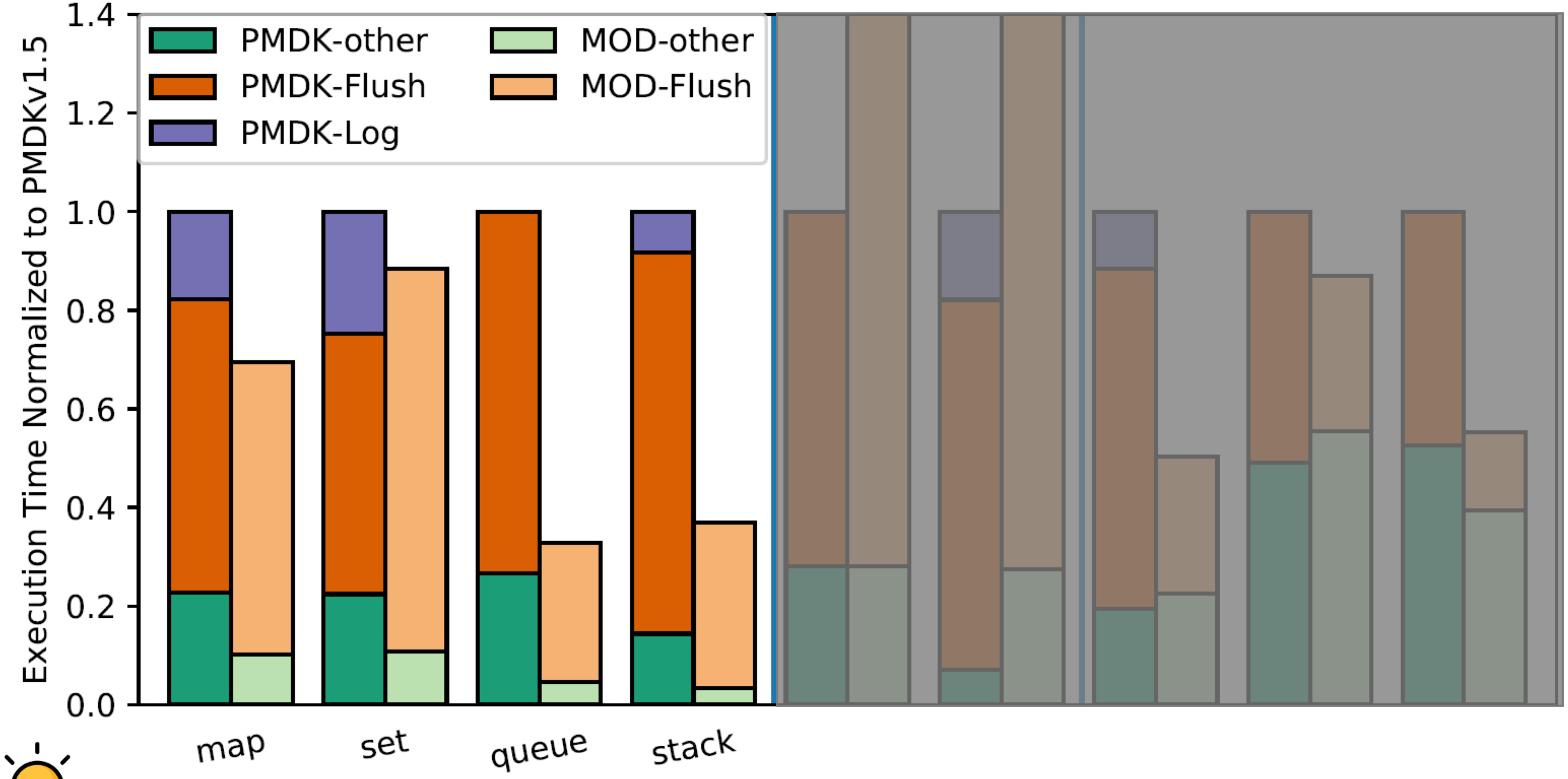
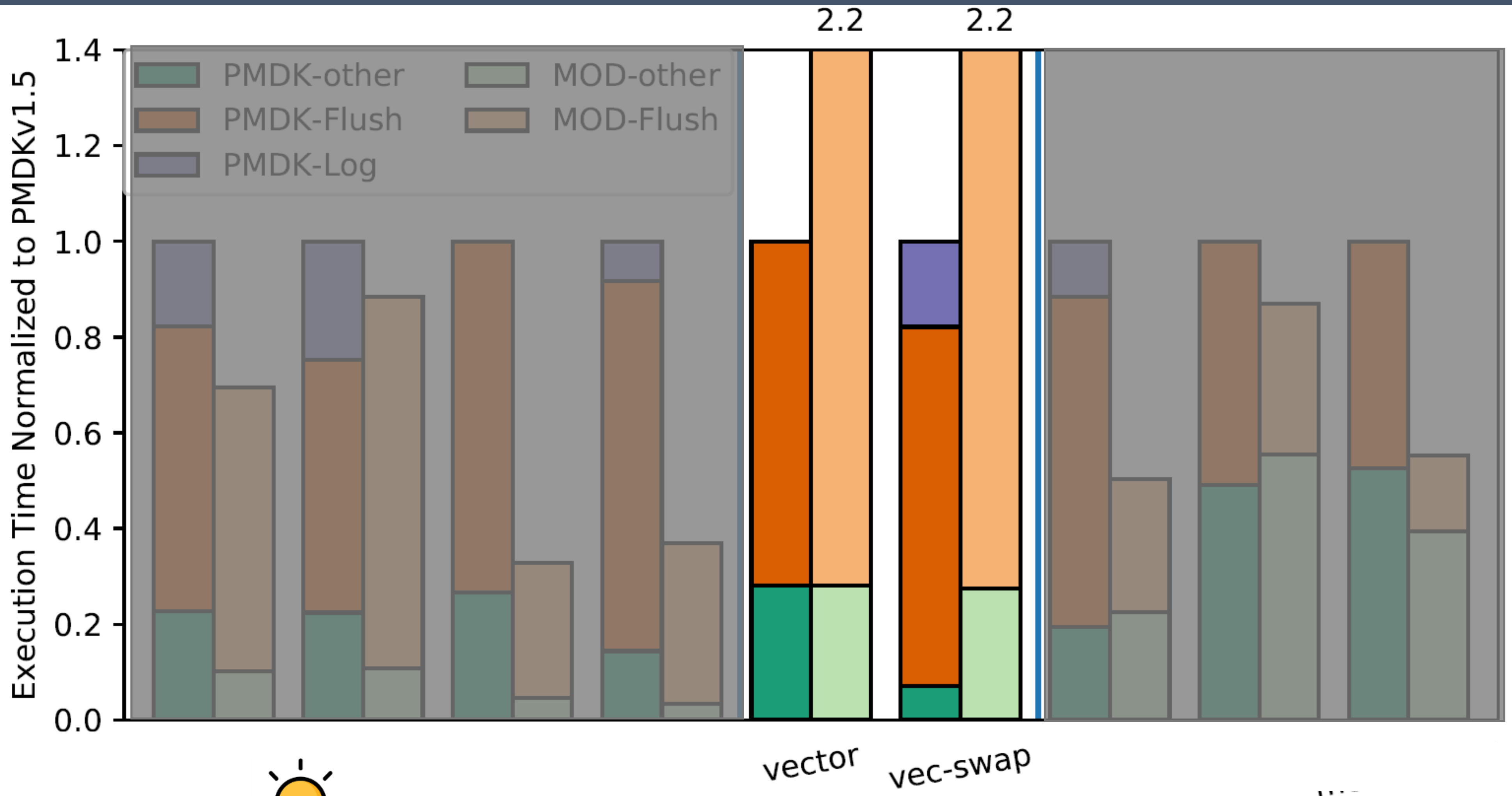


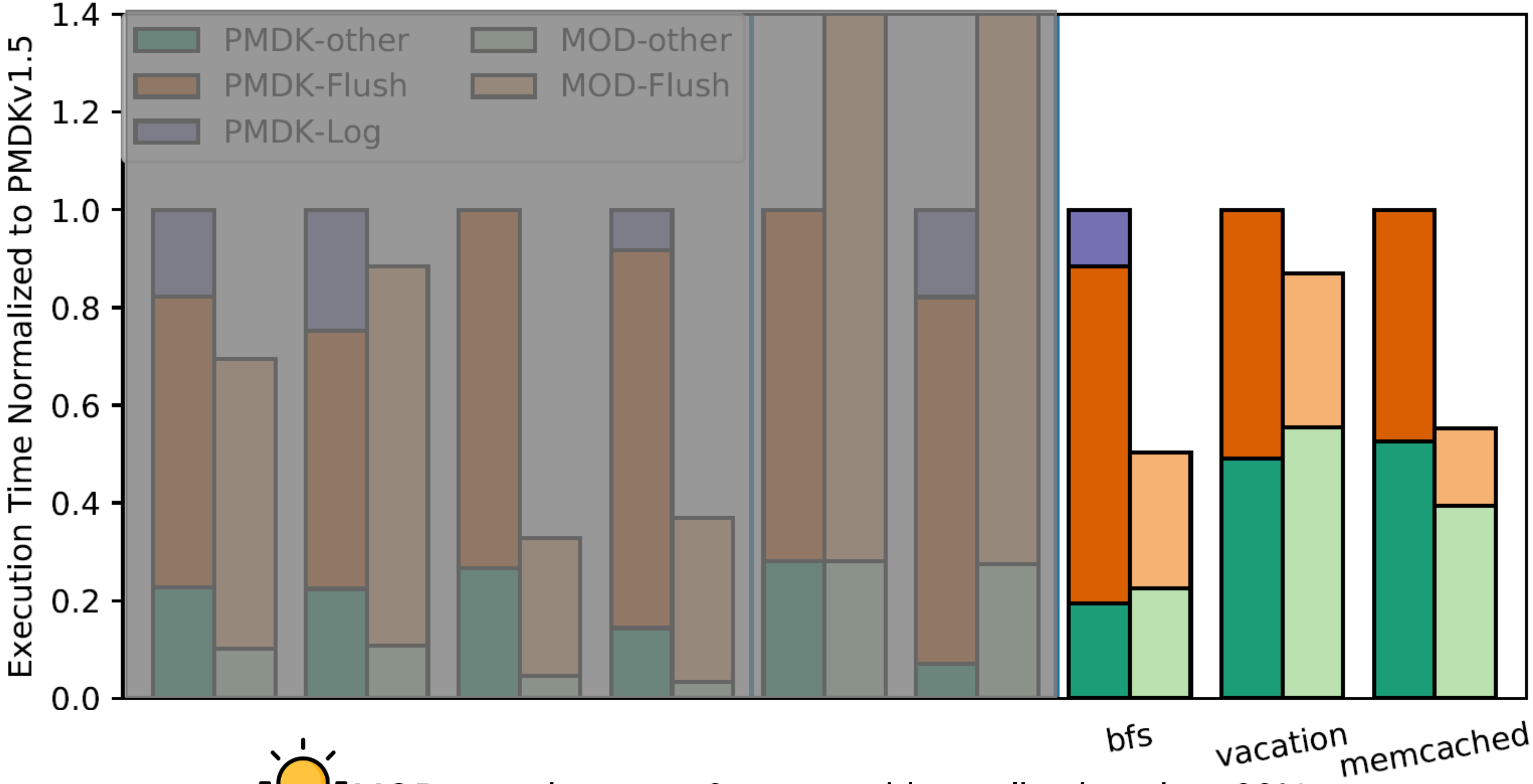
MOD offers ~43% speedup for pointer-based datastructures (map, set, stack, queue)

Performance Comparison on Optane



MOD degrades update performance of vectors by 120%

Performance Comparison on Optane



MOD speeds up our 3 recoverable applications by ~38%

Summary

Persistent memory enables recoverable applications

Analysis on Intel Optane memory reveals:

- ~73% of runtime is overhead: mostly flushing
- Flushing overhead reduces by 75% with flush overlap

Minimally Ordered Durable Datastructures:

- C++ datastructures: easy to use & good performance
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