Persistent Memory Advances

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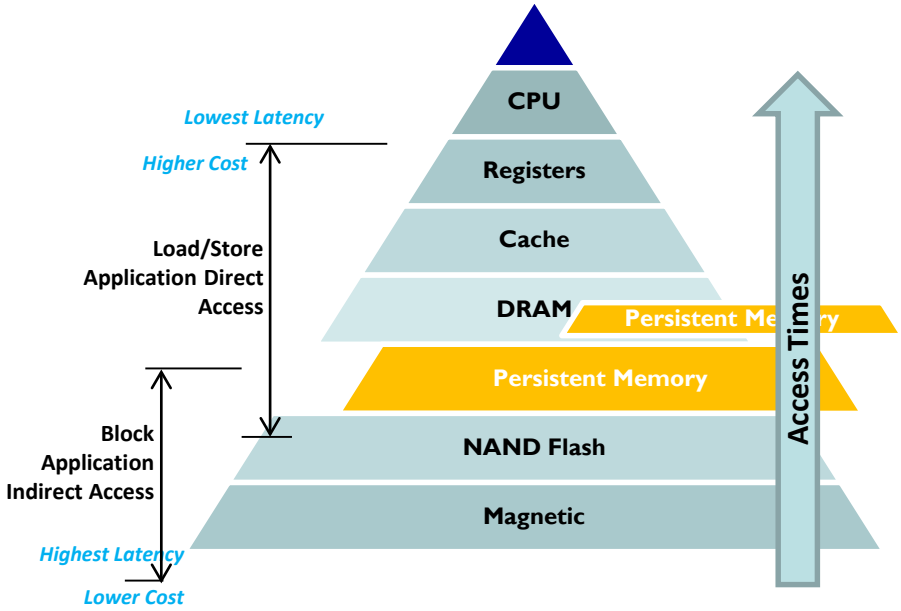
Agenda

- **Why Persistent Memory is Important**
- **Persistent Memory Applications**
- **SNIA and Industry Alliance Efforts on Persistent Memory**

Why is Persistent Memory Important?

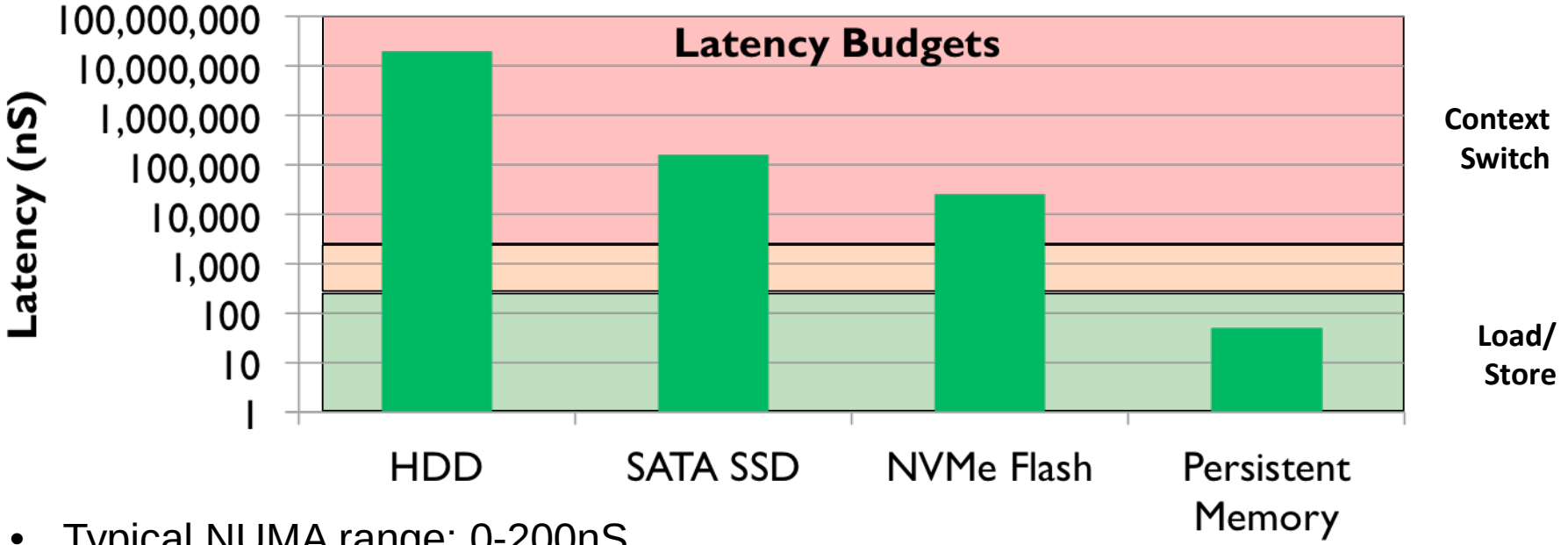
- Bridges the gap between DRAM and Flash
- Dramatically increases system performance
- Enables a fundamental change in computing architecture
- Apps, middleware and OSs are no longer bound by file system overhead in order to run persistent transactions



What It Is and Isn't and Why is it Important?

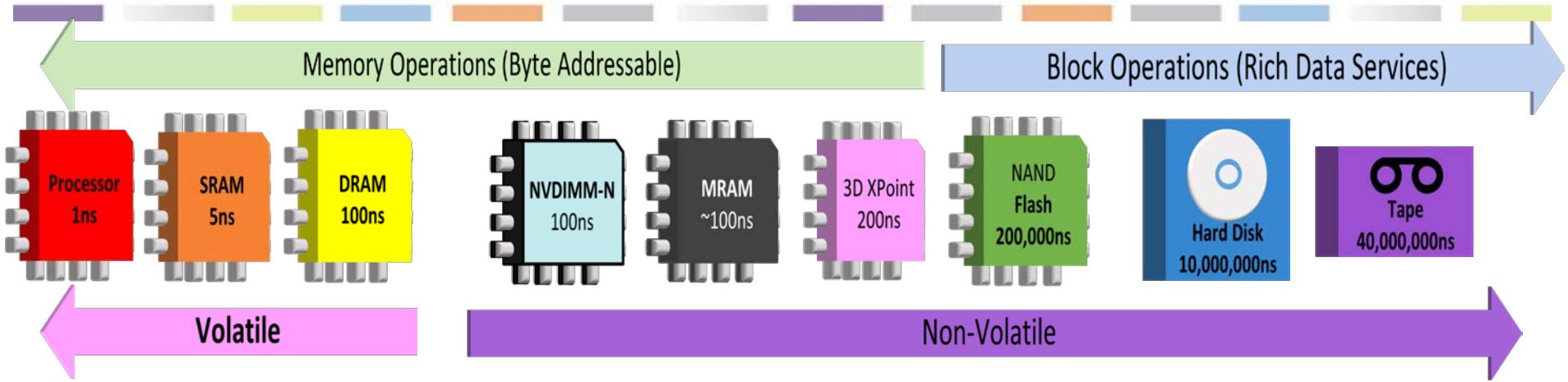
- **What is Persistent Memory?**
  - Non-Volatile
  - Byte Addressable
  - Low Latency <1µs
  - Densities greater than or equal to DRAM (for wide-scale adoption)
- **Why is persistent memory important?**
  - The vast majority of compute applications operate on 1, 2, 4, or 8 bytes at a time
  - For maximum performance memory technology must be directly addressable (load/store byte access)
  - With non-volatility, compute applications do not need serialization or to commit writes to a lower level (slower) memory tier
- **Non-Volatile Memory ≠ Persistent Memory**
  - Non-Volatile memory is not necessarily Persistent Memory in the industry term usage
  - NAND flash is paged-based and has millisecond write speeds
  - In it's current form NAND Flash by itself is not PM

Storage vs. Memory

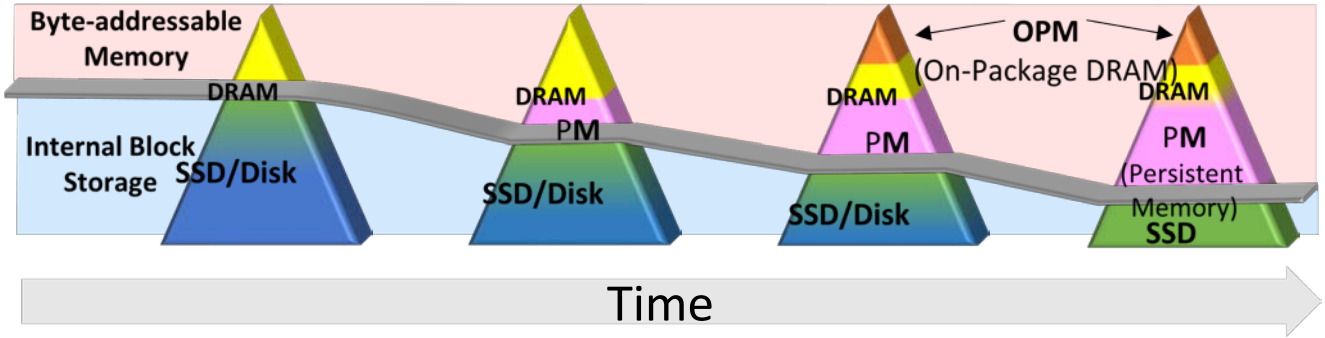


- Typical NUMA range: 0-200nS
- Typical context switch range: above 2-3µS

Memory and Storage are Converging



- Memory semantic operations become predominant (Volatile & Non-Volatile)



Source: Modified from Gen-Z Consortium 2017

Emerging Technologies

Multiple Persistent Memory technologies are nearing commercialization

- Phase Change (PCM): a middle ground between DRAM and Flash
- MRAM: DRAM replacement? density past 8Gb, lower idle power
- ReRAM: Flash replacement? High density, better endurance
- CNTRAM: Carbon Nanotube based memory – another DRAM replacement?

Source: FMS, Jim Harrell, Aug'18

Persistent Memory Technology Overview

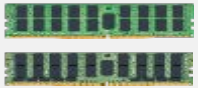
Technology	FRAM	MRAM	ReRAM	PCM	3D XPoint	NRAM	NVDIMM-N
Density	4K-4Mb	256Mb	TBD	128Mb	128Gb	16Gb	32GB
Endurance	10^{12}	10^{12}	10^{5}	10^{8}	10^{12}	10^{11}	∞
Writes	Byte	Byte	Byte	Byte	Byte	Byte	Byte
Read Latency	70-100ns	70ns	25ns	20ns	100ns	100ns	40-180ns
Write Latency	70-100ns	70ns	12µs	65ns	500ns	100ns	40-180ns
Power	Low	Med-Low	Low	Med	Med	Low	High
Interface	DRAM	DDR3 DDR4	Flash-Like	Unique	Unique	DDR4	DDR3 DDR4
Availability	Limited	Prod'n	Alpha	Limited	Samp.	Samp.	Volume

Source: Objective Analysis, May'18

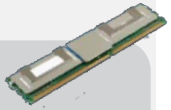
Existing and Emerging Variations of Persistent Memory Products

NVDIMM-N
(DRAM/NAND)

Performance Optimized PM



RDIMM/LRDIMM
(DRAM)



NVDIMM-P
(DRAM/NVM)

DIMMs
(NVM)

Cost Optimized PM

NVME SSD
(NVM)

NVME SSD
(NAND)

SATA/SAS SSD
(NAND)

Hard Disk Drive
(Spinning Media)

Cost

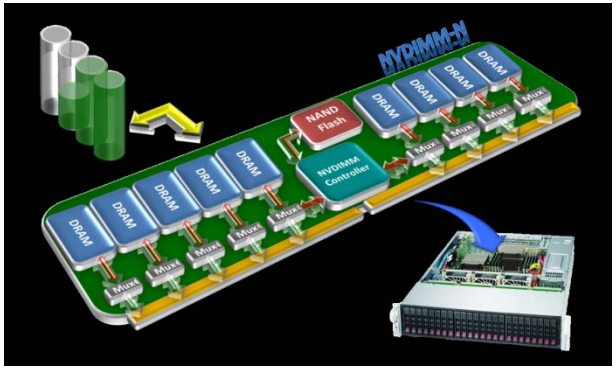
Nanoseconds **Microseconds** **Milliseconds**

Access Time

Source: Modified from Micron, FMS 2018

The Role of the NVDIMM-N

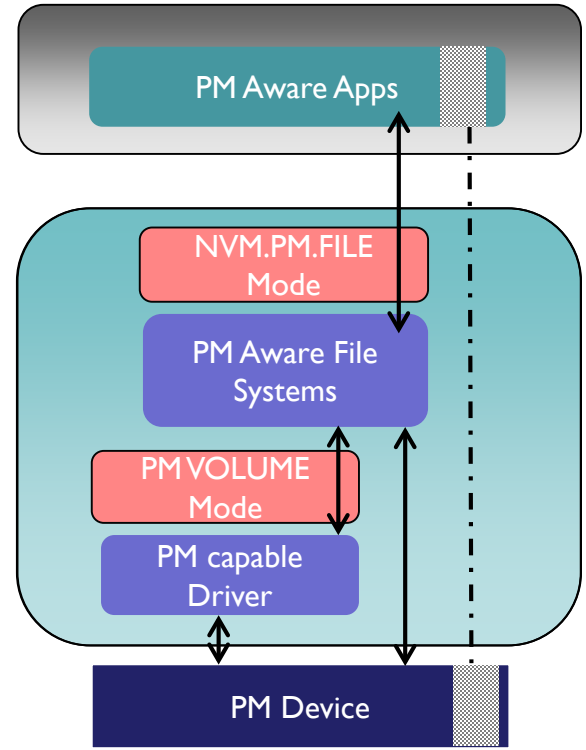
- Paves the path for Persistent Memory DIMMs
  - Allows software development today
  - Gets the creative process started
  - Supports segment of PM application needs
- A vehicle to debug PM-based systems
  - Software ready when hardware ships



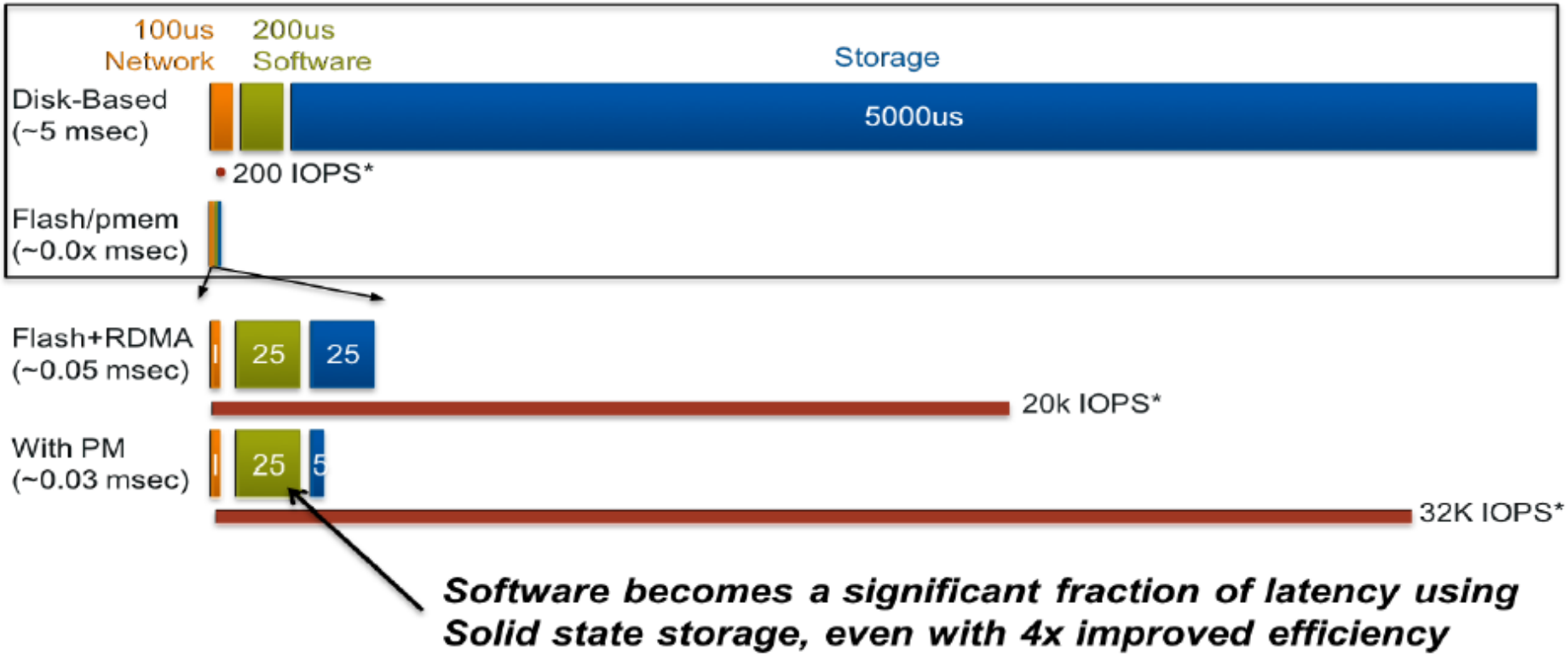
This Requires Standards!

SNIA NVM Programming Technical Work Group (TWG) Formed 06-11-2012

- Dell
- EMC
- Fujitsu
- HP
- Intel
- NetApp
- Oracle
- QLogic



Persistent Memory – Challenging DRAM and Flash



* Max potential 1-thread random sector

Source: FMS, Jim Harrell, Aug'18

Operating System Support

- Both Linux and Microsoft joined the SNIA effort to help steer the direction of PM
  - Applications have direct Load/Store access to PM
  - End result: Both OS's are structured almost identically (ex: DAX)
  - No other unique drivers needed
- VMWare has also offered support for PM

Persistent Memory support in OS's ahead of volume adoption

NVDIMM-N

- NVDIMM-N - the first HW available to run PM Applications.
  - Success stories emerge highlighting the application benefits of PM
    - Example: “Tail of Log” for SQL Server
    - Used in man All Flash Arrays
- Alliance formed between JEDEC and SNIA to effectively drive adoption of the technology

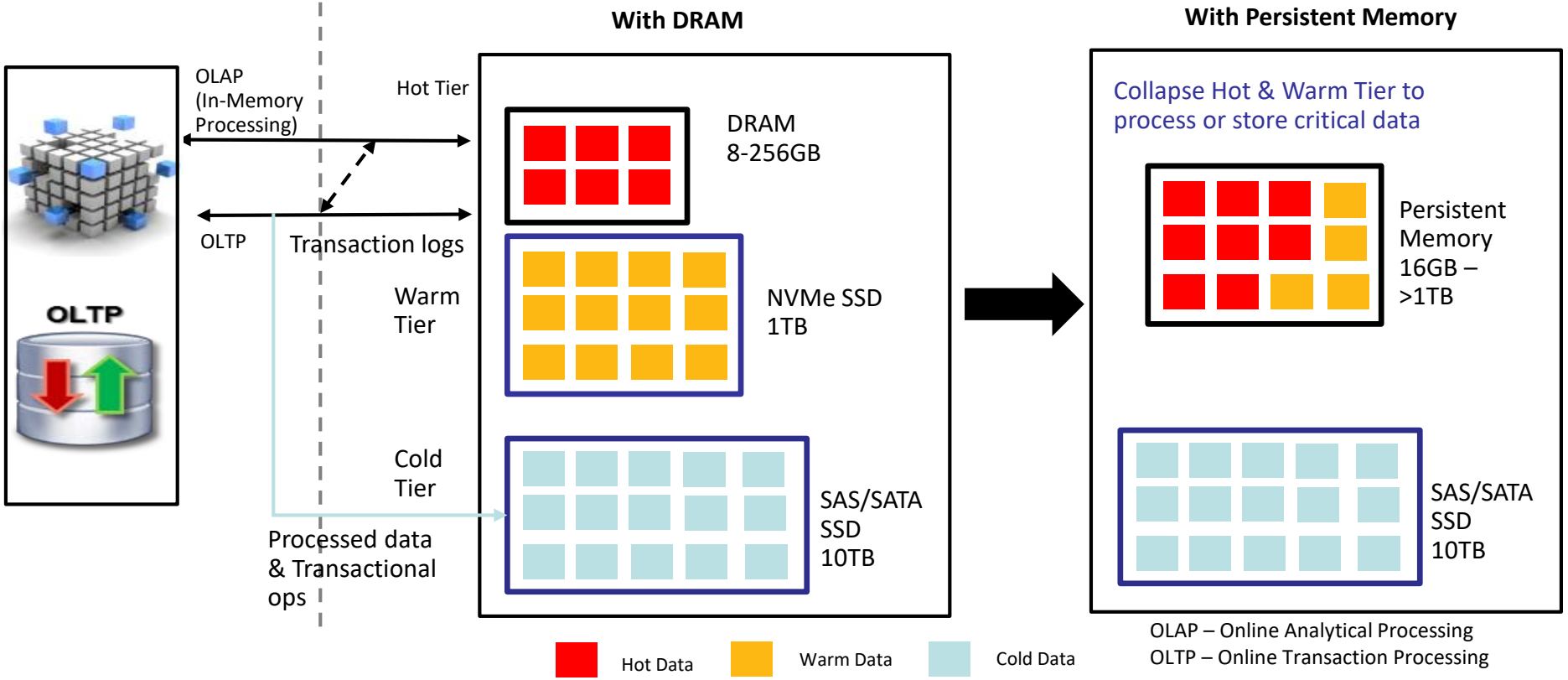
NVDIMM-N Prove the Benefits of PM

Persistent Memory Applications

What Applications will use PM?

- Applications that have a large working set of data with a need for persistence
  - Using NVMe or standard SSDs add latency
  - Decreasing the latency to avoid disk access
- In Memory Databases
  - Application driven data locality
  - Newer DB adaptations beginning to use PM
- Productivity Improvements
  - Software infrastructure is enabled
  - Standard libraries are available

Persistent Memory: Evolution of In-Memory Apps

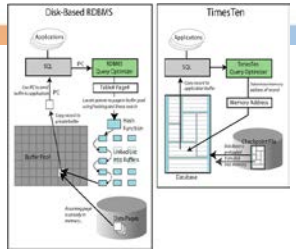


Source: Modified from VMWare, FMS 2018

Early PM System Support and Applications

A sample of companies publicly showing PM support

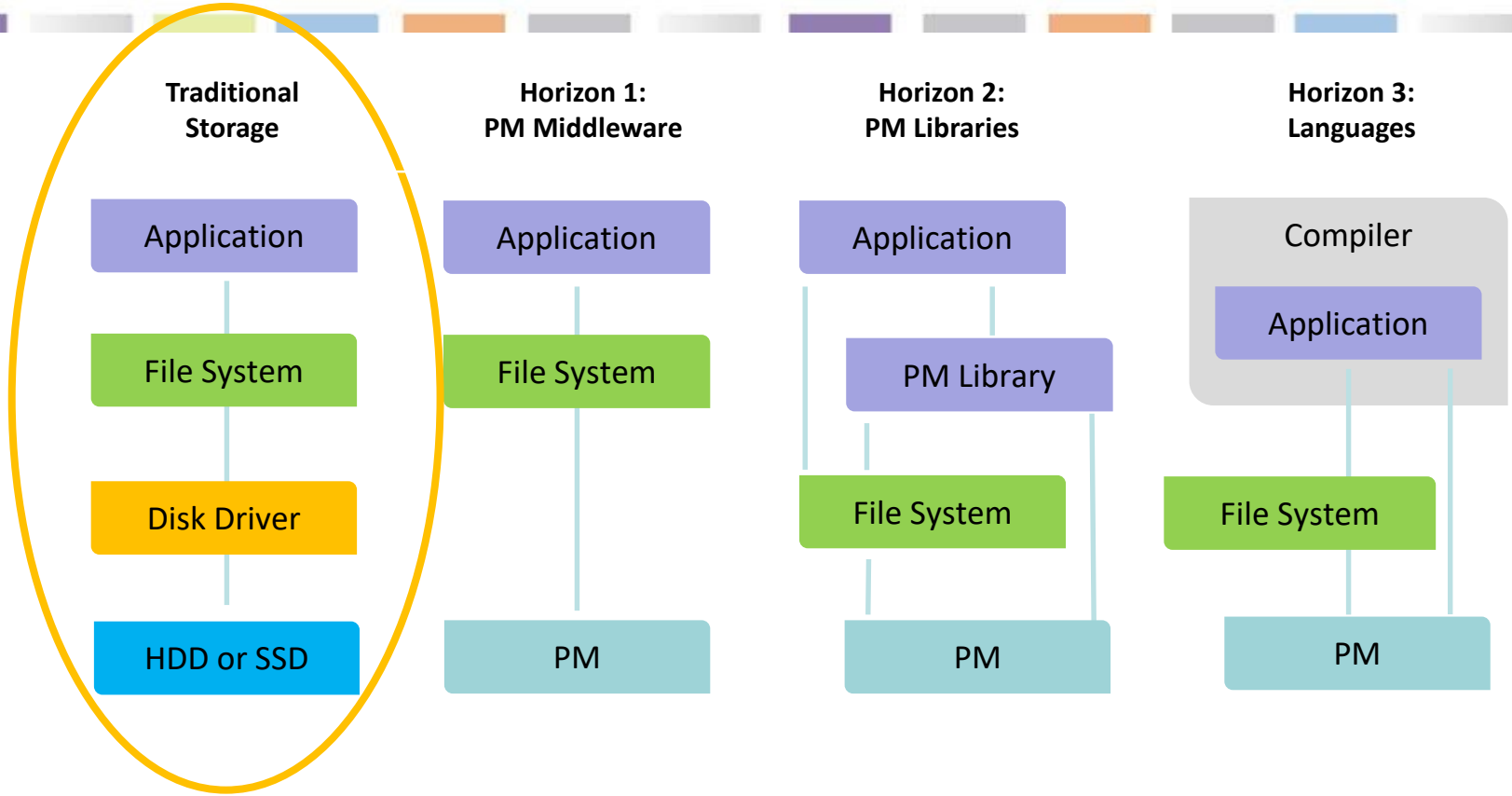
Persistent Memory Adds Value Across Diverse Applications



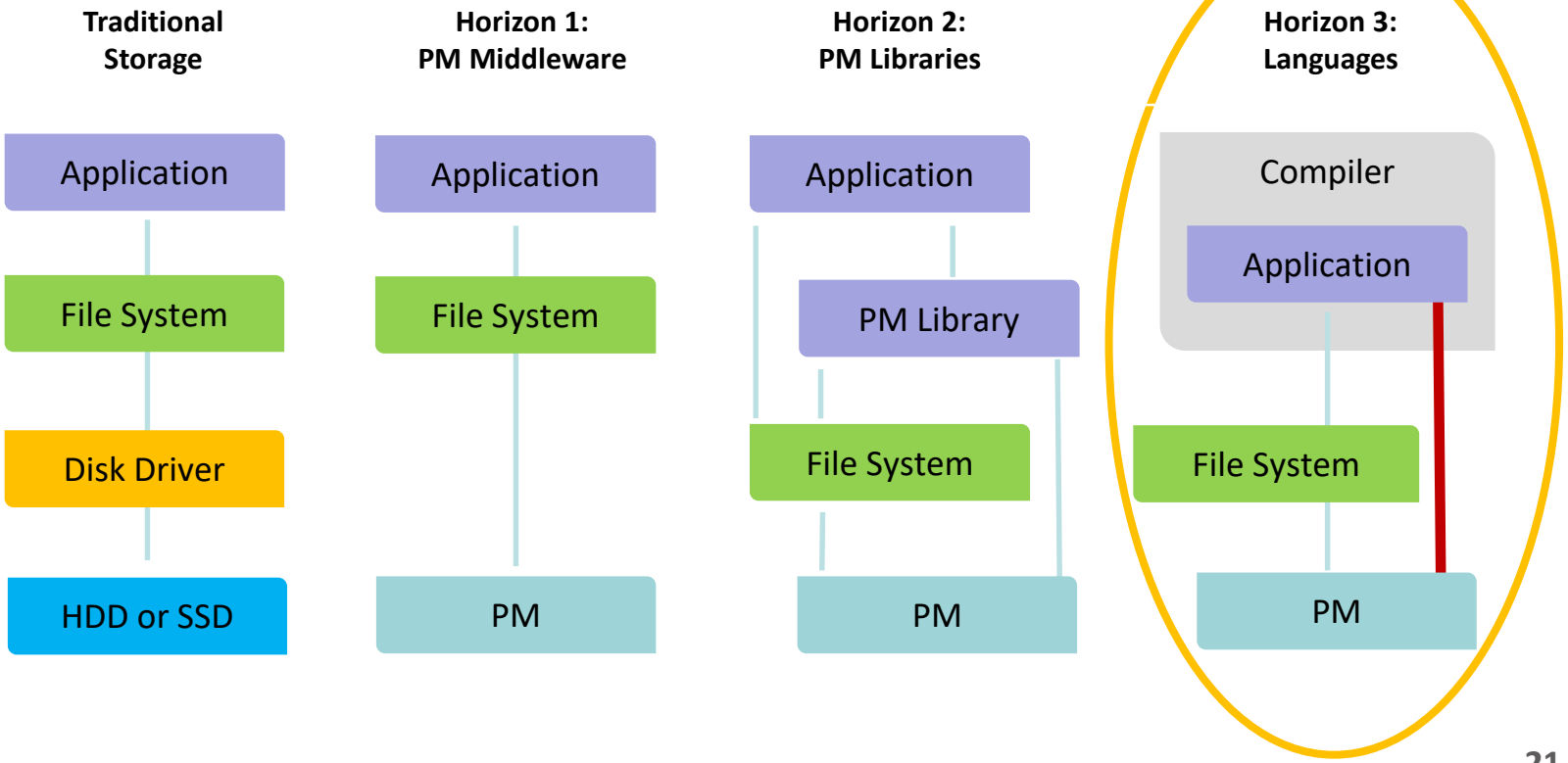
Relational Database	Scale-out Storage	Virtual Desktop Infrastructure	Big Data	In Memory Database	Middleware	HPC
MSFT SQL	Vmware VSAN	Vmware VDI	Mongo DB	SAP HANA	Java	HPC
MySQL	MSFT Azure	Citrix HDI	Cloudera	MSFT SQL Hekaton	.NET	
Maria DB	Store Virtual		HortonWorks	XAP Gigaspace		
Oracle			Hadoop			
			Cassandra			
			MSFT SQL Hadoop			
Log acceleration: write combining and caching	Tiering, caching, write buffering, meta-data storage	Higher VM consolidation	Higher performance	Journaling, Transaction logs	Optimized abstraction	Check point acceleration

Source: Micron HPE Discover 2018

Application Horizons - Today



Application Horizons – Ultimate Goal



NVDIMM-N and 3DXPoint Applications

- Many NAND flash storage array vendors are using NVDIMM-N modules for write acceleration and commit logging
  - These applications do not require a density higher than multiple GBs so they are well-suited for NVDIMM-N
- 3DXPoint is well-suited for PM applications like In-Memory databases that need 100’s of GBs to TBs of persistent memory that is used in combination with DRAM

Example: Need for In Memory Persistent Database

DreamWorks

- 600TB's of data in one film
- Many small items in a large working set
- Substantial re-use and repeat file I/O
- Expensive to compute and convert
- Distributed clients doing similar things
- Writes are immutable; lockless updates

Goal with PM

- NVDIMMs in each workstation and server
- Accelerate local workflows
- Cluster of Persistent Memory servers
- Software stack that provides RPM-as-a-Service
- A way for apps to persist things and reduce trips through the storage stack
- A way for apps to find and get things
- That behaves like named shared memory

Source: Modified from DreamWorks, FMS, Aug'18

Example: Using Persistent Memory to Accelerate HCI Storage Performance

Differentiated value with Persistent Memory in HCI storage tier

Create a new persistent memory tier for metadata (benefits ALL apps)

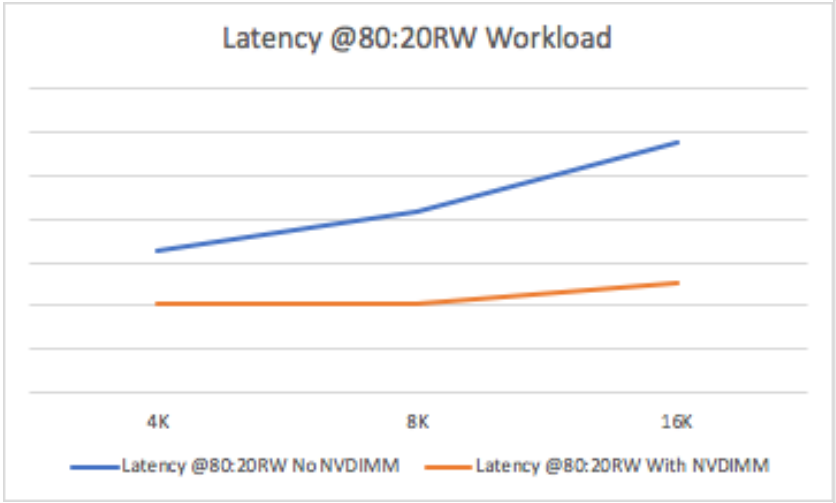
1. Read-modify-write with persistent memory as byte addressable is 100X faster than block storage
2. Faster metadata access for dedup, checksum etc results in reduced CPU utilization and higher IOPS for all apps
3. Faster reboots due to persistence of metadata in persistent memory (save time for not having to rebuild metadata from logs)

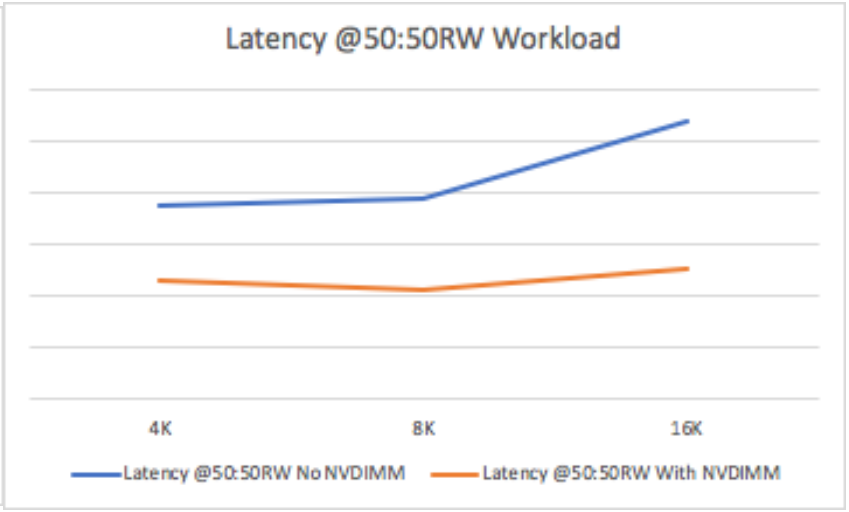
Source; Modified from VMWare, FMS 2018

Example: WDC IntelliFlash Write Cache

- Separate logging for incoming writes
- Write is acknowledged after persisting to the write cache
- Coalesced I/O is flushed to drives after dedupe and compression
- Uses high performance media as the latency is crucial for many applications like DBT and OLTP
- Best fit for NVDIMM

Example Results – Latency Comparison





- All flash array with 24TB capacity
- iSCSI protocol
- fio with 4 clients and 8 LUNs

Source: WDC, FMS 2018

SNIA and Alliance Efforts on Persistent Memory

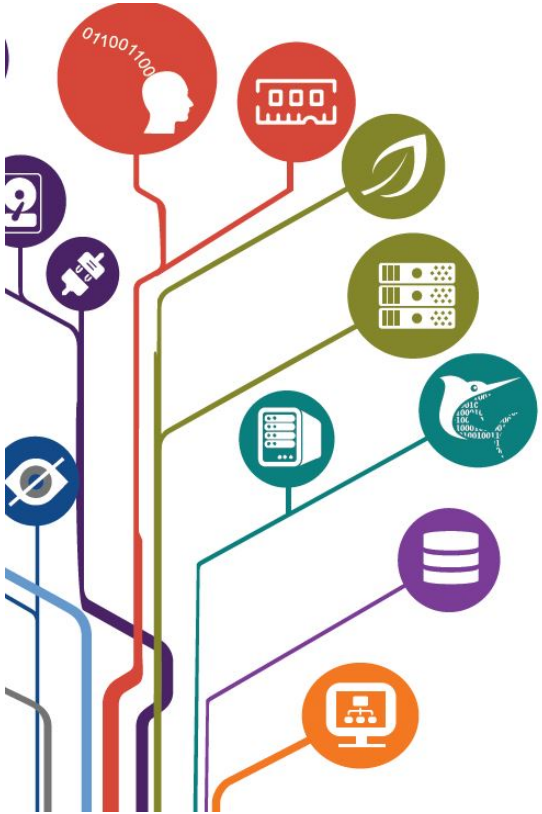
Who is SNIA?

170
industry leading organizations

2,500
active contributing members

50,000
IT end users & storage pros worldwide

What SNIA Does



- Leads the storage industry worldwide in developing and promoting:
  - Standards development and adoption of open source software
  - Interoperability assurance – plugfests and conformance testing
  - Technology acceleration – SIGs and collaborations
  - Global vendor neutral education – certification, webcasts, white papers

SNIA Efforts on Persistent Memory

- SNIA Technical Council & Technical Working Groups (TWGs)
  - Non-Volatile Memory Programming TWG
  - This is the body developing the NVM Programming Model
- SNIA Standards (aka Technical Positions), Software & White Papers
  - NVM Programming Model v1.2 (June 2017) – Technical Position
  - PM Remote Access for High Availability v1 (February 2016) –White Paper
  - PM Atomics and Transactions v1r1 (January 2017) – White Paper
- SNIA Solid State Storage Initiative (SSSI)
  - One of many Forums and Initiatives within SNIA
  - SSSI sponsors the Persistent Memory and NVDIMM Special Interest Group (SIG)
  - Deliverables: PM Summit, webcasts, videos, presentations, tutorials

JEDEC

- JEDEC standards address architectural, electrical, test, and SPD issues relating to memory design and manufacturing for commercial applications

- JC-45.6 subcommittee:
  - Hybrid Modules
    - This is the subcommittee that governs NVDIMM work
    - Most recent – JESD248A – DDR4 NVDIMM-N (March 2018)
    - Governs all behavior of module including backup/restore

Persistent Memory and NVDIMM SIG Charter

- To accelerate the awareness and adoption of Persistent Memories and NVDIMMs for computing architectures
- The Persistent Memory and NVDIMM SIG will:
  - Educate on the types, benefits, value, and integration of Persistent Memories
  - Communicate usage of the NVM Programming Model developed to simplify system integration of current and future PM technologies
  - ***Influence and collaborate with middleware and application vendors to support Persistent Memories***
  - Develop user perspective case studies, best practices, and vertical industry requirements
  - Coordinate with industry standards groups and promote industry standards related to PM and NVDIMM
  - Synchronize and communicate a common Persistent Memory taxonomy

Application Development Enabling

- SNIA Persistent Memory Application Enabling
  - A program is being formed to enable the application development community to build Persistent Memory applications
  - Will launch in early 2019
  - ***Looking for new members/contributors***

Goal: Accelerate Development of PM Applications

Thank You!