Persistent Memory

Industry Status and Update

What we will cover

- PMEM – Hardware…and the associated programing model
- What everyone already <u>should</u> know about pmem…
- What everyone forgets…
- Ways to use pmem with no app modifications
- Ways to use pmem with app modifications
- Learnings so far
- Where we're heading

A Fundamental Change Requires An Ecosystem

SNIA

Microsoft Linux
vmware ORACLE

- Windows Server 2016
- Windows 10 Pro for Workstations
- Linux Kernel 4.2 and later
- VMware, Oracle, SAP HANA early enablement programs

JEDEC SNIA uefi

- JEDEC JESD245B.01: Byte Addressable Energy Backed Interface (released Jul'17)
- JEDEC JESD248A: NVDIMM-N Design Standard (released Mar'18)
- SNIA NVM Programming Model (v1.2 released Jun'17)
- unfit ACPI NVDIMM Firmware Interface Table (v6.2 released May'17)

AGIGA TECH
Micron SK hynix
SMART Modular Technologies viking TECHNOLOGY NETLIST

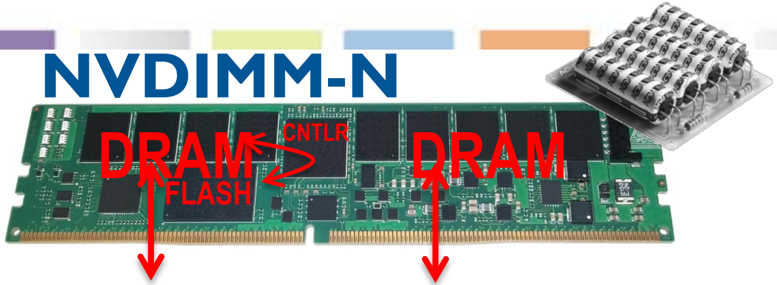
- Multiple vendors shipping NVDIMMs
- SNIA NVDIMM Special Interest Group (formed Jan'14)
- Successful demonstrations of interoperability among vendors

intel AMD
OTHERS
Hewlett Packard Enterprise DELL SUPERMICRO

- All major OEMs shipping platforms with NVDIMM support
- Requires hardware and BIOS mods

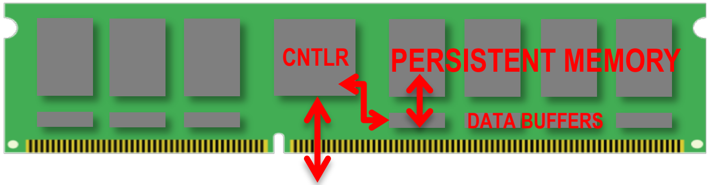
JEDEC-Defined NVDIMM Types

NVDIMM-N



- Host has direct access to DRAM
- NAND flash is only used for backup
- Capacity = DRAM (10’s - 100’s GB)
- Latency = DRAM (10’s of nanoseconds)
- Endurance = DRAM (effectively infinite)
- No impact to memory bus performance
- Low cost controller can be implemented
- Specifications completed and released
- Ecosystem moving into mature stage

NVDIMM-P



Host is decoupled from the media (agnostic to PM type)

New protocol to “hide” non-deterministic access

Capacity = PM (100’s GB+)

Latency = PM (>> 10’s of nanoseconds)

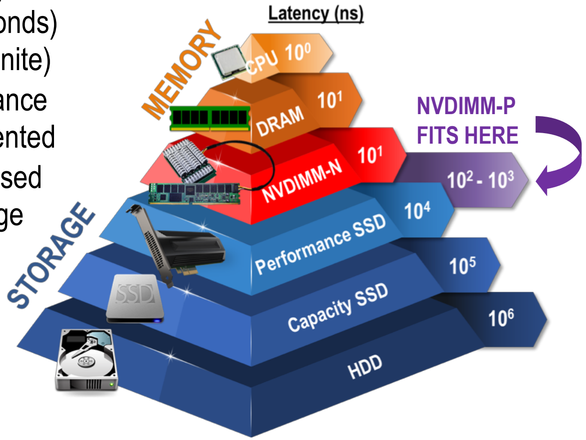
Endurance = PM (finite)

Likely to impact memory bus performance

Complex controller & buffer scheme likely required

Specifications still under definition (2H’19 release?)

No ecosystem yet, likely DDR5 timeframe



NVDIMM Types Are Complementary, Not Competing

NVDIMM Target Application Areas

SNIA®

	Databases	Storage	Virtualization	Big Data	Cloud Computing/ IoT	Artificial Intelligenc
USE CASES	Log Acceleration In-Memory Commit	Filesystems Fast Caching SSD Wear-Out	Higher VM Consolidation More Virtual Users/System	Fast IOPs Workloads In-Memory Processing	Byte-Level Data Processing Metadata Store	Low Latency Look-Up & Processing

The same factors driving NAND Flash adoption apply to NVDIMMs: IOPS, Latency, Performance

NVDIMM addressing is exactly like DRAM

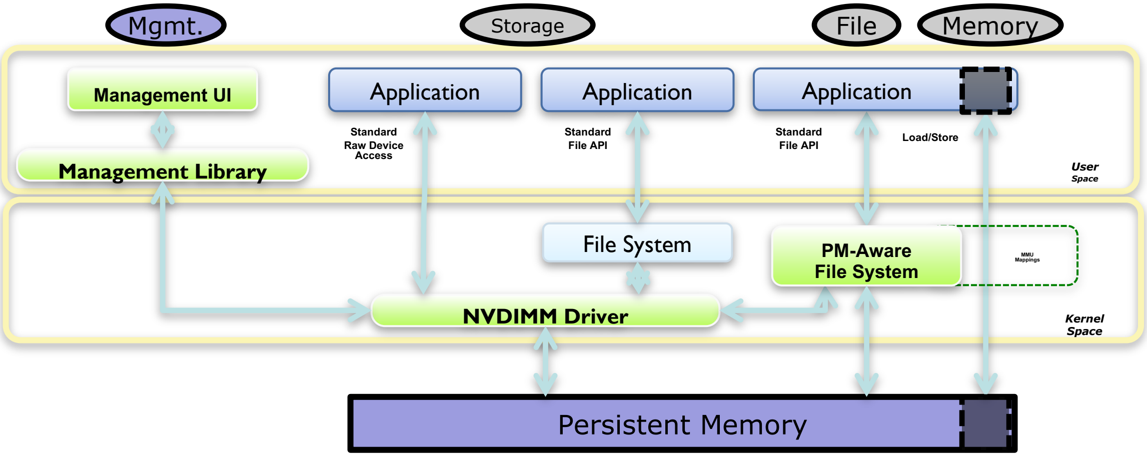
Everyone should know…

- Persistent memory…
  - Allows load/store access like memory
  - Is persistent like storage
  - Exposed to applications using SNIA NVM TWG model

- What isn't persistent memory:
  - Something that can only speak blocks (like a disk/SSD)
  - Something that is too slow for load/store access
    - TWG's language: Would reasonably stall the CPU waiting for a load to complete

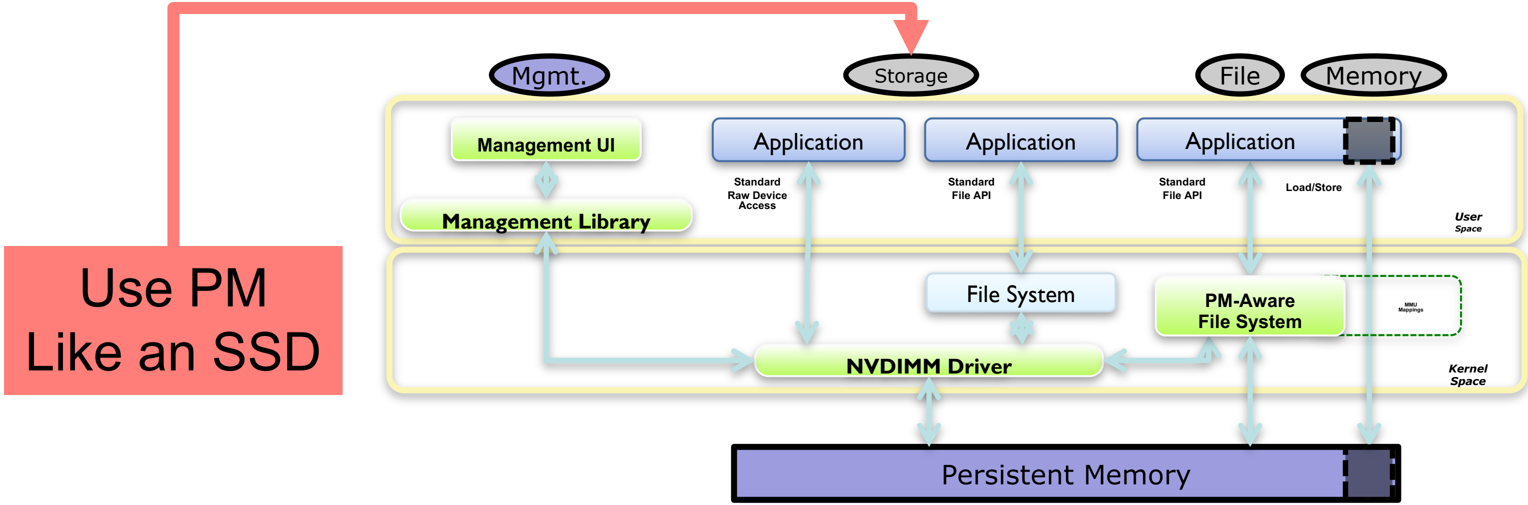
Often forgotten

- The programming model includes the storage APIs!



Often forgotten: Storage Access

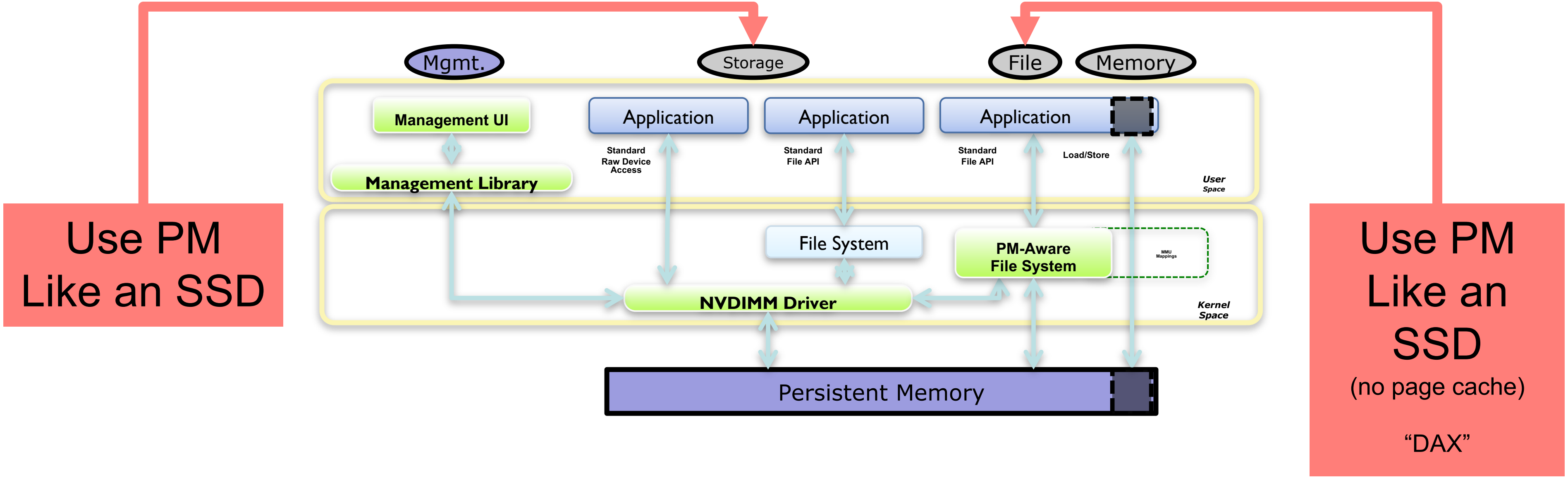
- The programming model includes the storage APIs!



Use PM Like an SSD

Often forgotten: DAX Access

- The programming model includes the storage APIs!

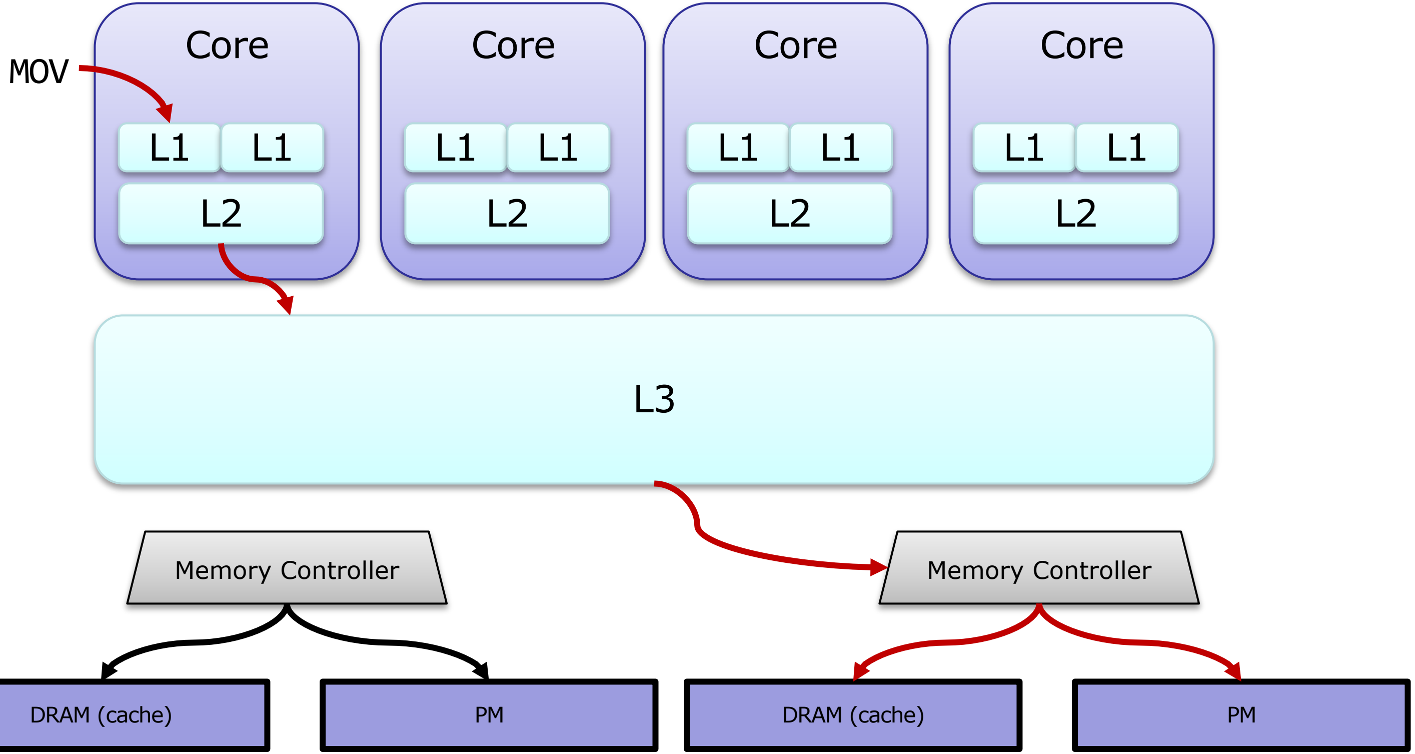


Use PM
Like an SSD

Use PM
Like an
SSD
(no page cache)

“DAX”

Memory Mode: Volatile Capacity

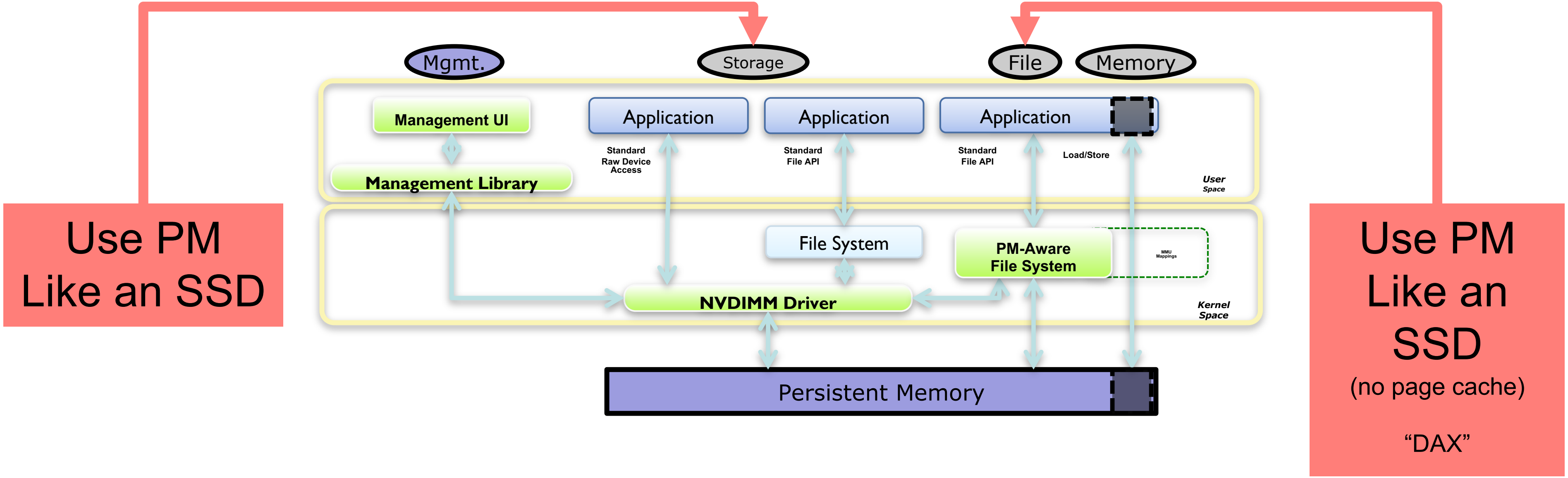


No Application Modification

- Using PM as a fast SSD
  - Storage APIs work as expected
  - Memory-mapping files will page them into DRAM
- Using PM as DAX
  - Storage APIs work as expected
  - No paging (DAX stands for “Direct Access”)
- Using PM as volatile capacity
  - Just big main memory
  - Vendor-specific feature

Often forgotten: DAX Access

- The programming model includes the storage APIs!



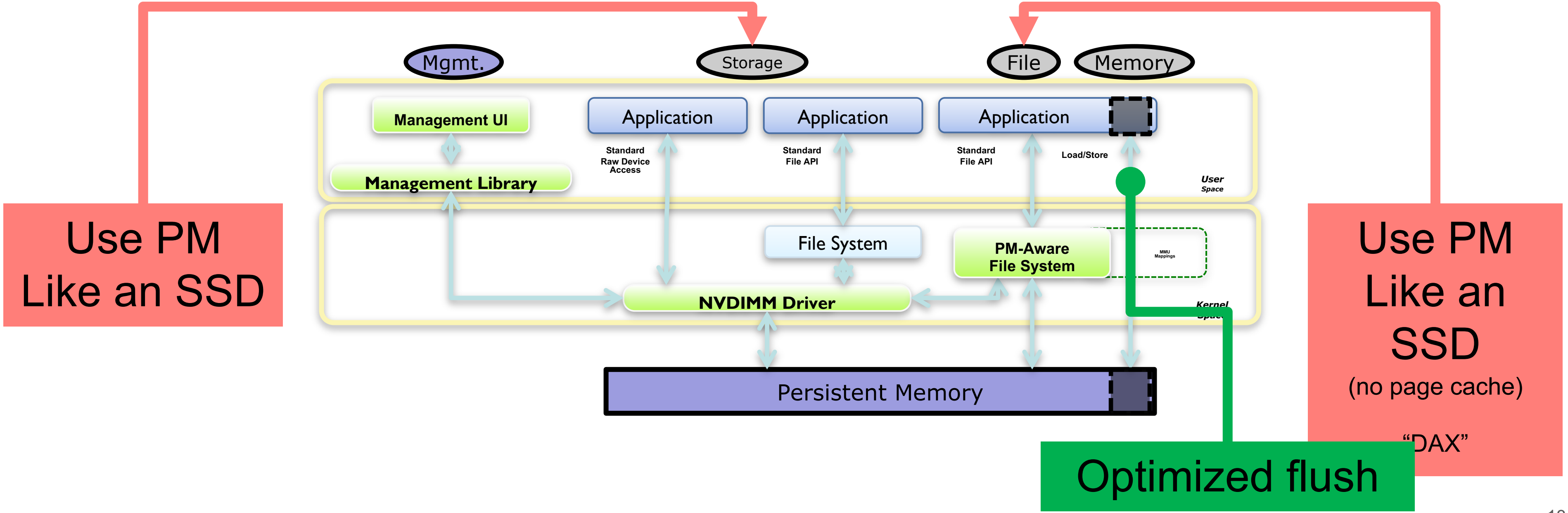
Use PM Like an SSD

Use PM Like an SSD (no page cache)

“DAX”

Optimized Flush: Flushing from Userspace

- The programming model includes the storage APIs!



Use PM Like an SSD

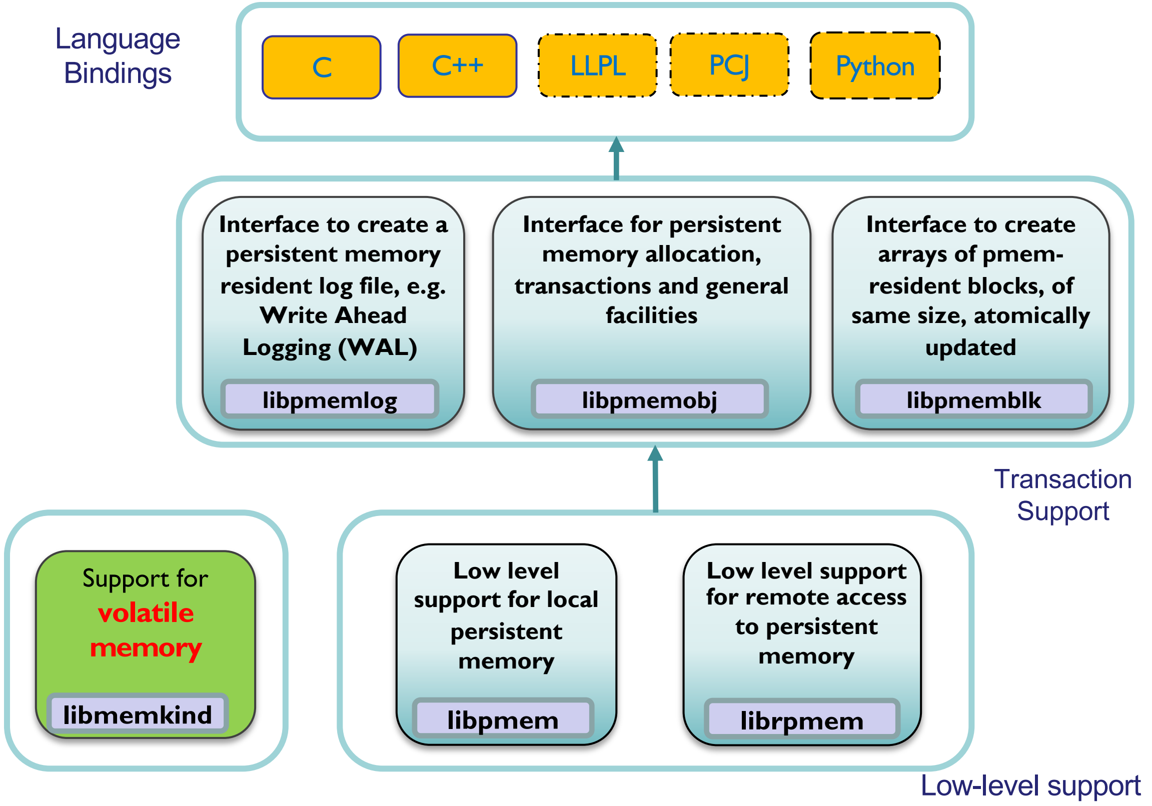
Use PM Like an SSD

(no page cache)

“DAX”

Optimized flush

Application Modification



Language Bindings

C

C++

LLPL

PCJ

Python

Interface to create a persistent memory resident log file, e.g. Write Ahead Logging (WAL)

libpmemlog

Interface for persistent memory allocation, transactions and general facilities

libpmemobj

Interface to create arrays of pmem-resident blocks, of same size, atomically updated

libpmemblk

Transaction Support

Support for **volatile memory**

libmemkind

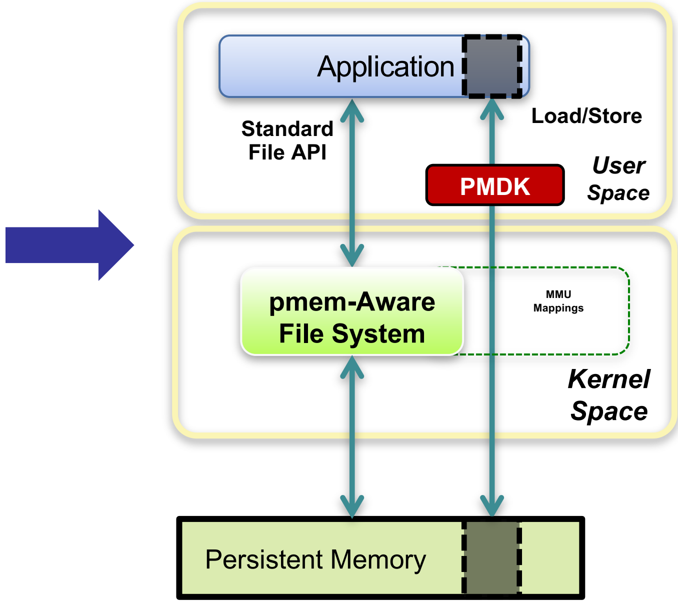
Low level support for local persistent memory

libpmem

Low level support for remote access to persistent memory

librpmem

Low-level support



Application

Standard File API

Load/Store

PMDK

User Space

pmem-Aware File System

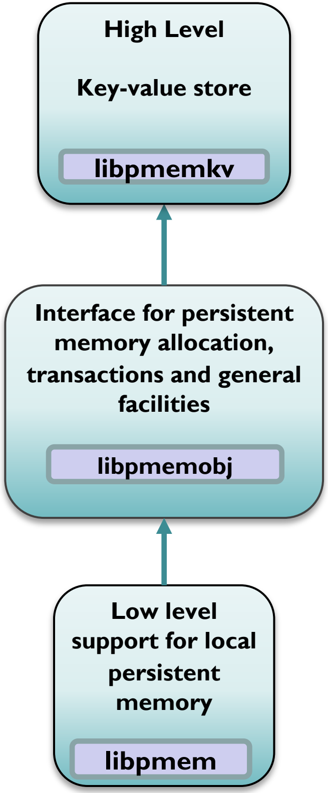
MMU Mappings

Kernel Space

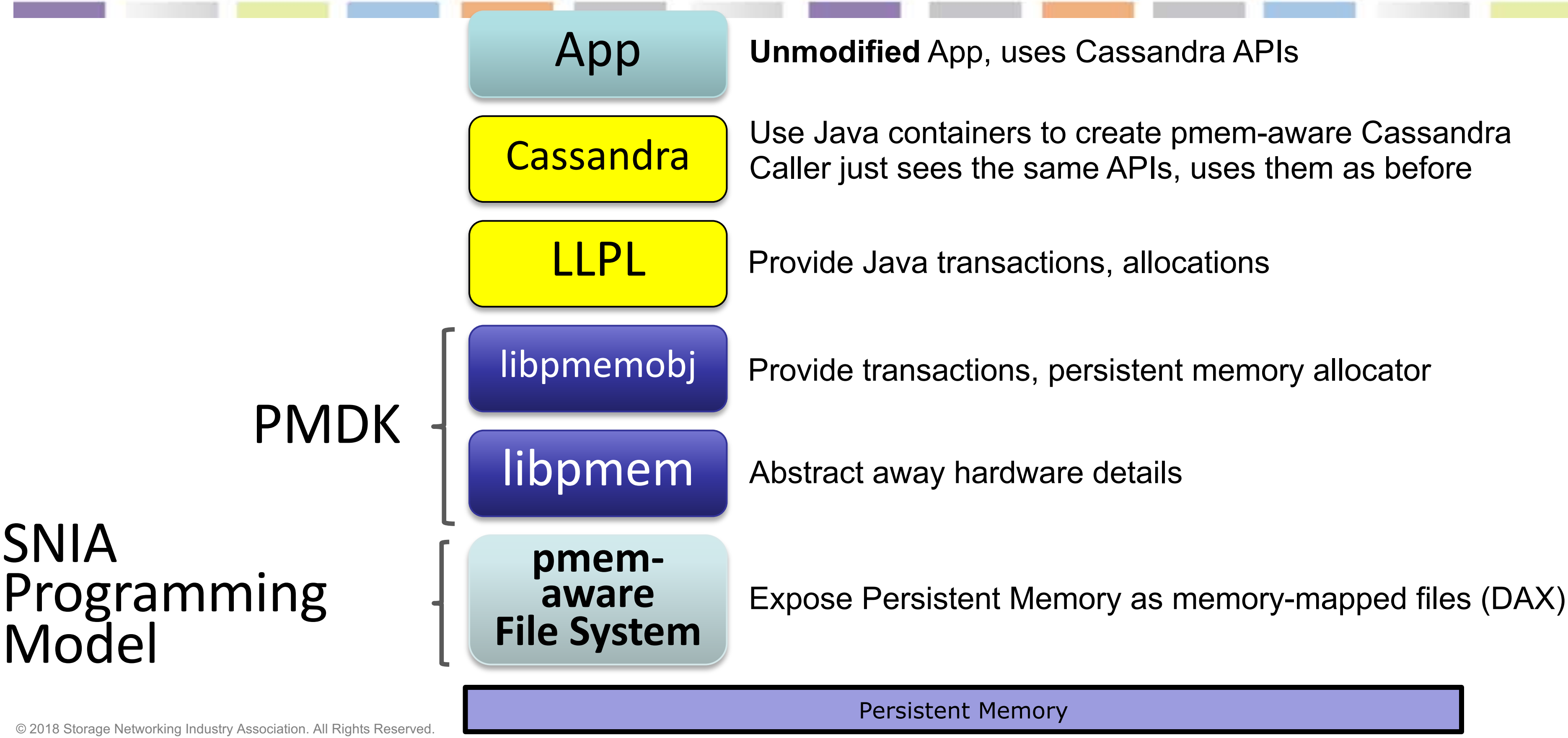
Persistent Memory

In Development:
PCJ – Persistent Collection for Java
LLPL – Low-Level Persistence Java Library

Application Modification: pmemkv


High Level
Key-value store
libpmemkv
Interface for persistent memory allocation, transactions and general facilities
libpmemobj
Low level support for local persistent memory
libpmem

- libpmemkv
  - Experimental
  - General-purpose key-value store
  - Multiple pluggable engines
  - Multiple language bindings
  - Productization underway
- Caller uses simple API
  - But gets benefits of persistent memory



App — **Unmodified** App, uses Cassandra APIs

Cassandra — Use Java containers to create pmem-aware Cassandra
Caller just sees the same APIs, uses them as before

LLPL — Provide Java transactions, allocations

PMDK

libpmemobj — Provide transactions, persistent memory allocator

libpmem — Abstract away hardware details

SNIA Programming Model

pmem-aware File System — Expose Persistent Memory as memory-mapped files (DAX)

Persistent Memory

Learnings so far…

- Lots of ways to use PM without app modifications
- Try first to use existing APIs
  - Example: app that can be configured for SSD tier
- Try next to use highest abstraction possible
  - Key-value store, simple block or log interfaces
- Try next to use a transaction library
  - libpmemobj
- Finally, if you must program to raw mapped access

Where we’re heading

- More transparent use cases
  - Either kernel or library features, transparent to app
- More high-level abstractions
  - Easier to program, less error prone
- More support for experts as well
  - More features in transaction libraries
  - More language integration
  - Faster remote (RPM) access

RPM…Some Challenges, But Usable

- NUMA, by definition
  - Probably okay, just be aware of it
- Generally requires asynchronous operation
  - Including delayed completions
- Networks introduce unavoidable latencies
  - As long as the application can tolerate it
- Transaction model will often favor pull vs push operations
  - not necessarily native to the way application writers think

Net-net, probably can’t treat remote and local PM exactly the same.
Not quite transparent, but close.

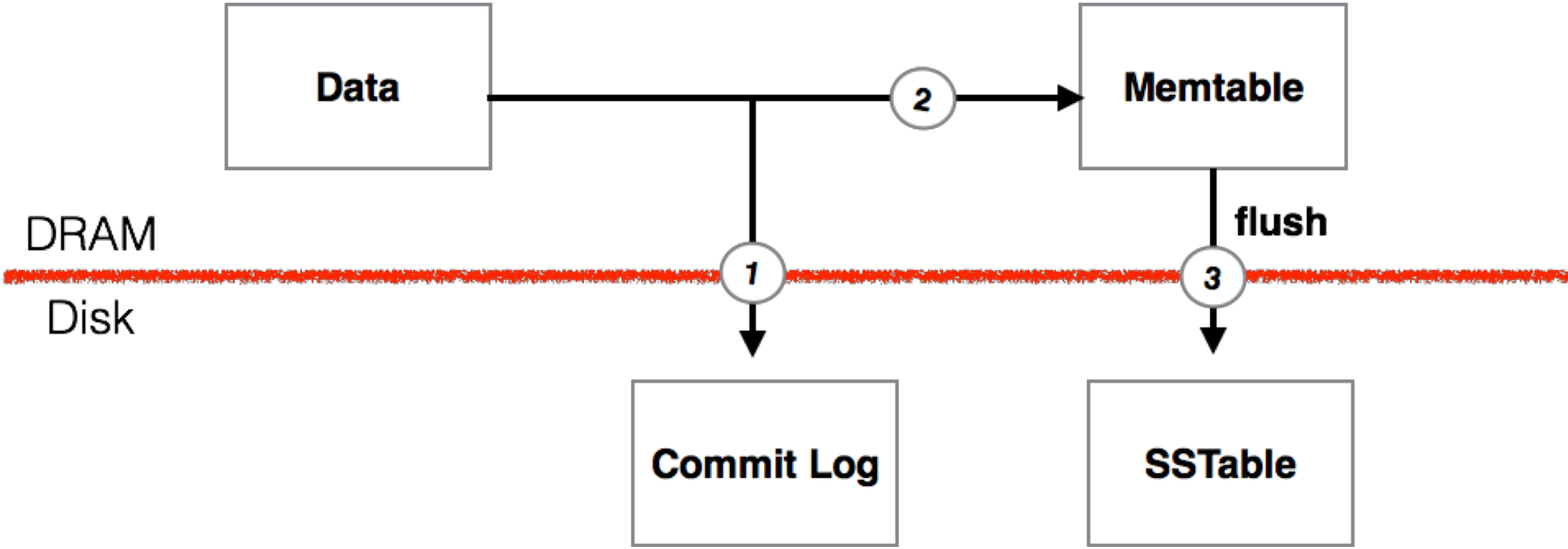
Java Access to Persistent Memory

- **Java is a very popular language on servers, especially for databases, data grids, etc., e.g. Apache projects:**
  - Cassandra
  - Ignite
  - HBase
  - Lucene
  - Spark
  - HDFS
- **Want to offer benefits of persistent memory to such applications**

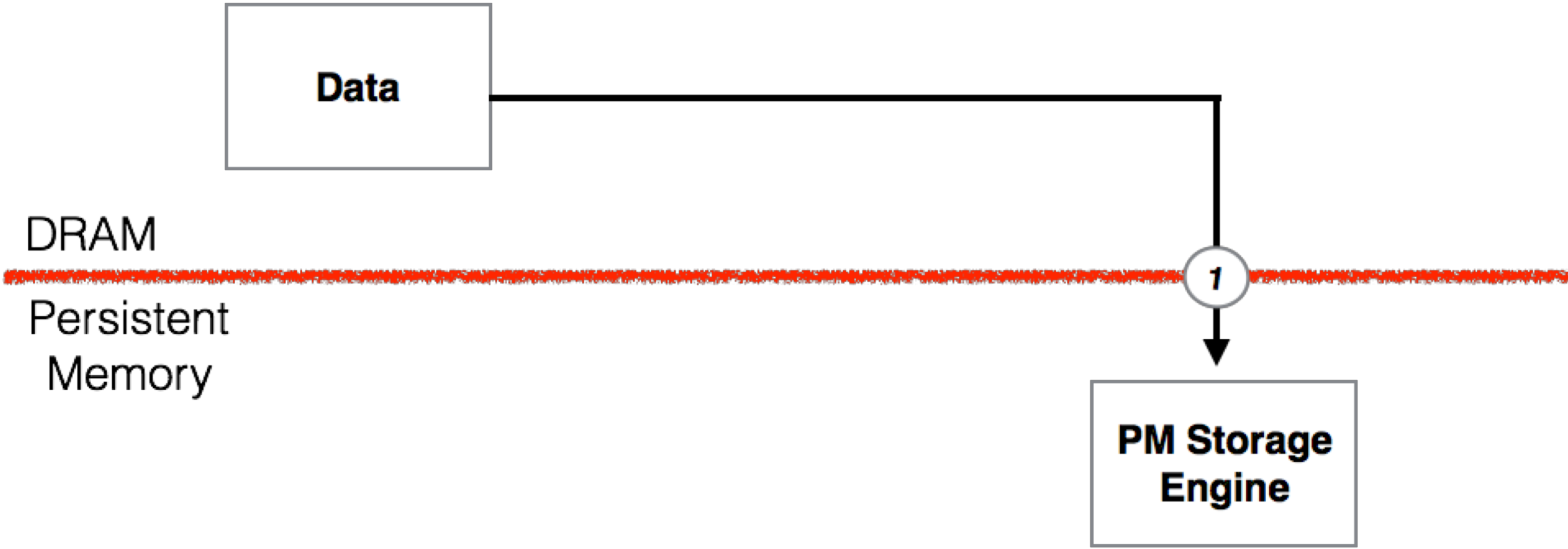
PM Storage Engine for Cassandra

- Cassandra is a popular distributed NoSQL database written in Java
- Uses a storage engine based on a Log Structured Merge Tree with DRAM and disk levels
- Could persistent memory offer Cassandra opportunities for simpler code and improved performance?

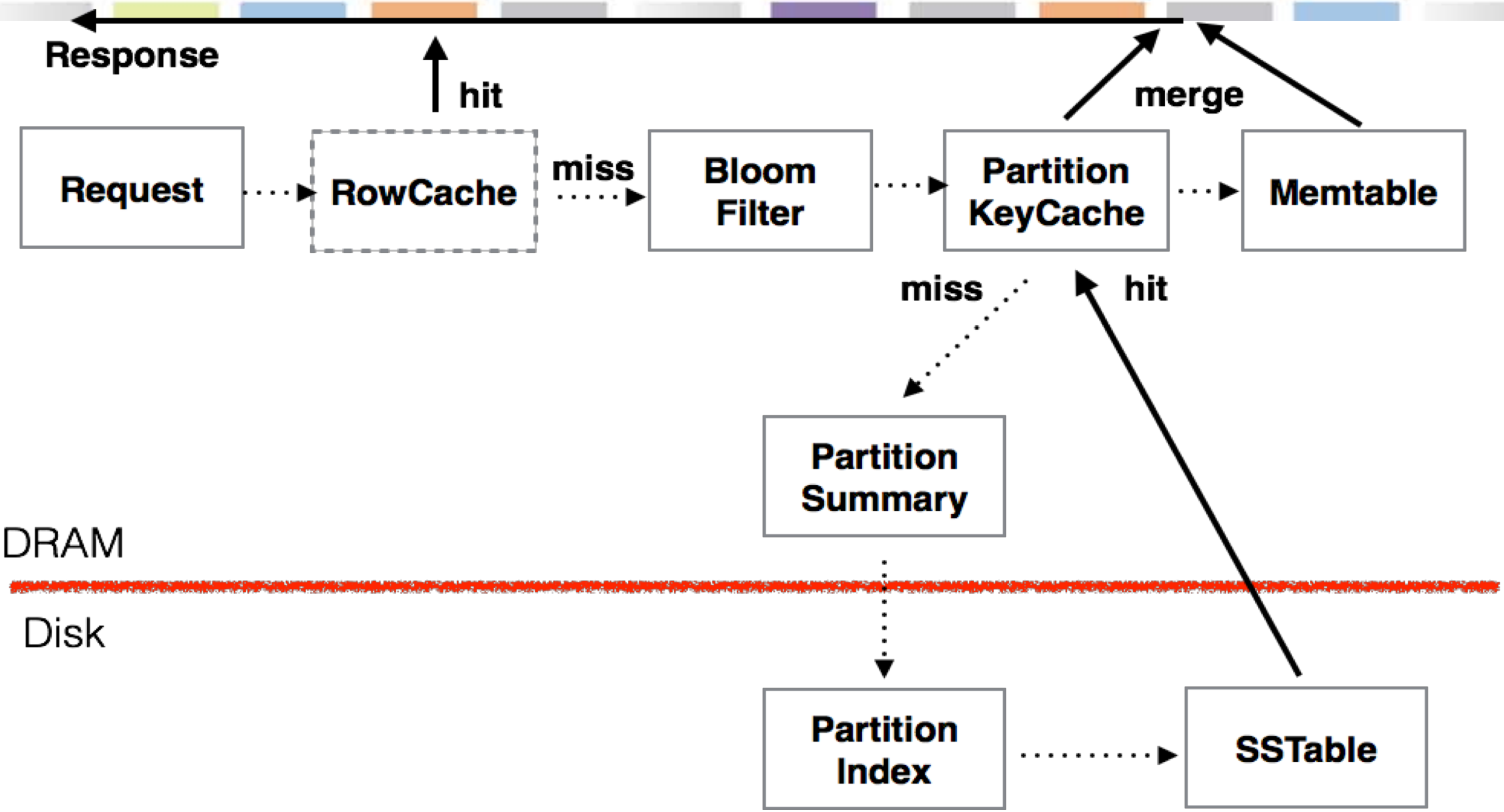
Cassandra Write Path



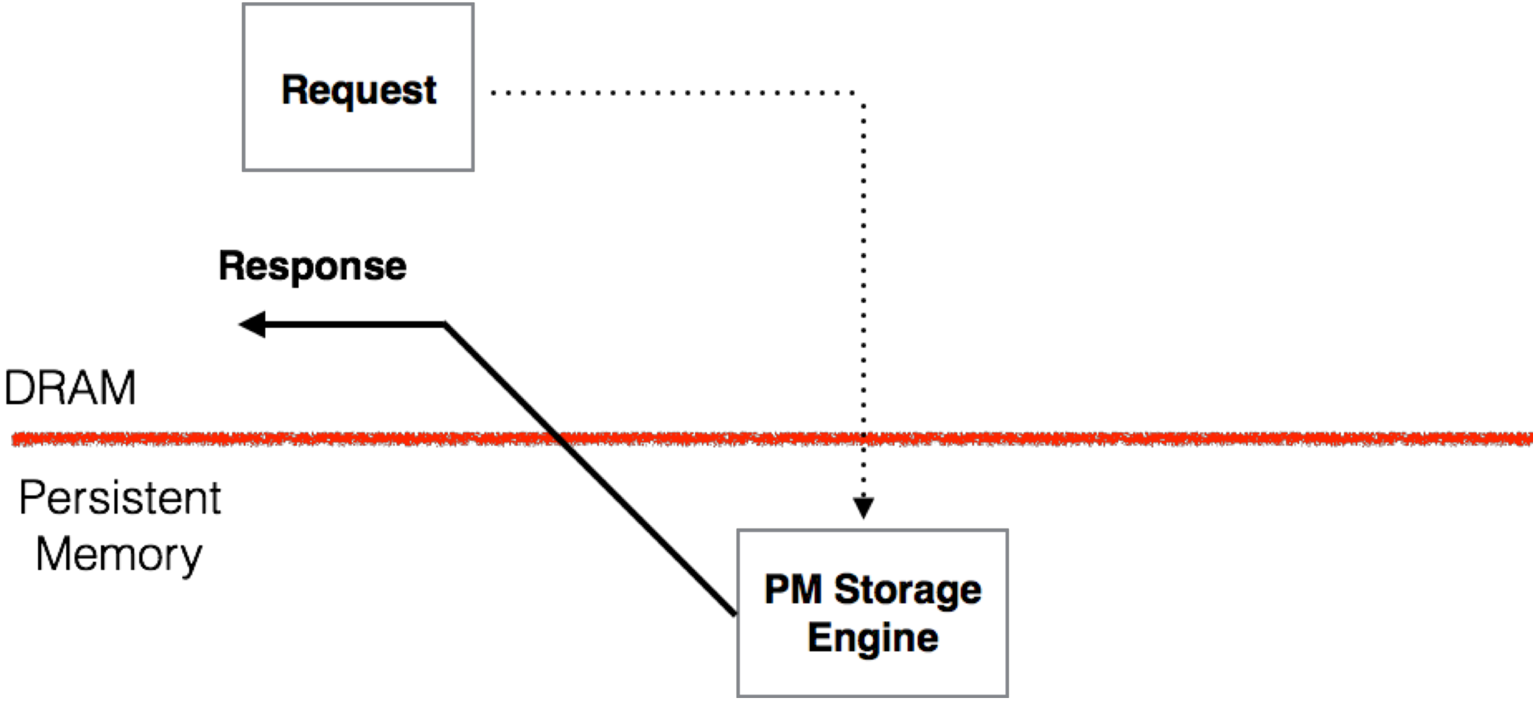
Cassandra Write Path – PM Storage Engine



Cassandra Read Path



Cassandra Read Path – PM Storage Engine



Request

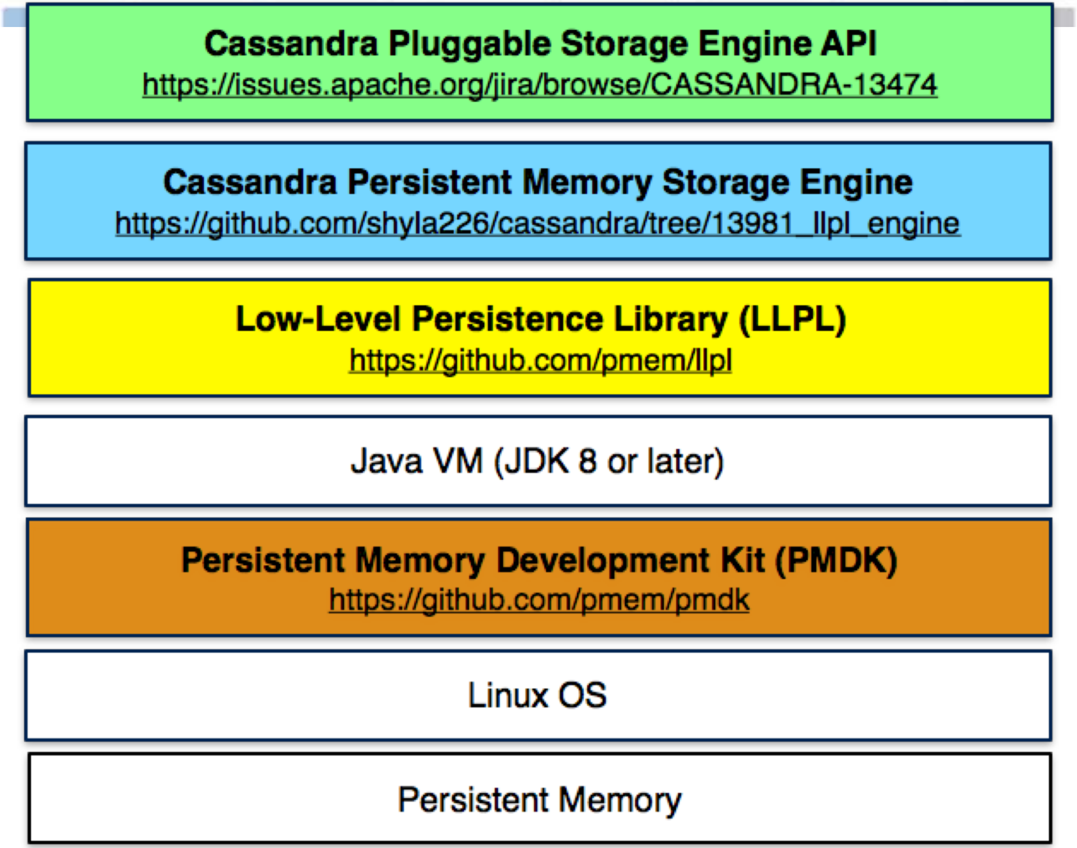
Response

DRAM

Persistent Memory

PM Storage Engine

Software - Persistent Memory Storage Engine



Cassandra Pluggable Storage Engine API
https://issues.apache.org/jira/browse/CASSANDRA-13474

Cassandra Persistent Memory Storage Engine
https://github.com/shyla226/cassandra/tree/13981_llpl_engine

Low-Level Persistence Library (LLPL)
https://github.com/pmem/llpl

Java VM (JDK 8 or later)

Persistent Memory Development Kit (PMDK)
https://github.com/pmem/pmdk

Linux OS

Persistent Memory

Want to learn more about PM?

- SNIA – Persistent Memory Resource Page
  https://www.snia.org/PM

- 2019 Persistent Memory Summit
  https://www.snia.org/pm-summit

- PM Hackathons…March…August…online/on-demand…
  Get hands-on training and experience