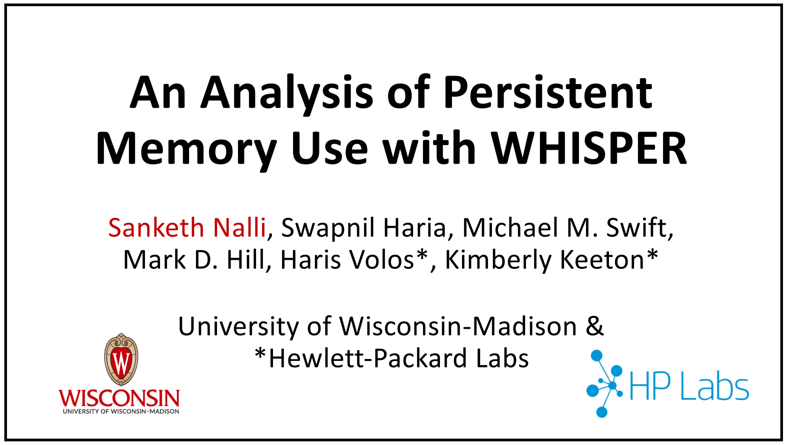
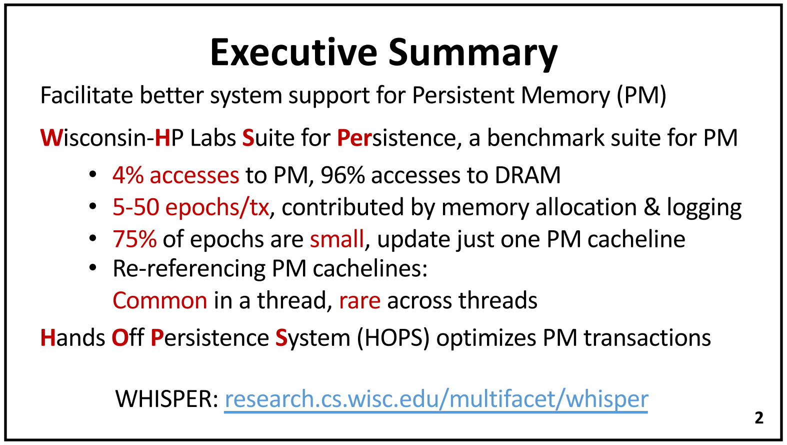


An Analysis of Persistent Memory Use with WHISPER

Sanketh Nalli, Swapnil Haria, Michael M. Swift,
Mark D. Hill, Haris Volos*, Kimberly Keeton*

University of Wisconsin-Madison &
*Hewlett-Packard Labs



Executive Summary

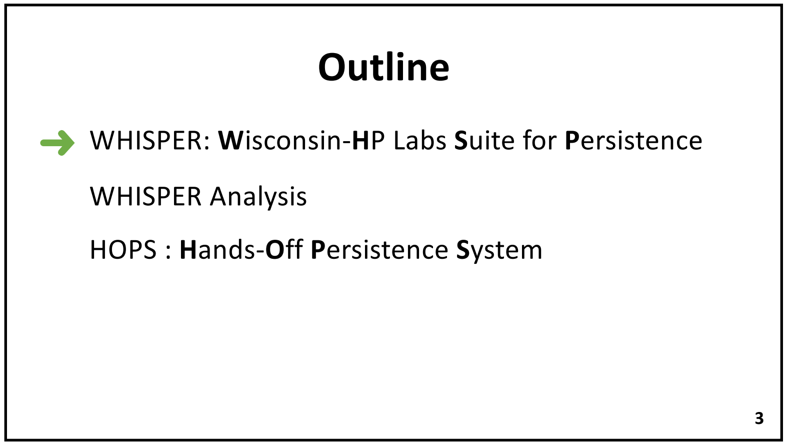
Facilitate better system support for Persistent Memory (PM)

Wisconsin-**HP** Labs **S**uite for **Per**sistence, a benchmark suite for PM

- 4% accesses to PM, 96% accesses to DRAM
- 5-50 epochs/tx, contributed by memory allocation & logging
- 75% of epochs are small, update just one PM cacheline
- Re-referencing PM cachelines:
  Common in a thread, rare across threads

Hands **O**ff **P**ersistence **S**ystem (HOPS) optimizes PM transactions

WHISPER: research.cs.wisc.edu/multifacet/whisper

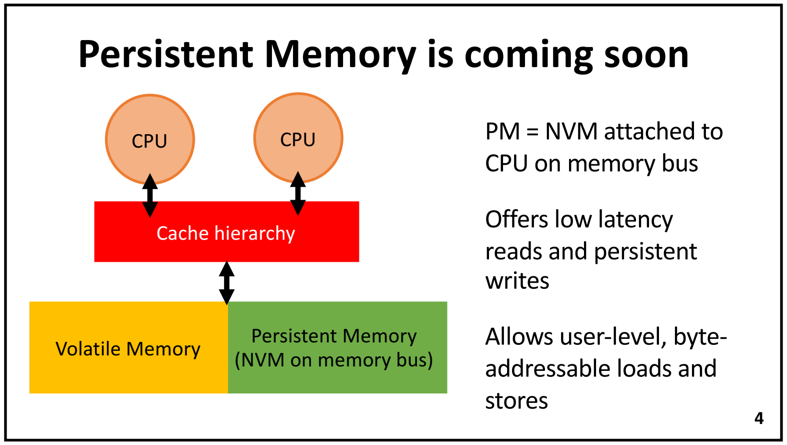


Outline

➜ WHISPER: **W**isconsin-**HP** Labs **S**uite for **P**ersistence

WHISPER Analysis

HOPS : **H**ands-**O**ff **P**ersistence **S**ystem



Persistent Memory is coming soon

PM = NVM attached to CPU on memory bus

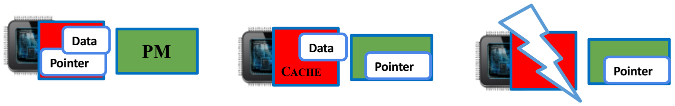
Offers low latency reads and persistent writes

Allows user-level, byte-addressable loads and stores

What guarantees after failure ?

Durability = Data survives failure

Consistency = Data is usable

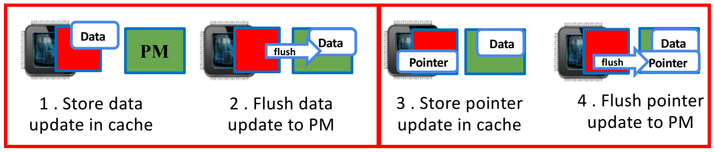


1 . Data update followed by pointer update in cache

2. Pointer is evicted from cache to PM

3. Data lost on failure, dangling pointer persists

Achieving consistency



1 . Store data update in cache

2 . Flush data update to PM

3 . Store pointer update in cache

4 . Flush pointer update to PM

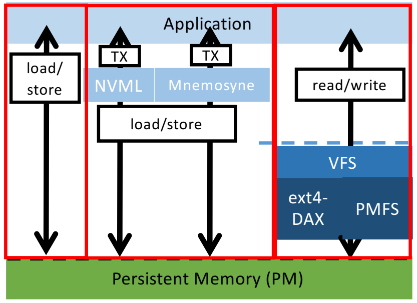
Ordering = Useful building block of consistency mechanisms

Epoch = Set of writes to PM guaranteed to be durable before ANY subsequent writes become durable

Ordering primitives: SFENCE on x86-64

PM systems for consistency

- **Native**
  Application-specific optimizations
- **Persistent library**
  Atomic allocations, transactions
- **PM-aware Filesystems**
  POSIX interface



What's the problem ?

Lack of standard workloads slows research

Micro-benchmarks not very representative

Partial understanding of how applications use PM

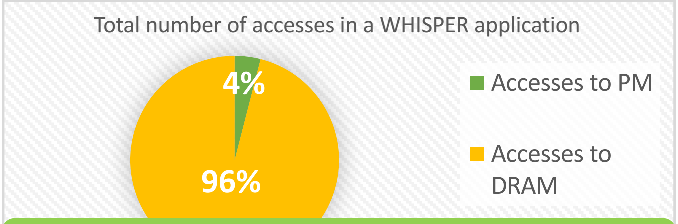
WHISPER benchmark suite

Benchmark	Type	Brief description (*Adapted to PM)
Echo*	KV store	Scalable, multi-version key-value store
N-store*	Database	Fast, in-memory relational DB
Redis	NVML	Remote Dictionary Service
C-tree	NVML	Microbenchmarks for simulations
Hashmap	NVML	Microbenchmarks for simulations
Vacation*	Mnemosyne	Online travel reservation system
Memcached*	Mnemosyne	In-memory key-value store
NFS	PMFS	Linux server/client for remote file access
Exim	PMFS	Mail server;stores mails in per-user file
MySQL	PMFS	Widely used RDBMS for OLTP

Outline

- ✔ WHISPER: **W**isconsin-**HP** Labs **S**uite for **P**ersistence
- ➜ WHISPER Analysis
- HOPS : **H**ands-**O**ff **P**ersistence **S**ystem

How many accesses to PM ?


Total number of accesses in a WHISPER application

Suggestion: Do not impede volatile accesses

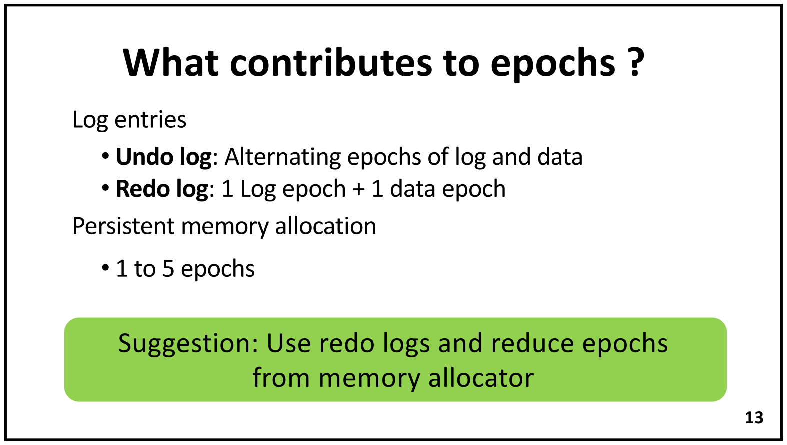
How many epochs/transaction ?

Durability after every epoch impedes execution

Expectation: 3 epochs/TX = log + data + commit

Reality: 5 to 50 epochs/TX

Suggestion: Enforce durability only at the end of a transaction



What contributes to epochs ?

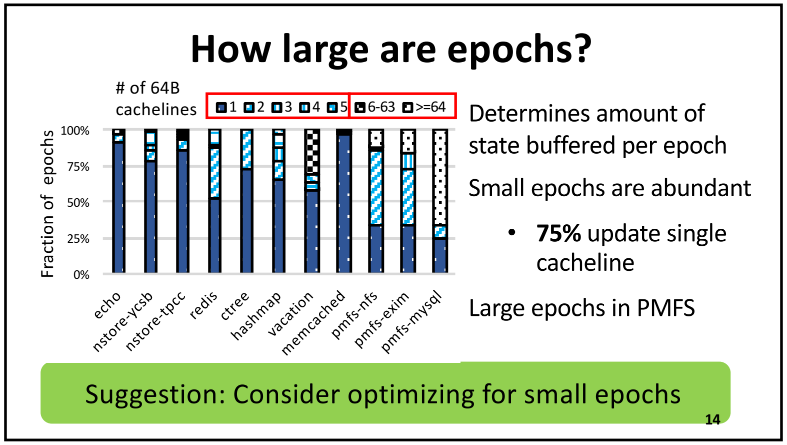
Log entries

- **Undo log**: Alternating epochs of log and data
- **Redo log**: 1 Log epoch + 1 data epoch

Persistent memory allocation

- 1 to 5 epochs

Suggestion: Use redo logs and reduce epochs from memory allocator



How large are epochs?

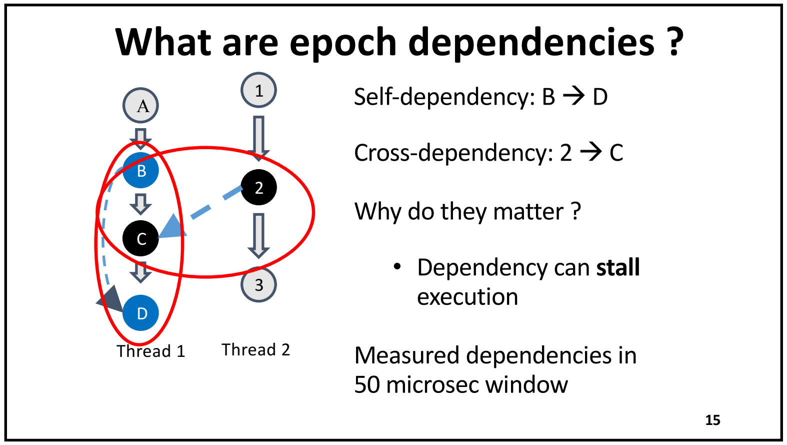
Determines amount of state buffered per epoch

Small epochs are abundant

- **75%** update single cacheline

Large epochs in PMFS

Suggestion: Consider optimizing for small epochs



What are epoch dependencies ?

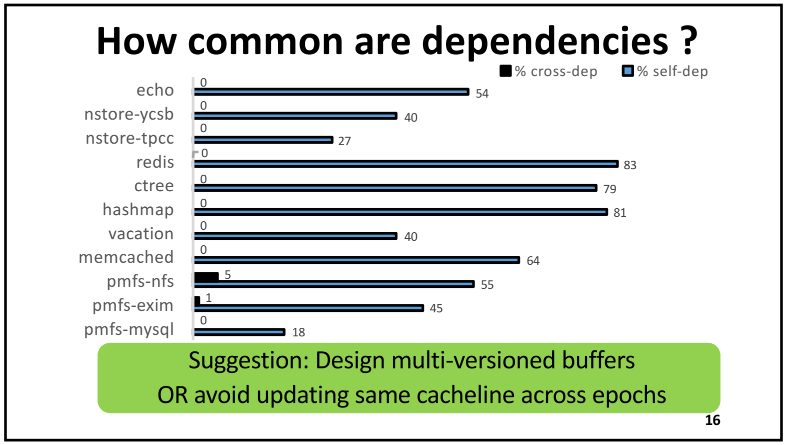
Self-dependency: B → D

Cross-dependency: 2 → C

Why do they matter ?

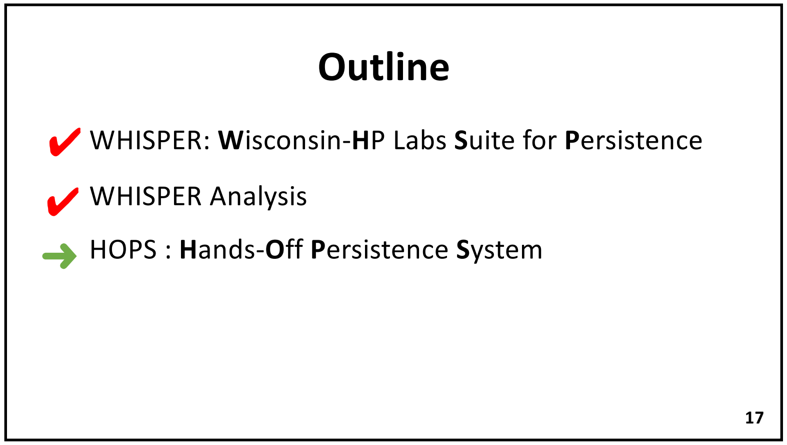
- Dependency can **stall** execution

Measured dependencies in 50 microsec window



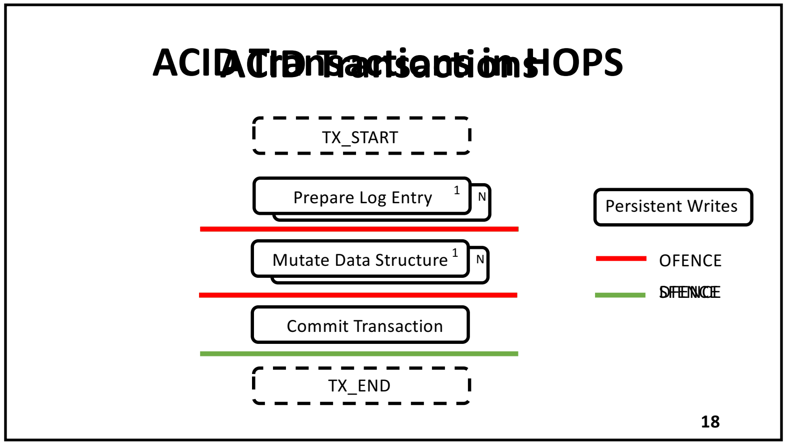
How common are dependencies ?

Suggestion: Design multi-versioned buffers OR avoid updating same cacheline across epochs



Outline

- ✓ WHISPER: **W**isconsin-**HP** Labs **S**uite for **P**ersistence
- ✓ WHISPER Analysis
- → HOPS : **H**ands-**O**ff **P**ersistence **S**ystem



ACID Transactions in HOPS

ACID Transactions

TX_START

Prepare Log Entry 1 N

Mutate Data Structure 1 N

Commit Transaction

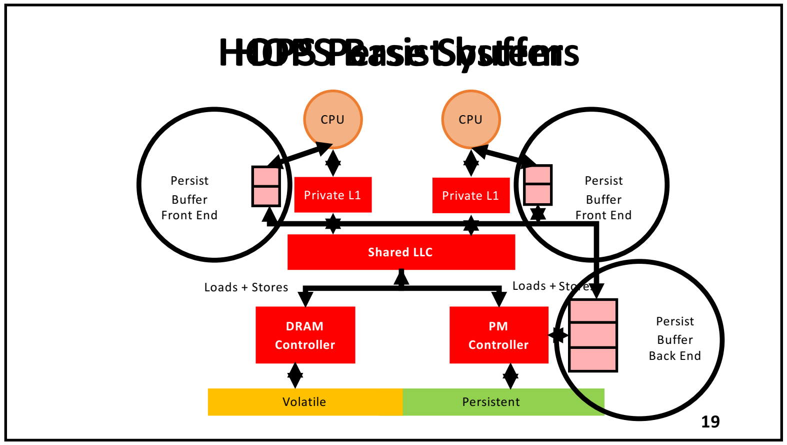
TX_END

Persistent Writes

🟥 OFENCE

🟩 DFENCE

🟩 SFENCE



HOPS Persist Buffers

HOPS Basic System

CPU

CPU

Persist Buffer Front End

Private L1

Private L1

Persist Buffer Front End

Shared LLC

Loads + Stores

Loads + Stores

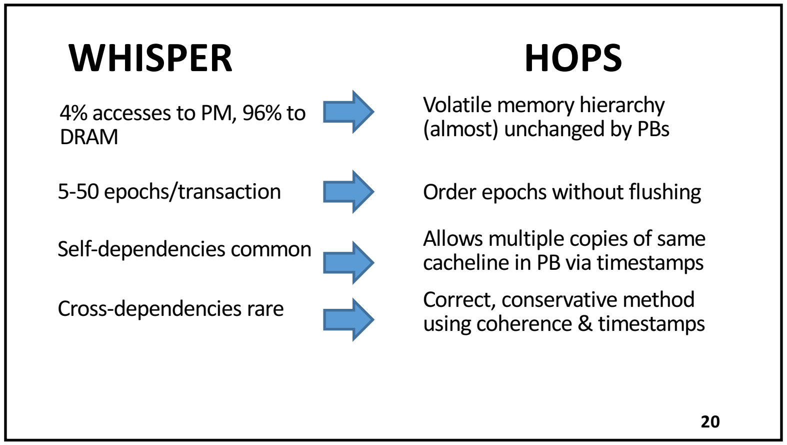
DRAM Controller

PM Controller

Persist Buffer Back End

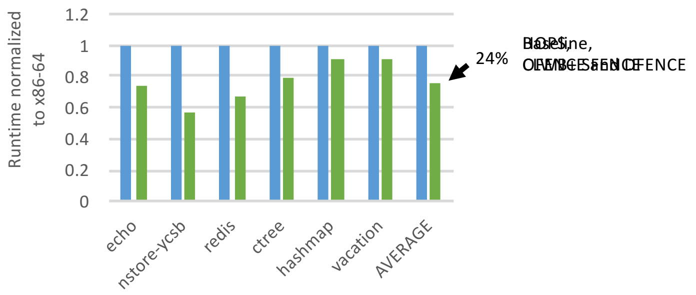
Volatile

Persistent



WHISPER		HOPS
4% accesses to PM, 96% to DRAM	→	Volatile memory hierarchy (almost) unchanged by PBs
5-50 epochs/transaction	→	Order epochs without flushing
Self-dependencies common	→	Allows multiple copies of same cacheline in PB via timestamps
Cross-dependencies rare	→	Correct, conservative method using coherence & timestamps

HOPS Evaluation with WHISPER



Summary

- Persistent Memory (PM) is coming soon
- Progress is slowed by ad-hoc micro-benchmarks
- We contributed **WHISPER**, open-source benchmark suite
- **HOPS** design, based on WHISPER analysis
- We hope for more similar analysis in the future !

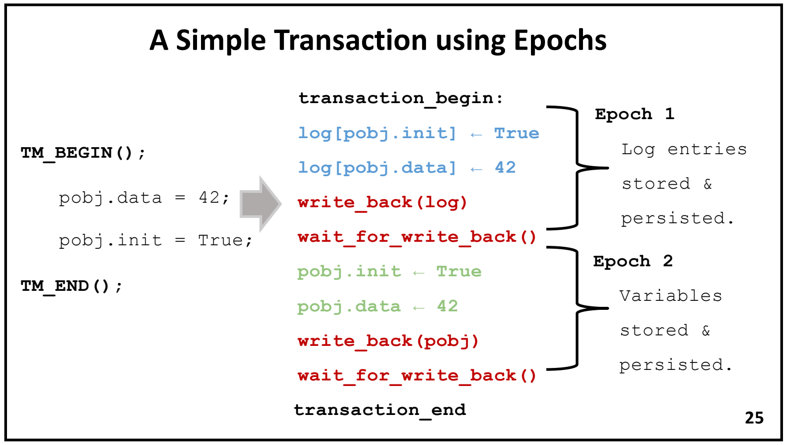
research.cs.wisc.edu/multifacet/whisper/

Extra

Summary

- WHISPER: **W**isconsin-**H**P Labs **S**uite for **Per**sistence
- 4% accesses to PM, 96% accesses to DRAM
- 5-50 epochs/TX, primarily small in size
- Cross-dependencies rare, self-dependencies common
- HOPS improves PM app performance by 24%
- More results in ASPLOS'17 paper and code at:

research.cs.wisc.edu/multifacet/whisper/



A Simple Transaction using Epochs

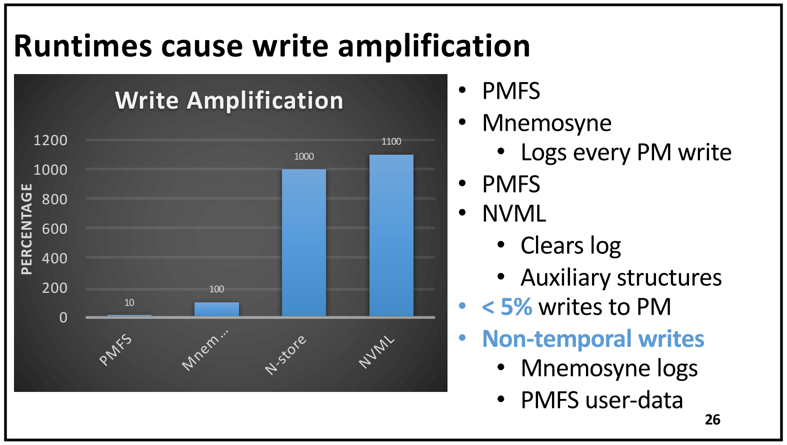
```
TM_BEGIN();
    pobj.data = 42;
    pobj.init = True;
TM_END();
```

```
transaction_begin:
log[pobj.init] ← True
log[pobj.data] ← 42
write_back(log)
wait_for_write_back()
pobj.init ← True
pobj.data ← 42
write_back(pobj)
wait_for_write_back()
transaction_end
```

Epoch 1
Log entries stored & persisted.

Epoch 2
Variables stored & persisted.

25



Runtimes cause write amplification

- PMFS
- Mnemosyne
    - Logs every PM write
- PMFS
- NVML
    - Clears log
    - Auxiliary structures
- < 5% writes to PM
- Non-temporal writes
    - Mnemosyne logs
    - PMFS user-data

26