Persistent Memory in Operation

[SPO1422] – 2019-04-03

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FUJITSU
shaping tomorrow with you

Human Centric Innovation
Digital Co-creation

Fujitsu Corporate Profile

Who we are

Japan's largest IT services provider and
No. 5 in the world.
(based on vendor revenue 2015)*

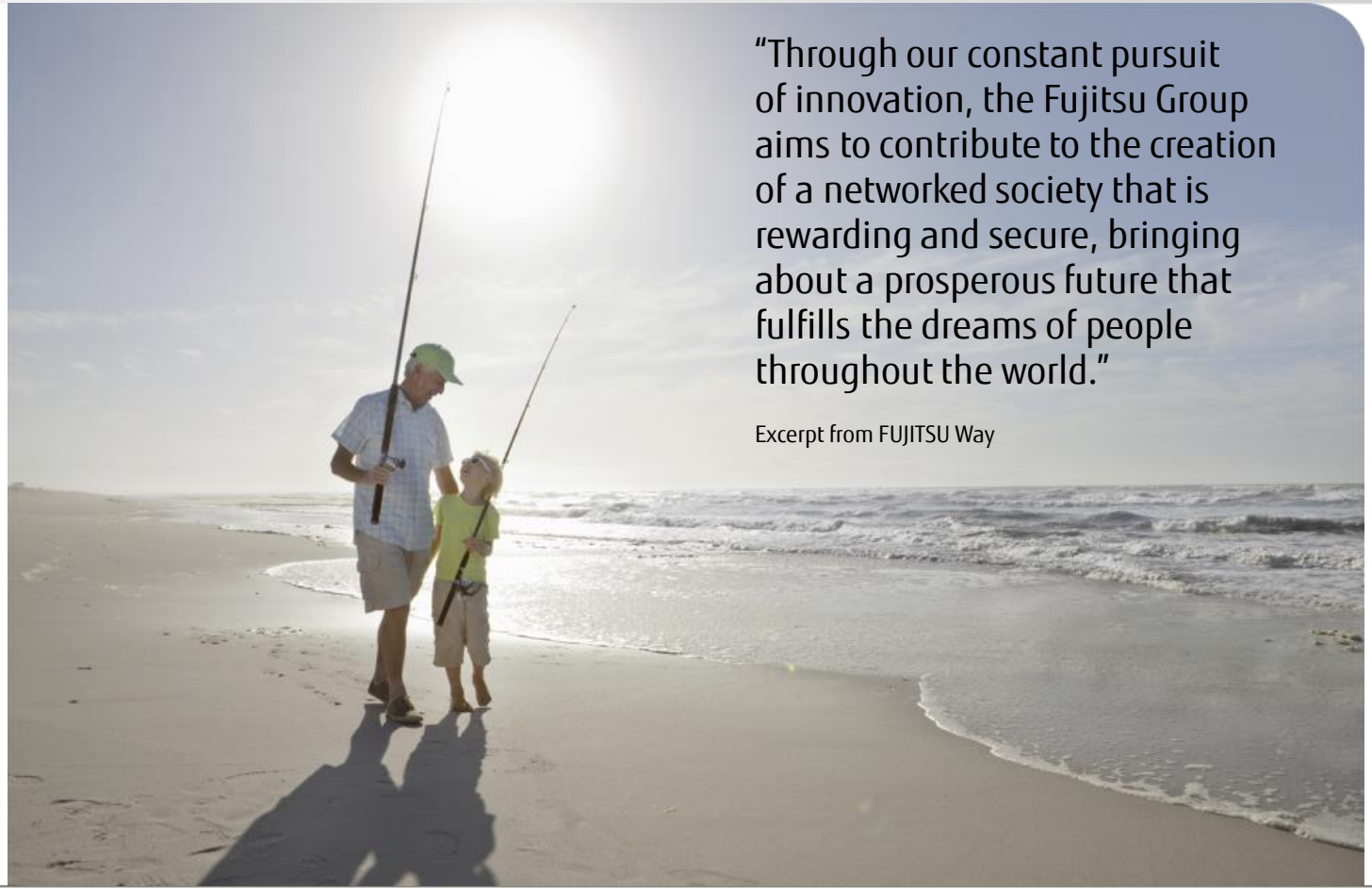
We do everything in ICT. We use our experience and the power of ICT to shape the future of society with our customers.

156,000 Fujitsu people support customers in more than 100 countries.

FORTUNE named Fujitsu as one of 'the World's Most Admired Companies' for the fourth consecutive year.

* Source: Gartner, " Market Share: IT Services, 2015" 06 April 2016 (GJ16139)

Corporate Vision – Human Centric Computing



"Through our constant pursuit of innovation, the Fujitsu Group aims to contribute to the creation of a networked society that is rewarding and secure, bringing about a prosperous future that fulfills the dreams of people throughout the world."

Excerpt from FUJITSU Way

A worldwide network to support our customers

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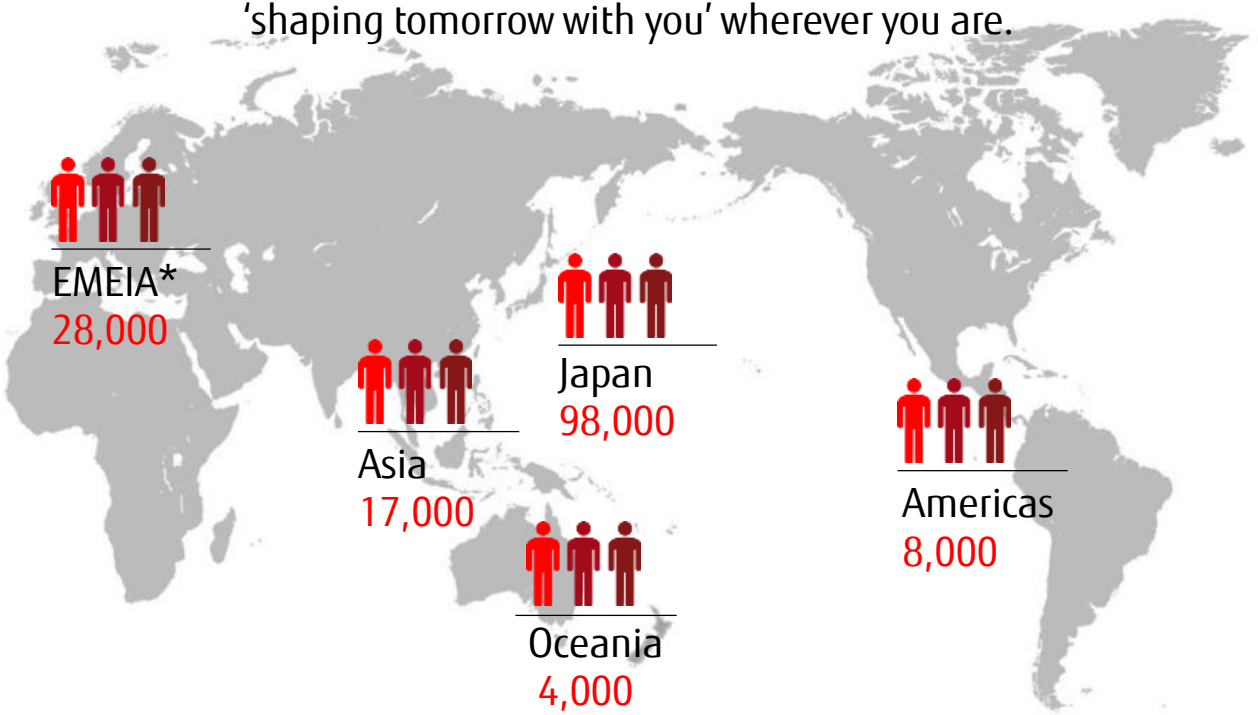
'shaping tomorrow with you' wherever you are.



Approximately 155,000 Fujitsu colleagues working with customers in over 100 countries

As of March 2017

* EMEIA - Europe, Middle East, India and Africa

Technology

Memory Storage Hierarchy

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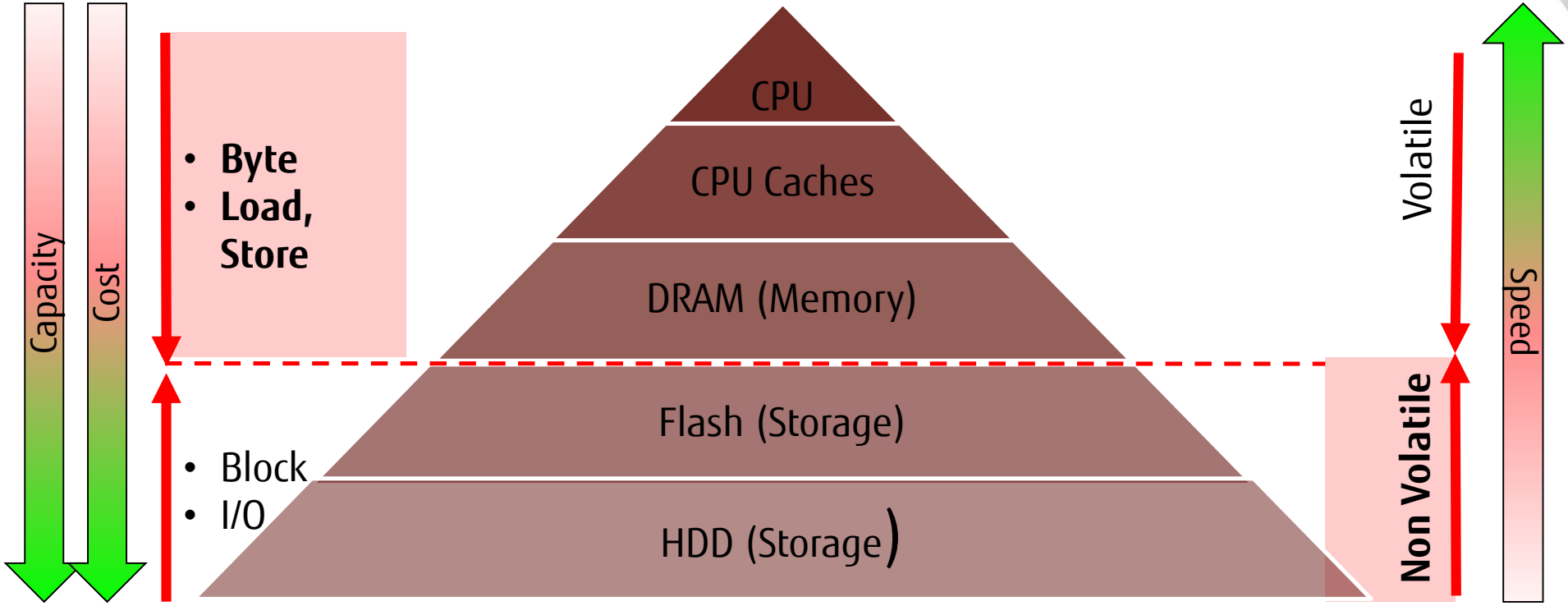

Memory Storage Hierarchy – Paradigm Shift

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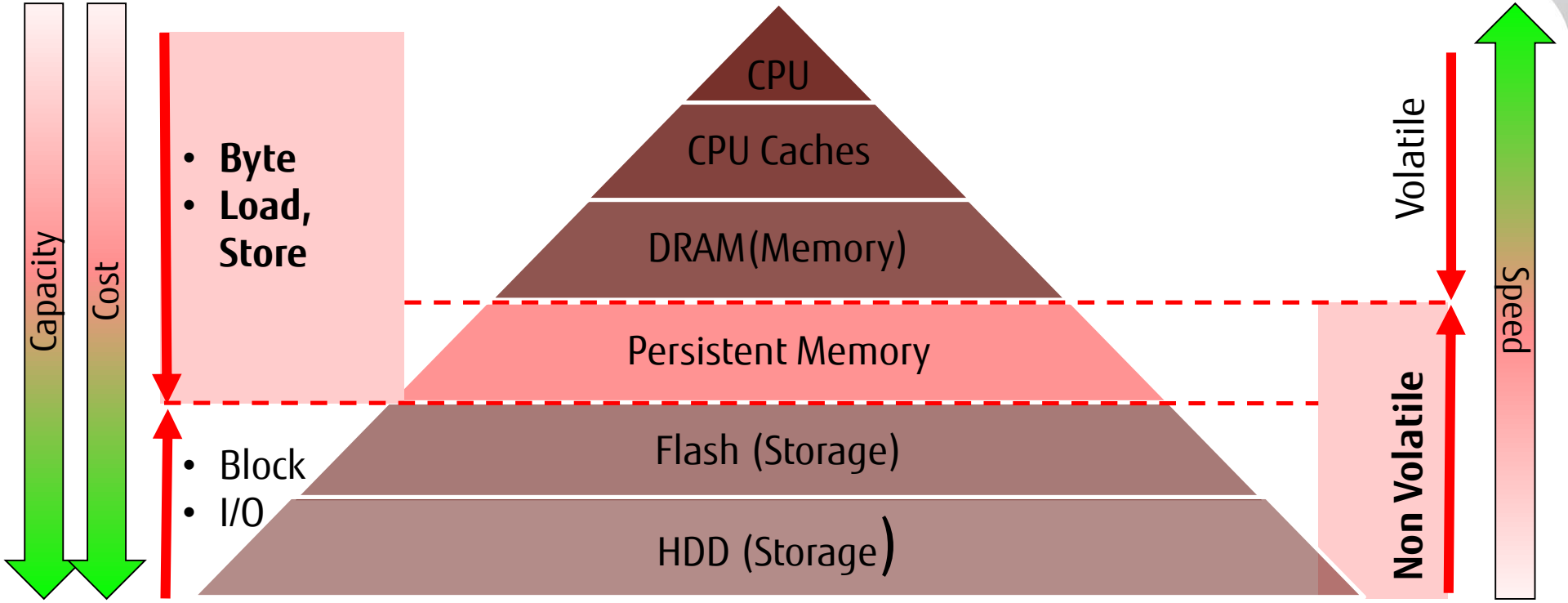
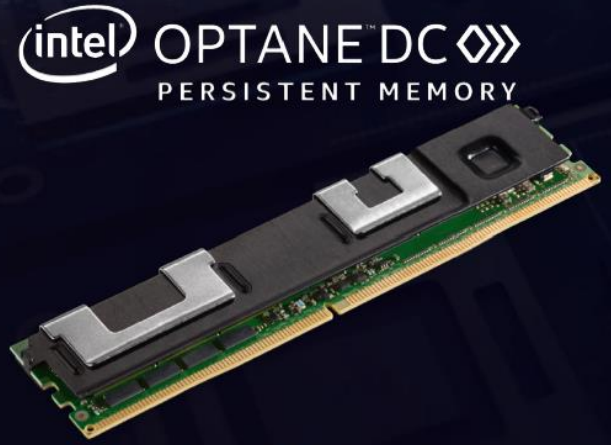


PERSISTENT MEMORY PLATFORM SUPPORT

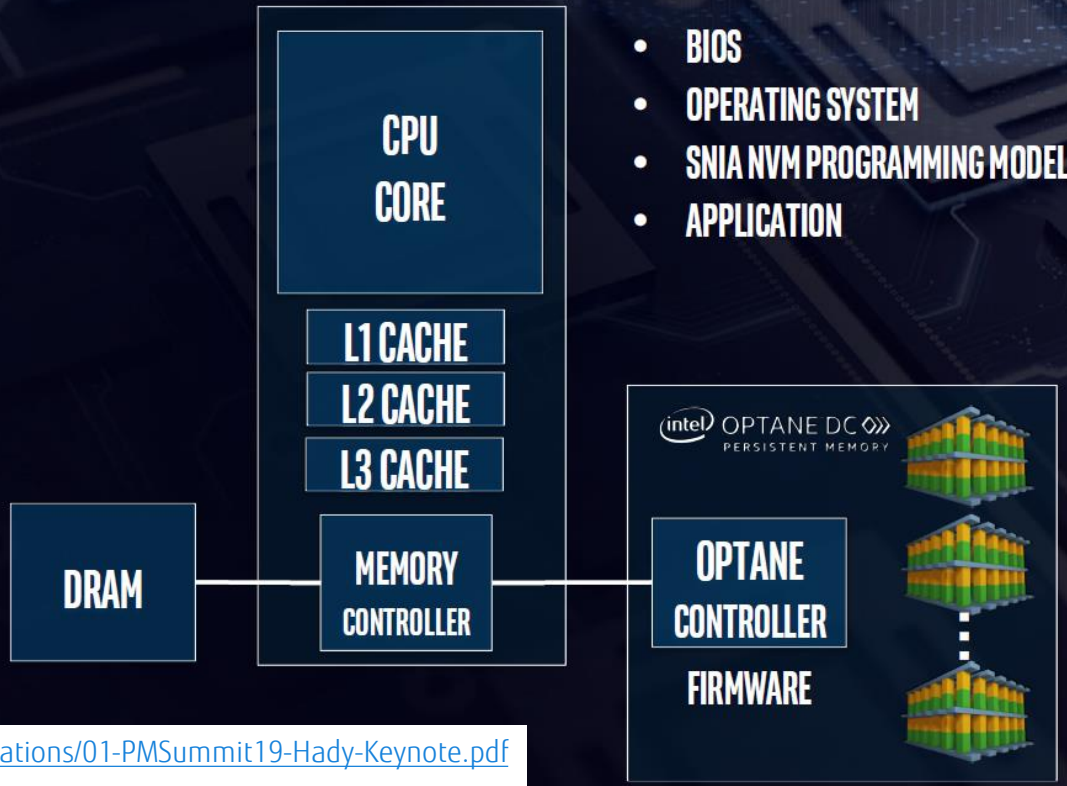


Direct Load/Store Access

Native Persistence

128, 256, 512GB

DDR4 Pin Compatible

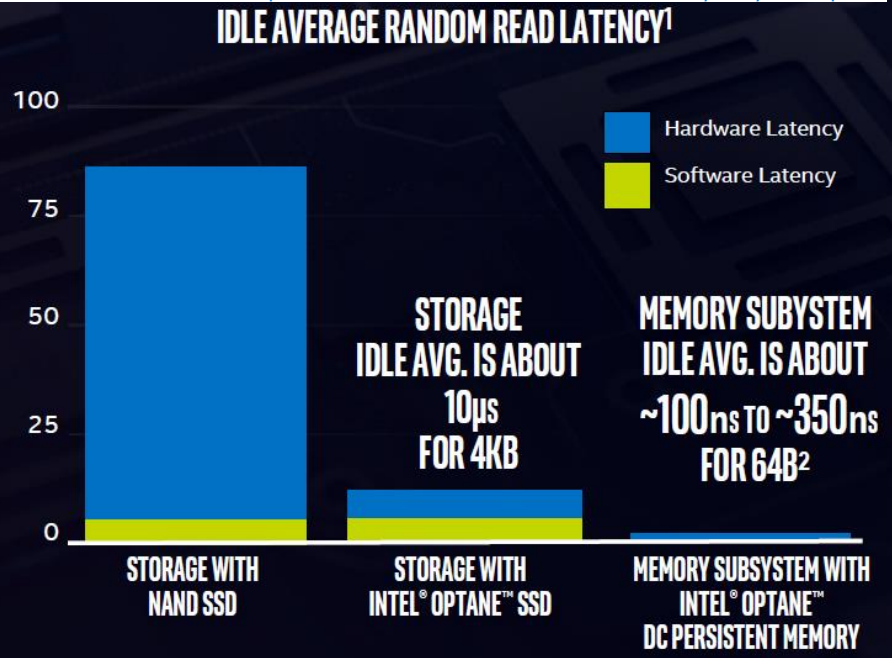


- BIOS
- OPERATING SYSTEM
- SNIA NVM PROGRAMMING MODEL
- APPLICATION

https://www.snia.org/sites/default/files/PM-Summit/2019/presentations/01-PMSummit19-Hady-Keynote.pdf

LOW LATENCY SYSTEM ACCESS TO PERSISTENT MEMORY

https://www.snia.org/sites/default/files/PM-Summit/2019/presentations/01-PMSummit19-Hady-Keynote.pdf



[1] Source: Intel-tested: Average read latency measured at queue depth 1 during 4k random write workload. Measured using FIO 3.1. comparing Intel Reference platform with Optane™ SSD DC P4800X 375GB and Intel® SSD DC P4600 1.6TB compared to SSDs commercially available as of July 1, 2018. Performance results are based on testing as of July 24, 2018 and may not reflect all publicly available security updates. See configuration disclosure for details. No product can be absolutely secure. For more complete information about performance and benchmark results, visit www.intel.com/benchmarks.

[2] App Direct Mode , NeonCity, LBG B1 chipset , CLX B0 28 Core (QDF QQYZ), Memory Conf 192GB DDR4 (per socket) DDR 2666 MT/s, Optane DCPMM 128GB, BIOS 561.D09, BKC version WW48.5 BKC, Linux OS 4.18.8-100.fc27, Spectre/Meltdown Patched (1,2,3, 3a)

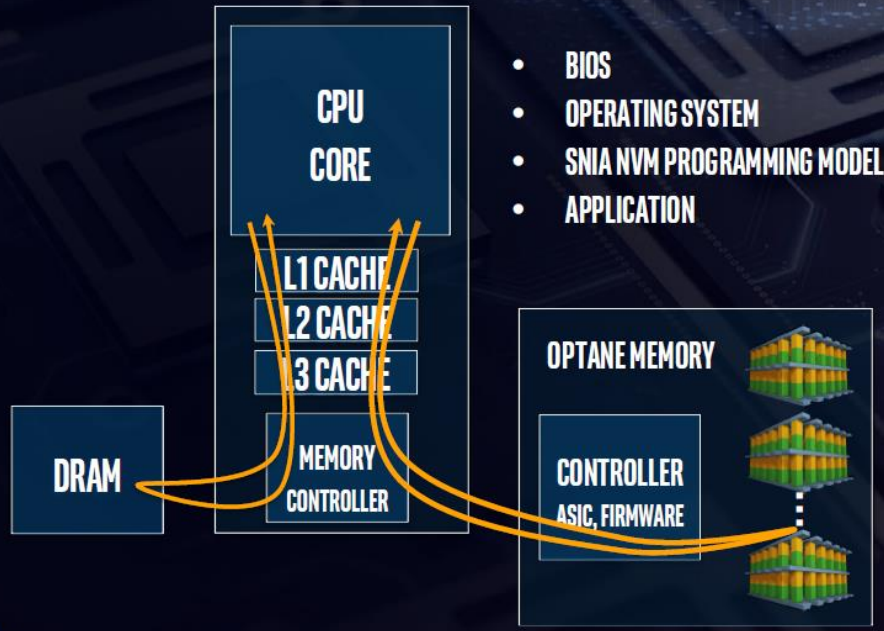
INTEL® OPTANE™ PERSISTENT MEMORY : APP DIRECT

App Direct Mode provides the persistent memory programming model

- Reported to OS by ACPI
- Linux and Windows expose via "DAX" file systems

Several use cases supported by OS & PMDK APIs

- Persistent memory, non-paged (no DRAM footprint when accessed)
- Volatile App Direct, an explicit pool of volatile memory
- Storage over App Direct, a very fast SSD built on persistent memory



- BIOS
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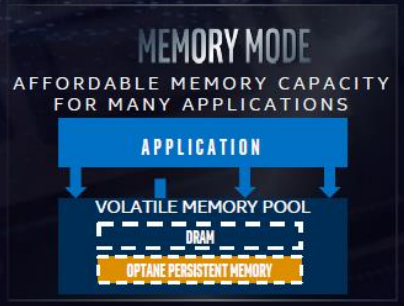
- SNIA NVM PROGRAMMING MODEL
- APPLICATION

https://www.snia.org/sites/default/files/PM-Summit/2019/presentations/01-PMSummit19-Hady-Keynote.pdf

INTEL® OPTANE™ PERSISTENT MEMORY: MEMORY MODE

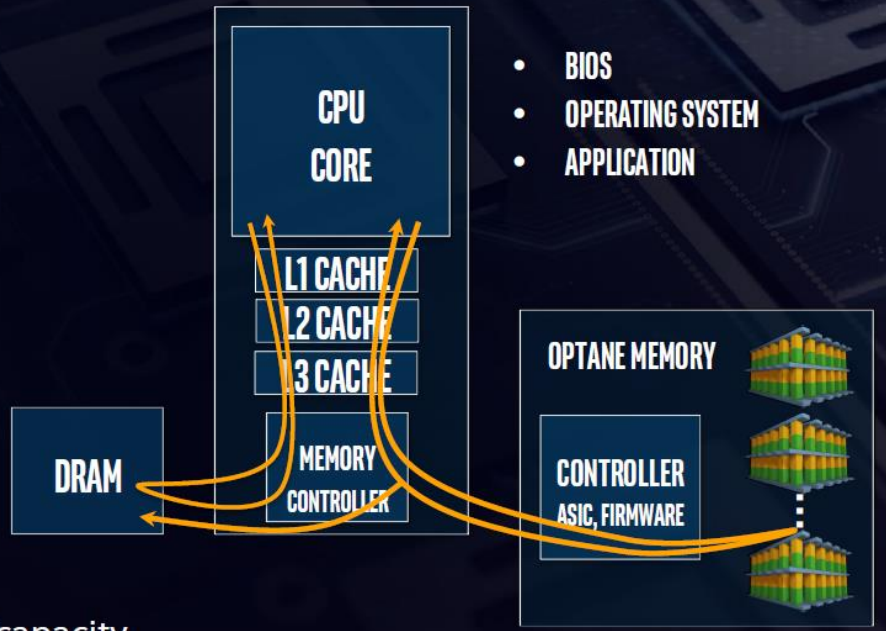


Memory Mode provides familiar volatile memory programming model

- Additional layer of caching: DRAM as WB cache
- Hardware managed, software sees very high capacity memory (6 TB)

Range of use cases supported

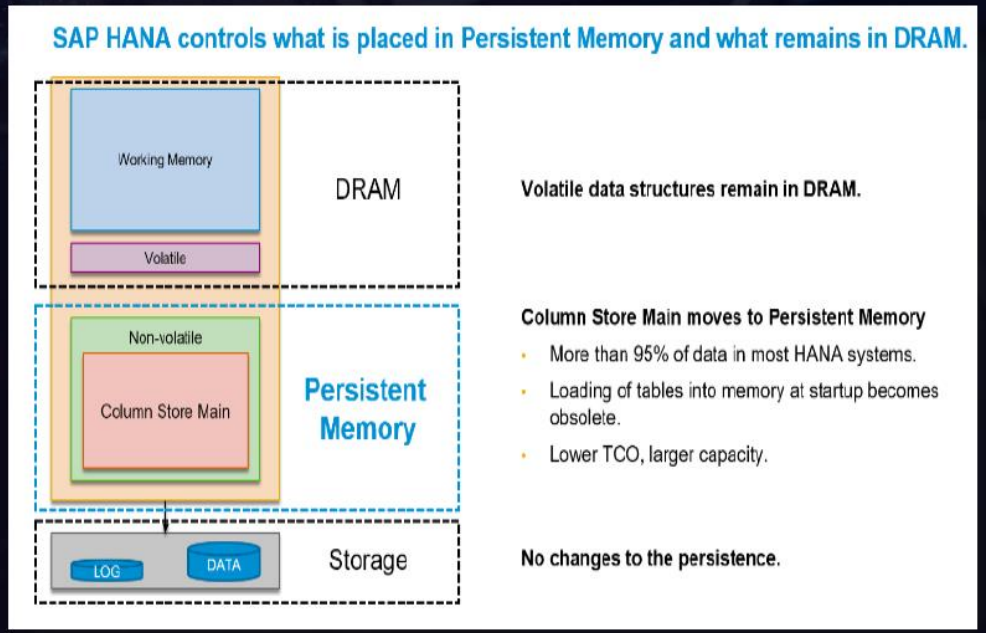
- No software change – big memory
- Applications/Algorithms changes for new hierarchy/capacity



https://www.snia.org/sites/default/files/PM-Summit/2019/presentations/01-PMSummit19-Hady-Keynote.pdf

[SPO1457]

APP DIRECT USAGE EXAMPLE



Developer placed data structures

"SAP HANA knows which data structures benefit most from persistent memory. SAP HANA automatically detects persistent memory hardware and adjusts itself by automatically placing these data structures on persistent memory, while all others remain in DRAM"

- Column Store Main in Persistent Memory
  - 90% of the data footprint
  - Nonvolatile – no initial load time
- High perf, volatile in DRAM
- SSDs still used for row store, column delta, replication, backups…

Source: "SAP HANA & Persistent Memory"
- Andreas Schuster
Dec 3 2018, https://blogs.sap.com/2018/12/03/sap-hana-persistent-memory/

[2] App Direct Mode , NeonCity, LBG B1 chipset , CLX B0 28 Core (QDF QQYZ), Memory Conf 192GB DDR4 (per socket) DDR 2666 MT/s, Intel® Optane Data Center Persistent Memory 128GB, BIOS 561.D09, BKC version WW48.5 BKC, Linux OS 4.18.8-100.fc27, Spectre/Meltdown Patched (1,2,3, 3a)

PMEM attributes

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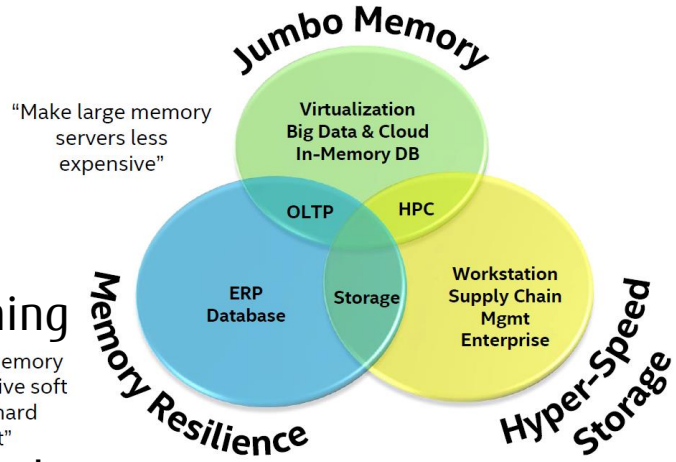
- Enables a fundamental change in computing architecture
- Standardized through NFIT and JEDEC
- Linux 4.4+ kernels and Windows2016 have the software stack
- Dramatically increases system performance
- Bridges the gap between DRAM and Flash
- Apps, middleware and OSs are no longer bound by file system overhead in order to run persistent transactions
- NVDIMMs BIOS/MRC (Memory Reference Code)
- Open source library is available for applications

Use Cases

- Execute in place for *.ko, *.so, …
- In Memory Database
  - Journaling, reduced recovery time, tables
- Traditional Database
  - Log acceleration by write combining, caching
- Enterprise Storage
  - Tiering, caching, write buffering and meta data storage
- High-Performance Computing
  - Check point acceleration and/or elimination
- Analytics, AI, HPC

Growing Need for New Class of Memory



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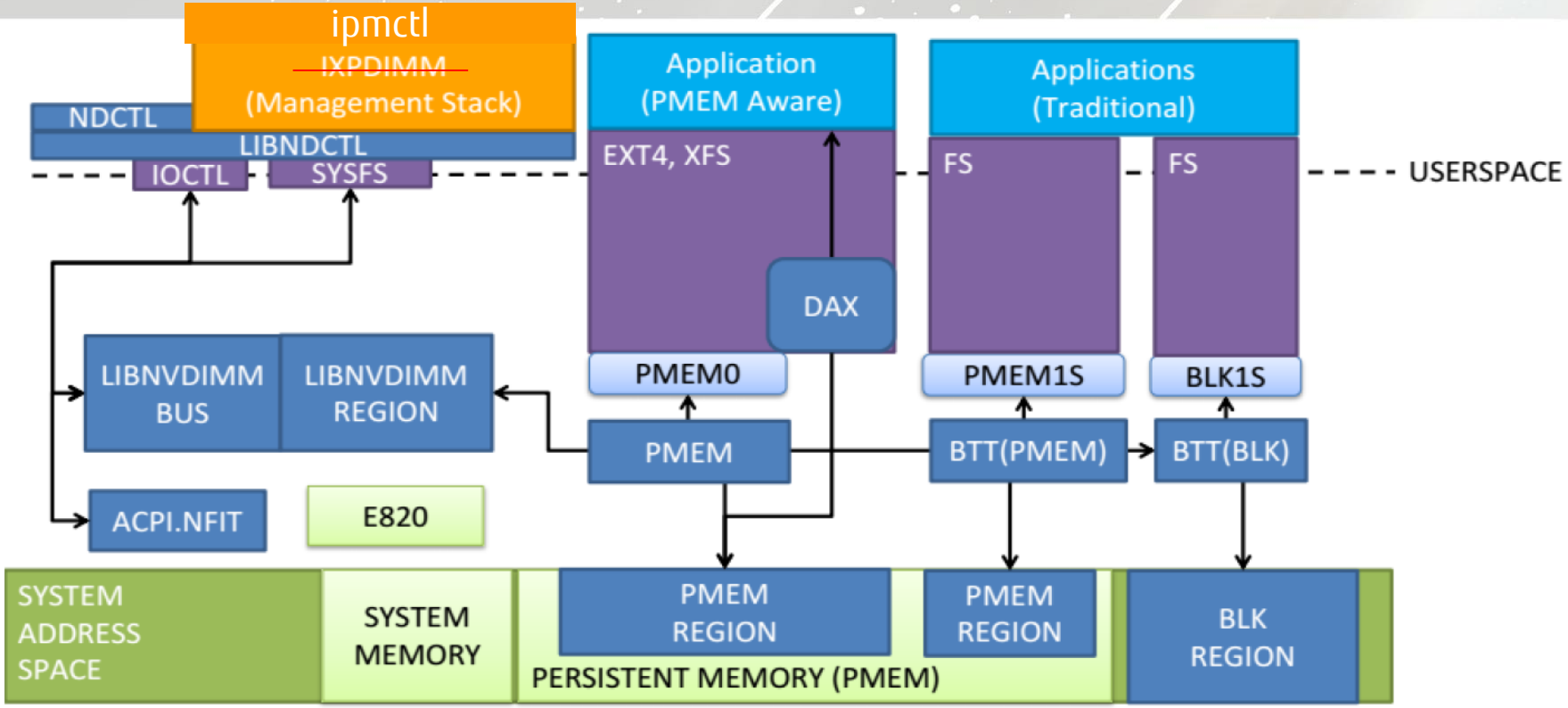
- Technology
- **Setup and Configuration**

Linux 4.9+



*Courtesy of Dan Williams <dan.j.williams@intel.com>

https://www.snia.org/sites/default/files/SDC/2017/presentations/Solid_State_Stor_NVM_PM_NVDIMM/Kasanicky_Tiffany_Managing_Persistent_Memory.pdf

Persistent Memory Tools

https://www.snia.org/sites/default/files/SDC/2018/presentations/PM/Upadhyayula_U_Scargall_S_Introduction_to_Persistent_Memory_Configuration_and_Analysis_Tools.pdf

Configuration

- Pre-boot
  - ipmctl
- Linux
  - ipmctl
  - ndctl
- Windows
  - ipmctl
  - New-StoragePool
  - New-Volume

Benchmark

- Intel® Memory Latency Checker (MLC)
- FIO (Flexible IO Tester)
- pmembench

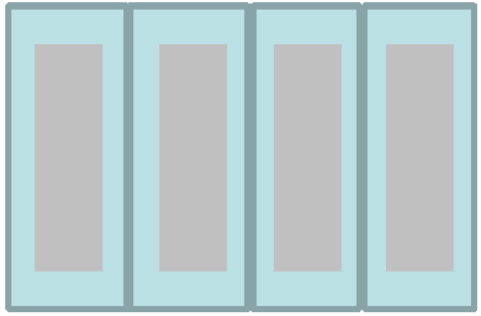
Analysis

- Intel® VTune Amplifier
  - Memory Analyzer
  - Storage Analyzer
- Intel® Persistent Inspector
- Intel® VTune Platform Profiler
- pmempool
- pmemcheck
- Valgrind

Provisioning Terms & Concepts

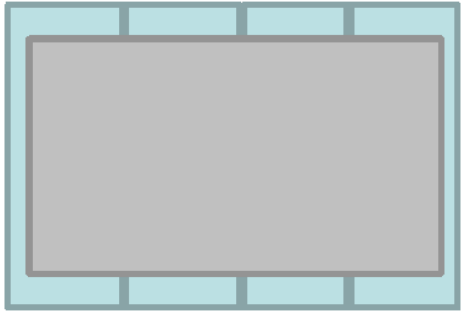
https://www.snia.org/sites/default/files/SDC/2018/presentations/PM/Upadhyayula_U_Scargall_S_Introduction_to_Persistent_Memory_Configuration_and_Analysis_Tools.pdf

Non-Interleaved Regions



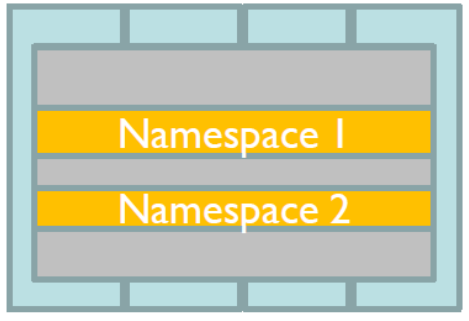
Regions are created within [non]interleaved sets. Interleaving can be 1 to n-way mapping.

Interleaved Regions



Creates contiguous physical address space and provides striped reads/writes for better throughput.

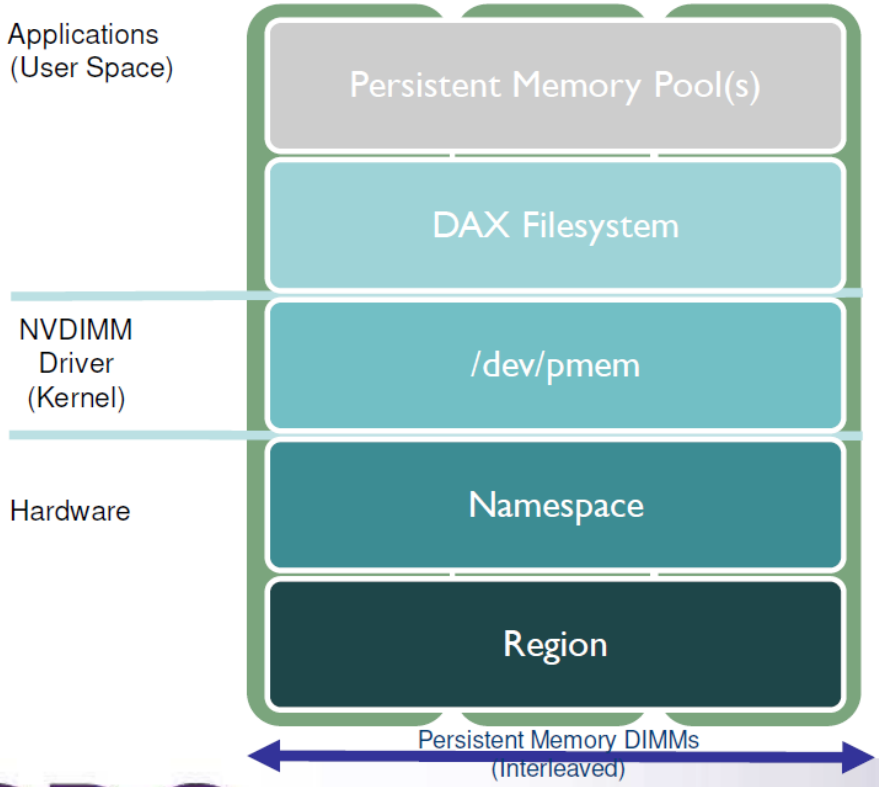
Namespaces



Similar to SSD, raw capacity of a region is partitioned into one or more logical devices called namespaces.

Exposing Persistent Memory to Applications

Filesystem DAX (FSDAX)



Persistent Memory Pool(s): persistent memory is exposed by the OS to the application as memory-mapped files when using PMDK.

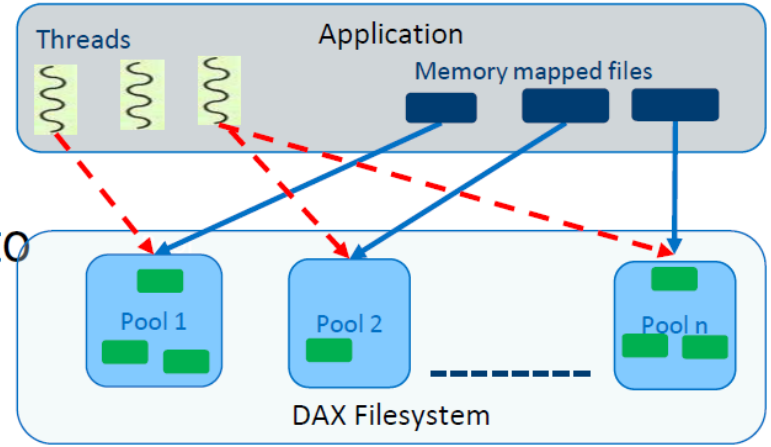
Direct Access (DAX) Filesystem: For file mappings (mmap), the storage device is mapped directly into user space and bypasses page cache.

/dev/pmem: a device used to create a filesystem.

https://www.snia.org/sites/default/files/SDC/2018/presentations/PM/Upadhyayula_U_Scargall_S_Introduction_to_Persistent_Memory_Configuration_and_Analysis_Tools.pdf

Persistent Memory Pools

- Intended for use on DAX File System
- Pools are tagged with a ‘layout’ name/string for identification
- Support for multiple pools per Application
- Pools can be aggregated into ‘pool sets’ to provide a larger address space and replication
- Easy backup/restore



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Configuration overview

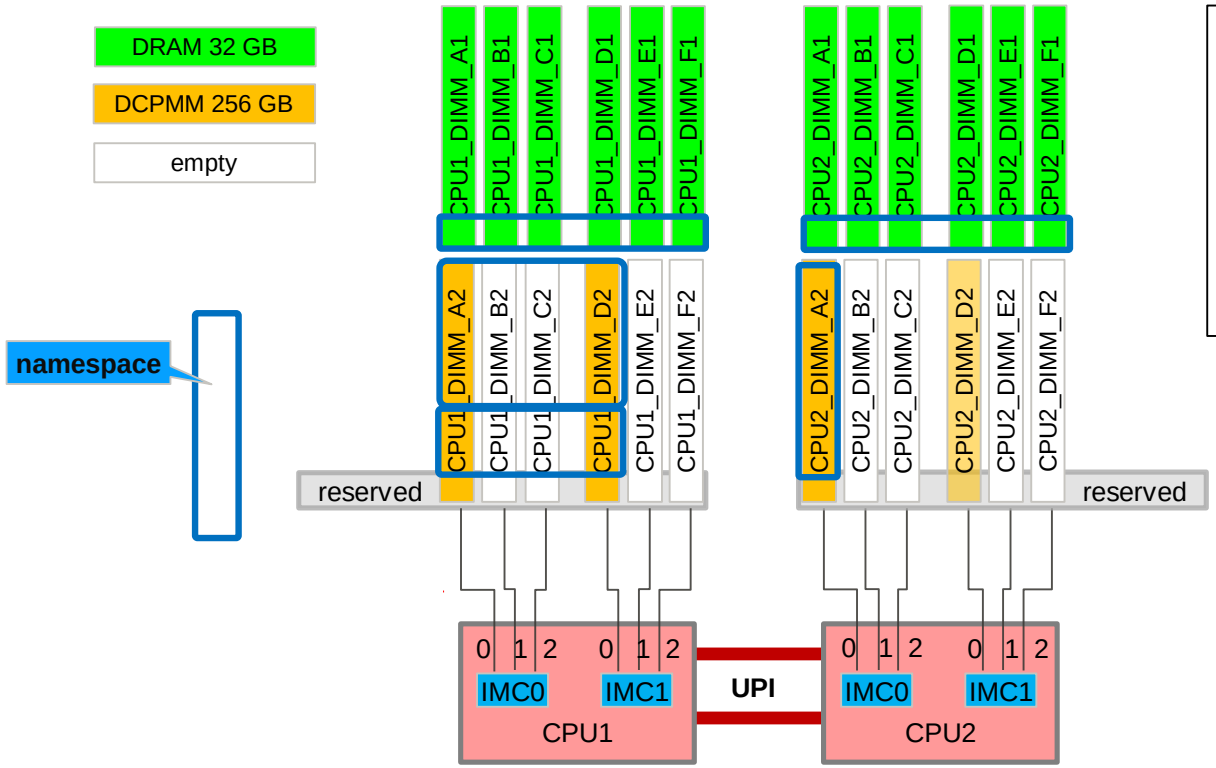
app_direct_mode **1LM = AD**	Support for accessing Apache Pass DIMM persistent memory in App Direct mode. In App Direct mode, Apache Pass DIMMs and DDR act as independent memory resources under direct load/store control of an application. (***One-Level Memory, or 1LM***)
memory_mode **2LM = MM**	Support for accessing Apache Pass DIMM capacity in memory mode where Apache Pass DIMMs act as system memory under the control of the operating system. In Memory mode, any DDR in the platform will act as a cache working in conjunction with the Apache Pass DIMMs. In some earlier documentation, this mode was referred to as ***Two-Level Memory, or 2LM***.

persistent memory concepts

	AEP memory modules	***AD or MM or mixed mode***	***allocation goals***	***regions***	***namespaces***
BIOS	detect			n/a	n/a
standalone UEFI shell					
Linux ipmctl	n/a	implied by allocation goal	define	administrate	n/a
Linux ndctl	n/a	n/a	n/a	administrate	define and administrate

- We use **BIOS** to detect memory modules
- BIOS could be used to define the operation mode (AD, MM or mixed mode) – but we do not use BIOS for that purpose.
- instead: the operation mode (AD, MM or mixed mode) is implied by the way we define allocation goals using Linux **ipmctl**
- we could use standalone UEFI shell for all configuration steps – but FJ does not use it at all

Test system PRIMERGY



rx24-1	RX2540-M4
CPU	Xeon 82xx, 24C, 2.6GHz
BIOS	R1.3.1 for D3384-B1x

Configuration – DIMM type and location

```
[root@rx24-1 ~]# ipmctl show -dimm
 DimmID | Capacity   | HealthState    | ActionRequired | LockState | FWVersion
==========================================================================
 0x0001 | 252.4 GiB | Healthy        | 0              | Disabled  | 01.01.00.5212
 0x0101 | 252.4 GiB | Healthy        | 0              | Disabled  | 01.01.00.5212
 0x1001 | 252.4 GiB | Healthy        | 0              | Disabled  | 01.01.00.5212
 0x1101 | 0.0 GiB   | Non-functional | N/A            | N/A       | N/A

[root@rx24-1 ~]# ipmctl show -topology
 DimmID | MemoryType                  | Capacity   | PhysicalID| DeviceLocator
============================================================================
 0x0001 | Logical Non-Volatile Device | 252.4 GiB | 0x0031    | CPU1_DIMM_A2
 0x0101 | Logical Non-Volatile Device | 252.4 GiB | 0x003d    | CPU1_DIMM_D2
 0x1001 | Logical Non-Volatile Device | 252.4 GiB | 0x0049    | CPU2_DIMM_A2
 0x1101 | Logical Non-Volatile Device | 0.0 GiB   | 0x0055    | CPU2_DIMM_D2
 N/A    | DDR4                        | 32.0 GiB  | 0x002f    | CPU1_DIMM_A1
 N/A    | DDR4                        | 32.0 GiB  | 0x0033    | CPU1_DIMM_B1
 N/A    | DDR4                        | 32.0 GiB  | 0x0036    | CPU1_DIMM_C1
 (…)
```

Configuration – DIMM location and nmem devices

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```
[root@rx24-1 ~]# ndctl list --dimms -u
[
  {
    "dev":"nmem1",
    "id":"8089-a2-1834-0000173b",
    "handle":"0x101",
    "phys_id":"0x3d"
  },
  {
    "dev":"nmem0",
    "id":"8089-a2-1834-000016b0",
    "handle":"0x1",
    "phys_id":"0x31"
  },
  {
    "dev":"nmem2",
    "id":"8089-a2-1834-00001a91",
    "handle":"0x1001",
    "phys_id":"0x49"
  }
```

```
[root@rx24-1 ~]# ls -l /dev/nmem*
crw------- 1 root root 251, 0 Mar 20 09:52 /dev/nmem0
crw------- 1 root root 251, 1 Mar 20 09:52 /dev/nmem1
crw------- 1 root root 251, 2 Mar 20 09:52 /dev/nmem2
crw------- 1 root root 251, 3 Mar 20 09:52 /dev/nmem3

[root@rx24-1 ~]# grep 251 /proc/devices
251 dimmctl
```

Configuration – Create Goal (1)

- ipmctl-create-goal - Creates a memory allocation goal on one or more DCPMM
  - Creates a memory allocation goal on one or more for the BIOS to read on the next reboot in order to map the DCPMM capacity into the system address space. Persistent memory can then be utilized by creating a namespace
  - ipmctl create [-help|-h] [-force|-f] [-units|-u (B|MB|MiB|GB|GiB|TB|TiB)] [-output|-o (text|nvmxml)] [-dimm [(DimmIDs)]] -goal [-socket (SocketIDs)] [MemoryMode=(0|%)] [PersistentMemoryType=(AppDirect|AppDirectNotInterleaved)] [Reserved=(0|%)] [NamespaceLabelVersion=(1.1|1.2)]

```
[root@rx24-1 ~]# ipmctl create -dimm 0x0001,0x0101 -goal PersistentMemoryType=AppDirect
The following configuration will be applied:
 SocketID | DimmID | MemorySize | AppDirect1Size | AppDirect2Size
==========================================================================
 0x0000   | 0x0001 | 0.0 GiB    | 252.0 GiB      | 0.0 GiB
 0x0000   | 0x0101 | 0.0 GiB    | 252.0 GiB      | 0.0 GiB
Do you want to continue? [y/n] y
Created following region configuration goal
 SocketID | DimmID | MemorySize | AppDirect1Size | AppDirect2Size
==========================================================================
 0x0000   | 0x0001 | 0.0 GiB    | 252.0 GiB      | 0.0 GiB
 0x0000   | 0x0101 | 0.0 GiB    | 252.0 GiB      | 0.0 GiB
A reboot is required to process new memory allocation goals.
```

Configuration – Create Goal (2)

```
[root@rx24-1 ~]# ipmctl show -region
 SocketID | ISetID             | PersistentMemoryType    | Capacity  | FreeCapacity | HealthState
==========================================================================================
 0x0000   | 0x8baaeeb8535e2444 | AppDirect               | 504.0 GiB | 504.0 GiB    | Healthy
 0x0001   | 0x7fe0da90c5328a22 | AppDirectNotInterleaved | 252.0 GiB | 252.0 GiB    | Healthy

[root@rx24-1 ~]# ipmctl show -dimm 0x1001 -pcd Config | grep Dimm
---DimmID=0x0001---
NumOfDimmsInInterleaveSet    : 0x2
DimmUniqueIdentifer          : 8089-a2-1834-000016b0
DimmUniqueIdentifer          : 8089-a2-1834-0000173b
(…)
---DimmID=0x0101---
NumOfDimmsInInterleaveSet    : 0x2
DimmUniqueIdentifer          : 8089-a2-1834-000016b0
DimmUniqueIdentifer          : 8089-a2-1834-0000173b
(…)
---DimmID=0x1001---
NumOfDimmsInInterleaveSet    : 0x1
DimmUniqueIdentifer          : 8089-a2-1834-00001a91
```

Configuration – Create Namespace

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- ndctl create-namespace - Create a maximally sized pmem namespace in 'fsdax' mode
  - -r, --region <region-id> — limit namespace to a region with an id or name of <region-id>
  - -v, --verbose — emit extra debug messages to stderr
  - -e, --reconfig <reconfig namespace> — reconfigure existing namespace
  - -n, --name <name> — specify an optional free form name for the namespace
  - -s, --size <size> — specify the namespace size in bytes (default: available capacity)
  - -m, --mode <operation-mode> — specify a mode for the namespace, 'sector', 'fsdax', 'devdax' or 'raw'
  - -M, --map <memmap-location> — specify 'mem' or 'dev' for the location of the memmap
  - -l, --sector-size <lba-size> — specify the logical sector size in bytes
  - -t, --type <type> — specify the type of namespace to create 'pmem' or 'blk'

```
[root@rx24-1 ~]# ndctl create-namespace  -v -r region0 -m fsdax -t pmem  -s 479857737728
   {   "dev":"namespace0.0",
       "mode":"fsdax",
       "map":"dev",
       "size":472356225024,
       "uuid":"8232e3e1-cafd-43d6-bdc9-fb6d9aa9b594",
       "sector_size":512,
       "align":2097152,
       "blockdev":"pmem0"
   }
```

Configuration – List Namespaces (1)

```
[root@rx24-1 ~]# ndctl list -D -R -u
(…)
 {
      "dev":"region1",
      "size":"252.00 GiB (270.58 GB)",
      "available_size":0,
      "max_available_extent":0,
      "type":"pmem",
      "iset_id":"0x7fe0da90c5328a22",
      "mappings":[
        {
          "dimm":"nmem2",
          "offset":"0x10000000",
          "length":"0x3f00000000",
          "position":0
        }
      ],
      "persistence_domain":"memory_controller"
    },
    {
"dev":"region0",
      "size":"504.00 GiB (541.17 GB)",
      "available_size":"504.00 GiB (541.17 GB)",
      "max_available_extent":"504.00 GiB (541.17 GB)",
      "type":"pmem",
      "iset_id":"0x8baaeeb8535e2444",
      "mappings":[
        {
          "dimm":"nmem1",
          "offset":"0x10000000",
          "length":"0x3f00000000",
          "position":1
        },
        {
          "dimm":"nmem0",
          "offset":"0x10000000",
          "length":"0x3f00000000",
          "position":0
        }
      ],
      "persistence_domain":"memory_controller"
    }
```

Configuration – List Namespaces (2)

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```
[root@rx24-1 ~]# ndctl list -N -B -D -R -u
(…)
        "dev":"region3",
        "size":"50.00 GiB (53.69 GB)",
        "type":"pmem",
        "persistence_domain":"unknown",
        "namespaces":[
          {
            "dev":"namespace3.0",
            "mode":"fsdax",
            "map":"mem",
            "size":"50.00 GiB (53.69 GB)",
            "sector_size":512,
            "blockdev":"pmem3"
(…)
BOOT_IMAGE=/vmlinuz-4.20.16-200.fc29.x86_64 root=/dev/mapper/fedora-root  resume=/dev/fedora/swap quiet showopts
crashkernel=202M,high crashkernel=72M,low memmap=50G!4G memmap=50G!1176G

memmap=nn[KMG]!ss[KMG]          [KNL,X86] Mark specific memory as protected. Region of memory to be used,
                                from ss to ss+nn. The memory region may be marked as e820
                                type 12 (0xc) and is NVDIMM or ADR memory.
```

Configuration – memmap= ... (1)

```
Dec 11 10:56:47 rx24-2 kernel: BIOS-provided physical RAM map:
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x0000000000000000-0x000000000009bff] usable
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x000000000009c00-0x000000000009ffff] reserved
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x00000000000e0000-0x00000000000fffff] reserved
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x0000000000100000-0x00000000652b9fff] usable
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x00000000652ba000-0x0000000067c88fff] reserved
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x0000000067c89000-0x0000000067df0fff] ACPI data
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x0000000067df1000-0x000000006d893fff] ACPI NVS
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x000000006d894000-0x000000006f367fff] reserved
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x000000006f368000-0x000000006f7fffff] usable
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x000000006f800000-0x00000008fffffff] reserved
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x00000000fd000000-0x00000000fe7fffff] reserved
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x00000000fed20000-0x00000000fed44fff] reserved
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x00000000ff000000-0x00000000ffffffff] reserved
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x0000000100000000-0x000000306fffffff] usable
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x0000003070000000-0x000000ab2fffffff] persistent (type 7)
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x000000ab30000000-0x000000d32fffffff] usable
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x000000d330000000-0x000001c8affffff] persistent (type 7)
Dec 11 10:56:47 rx24-2 kernel: BIOS-e820: [mem 0x000001c8b0000000-0x000001c8c7ffffff] reserved
```

Configuration – memmap= ... (2)

```
Dec 11 10:56:47 rx24-2 kernel: NX (Execute Disable) protection: active
Dec 11 10:56:47 rx24-2 kernel: user-defined physical RAM map:
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000000000000000-0x0000000000099bff] usable
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000000000099c00-0x000000000009ffff] reserved
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x00000000000e0000-0x00000000000fffff] reserved
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000000000100000-0x00000000652b9fff] usable
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x00000000652ba000-0x0000000067c88fff] reserved
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000000067c89000-0x0000000067df0fff] ACPI data
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000000067df1000-0x000000006d893fff] ACPI NVS
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x000000006d894000-0x000000006f367fff] reserved
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x000000006f368000-0x000000006f7fffff] usable
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x000000006f800000-0x00000008ffffffff] reserved
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x00000000fd000000-0x00000000fe7fffff] reserved
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x00000000fed20000-0x00000000fed44fff] reserved
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x00000000ff000000-0x00000000ffffffff] reserved
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000000100000000-0x0000000d7fffffff] persistent (type 12)
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000000d80000000-0x000000306fffffff] usable
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000003070000000-0x000000ab2fffffff] persistent (type 7)
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x000000ab30000000-0x000000d32fffffff] usable
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x000000d330000000-0x00000125ffffffff] persistent (type 7)
Dec 11 10:56:47 rx24-2 kernel: user: [mem 0x0000012600000000-0x000001327fffffff] persistent (type 12)
```

Configuration –File Systems

```
[root@rx24-1 ~]# ll /dev/pm*
brw-rw---- 1 root disk 259, 5 Mar 21 09:35 /dev/pmem0
brw-rw---- 1 root disk 259, 4 Mar 20 09:52 /dev/pmem1
brw-rw---- 1 root disk 259, 7 Mar 21 09:37 /dev/pmem2
[root@rx24-1 ~]# mkfs -t ext4 /dev/pmem0
[root@rx24-1 ~]# mkfs -t ext4 /dev/pmem1
[root@rx24-1 ~]# mkfs -t ext4 /dev/pmem2
[root@rx24-1 ~]# mount -o dax /dev/pmem0 /mnt/pmem0
[root@rx24-1 ~]# mount -o dax /dev/pmem1 /mnt/pmem1
[root@rx24-1 ~]# mount -o dax /dev/pmem2 /mnt/pmem2
[root@rx24-1 ~]# mount | grep pm
/dev/pmem0 on /mnt/pmem0 type ext4 (rw,relatime,dax)
/dev/pmem1 on /mnt/pmem1 type ext4 (rw,relatime,dax)
/dev/pmem2 on /mnt/pmem2 type ext4 (rw,relatime,dax)
[root@rx24-1 ~]# df -k | egrep 'pm|File'
Filesystem              1K-blocks      Used Available Use% Mounted on
/dev/pmem0              452995648     73756 429841240   1% /mnt/pmem0
/dev/pmem1              254978620  36955404 205001316  16% /mnt/pmem1
/dev/pmem2               51343840     53272  48652744   1% /mnt/pmem2
```

FUJITSU

- Technology
- Setup and Configuration
- **Software Programming Stack**

Intel® DIMMs: Broad Ecosystem Enabling

Open Interfaces and Tools

SNIA
Standard NVM Programming Model

10th ANNIVERSARY
Standard NVDIMM Platform Interface ACPI 6.0

www.PMEM.io
Open Source NVM Enabling (NVML)

Operating Environments

Microsoft

Linux* Kernel 4.4†

fedora

redhat

suse

vmware

Future vSphere* Release†

Public Statements of Support for Products or Programming Model

cloudera

Microsoft

ORACLE

redhat

SAP

vmware

IDF16 INTEL DEVELOPER FORUM

† Planned. Subject to change

Open NVM Programming Model

SNIA Technical Working Group
Initially defined 4 programming modes required by developers

Spec 1.0 developed, approved by SNIA voting members and published

Interfaces for PM-aware file system accessing kernel PM support	interfaces for application accessing a PM-aware file system	Kernel support for block NVM extensions	Interfaces for legacy applications to access block NVM extensions

NVM-Libraries & Drivers

NVMe Block Interface

DCPMM as Storage SW Architecture

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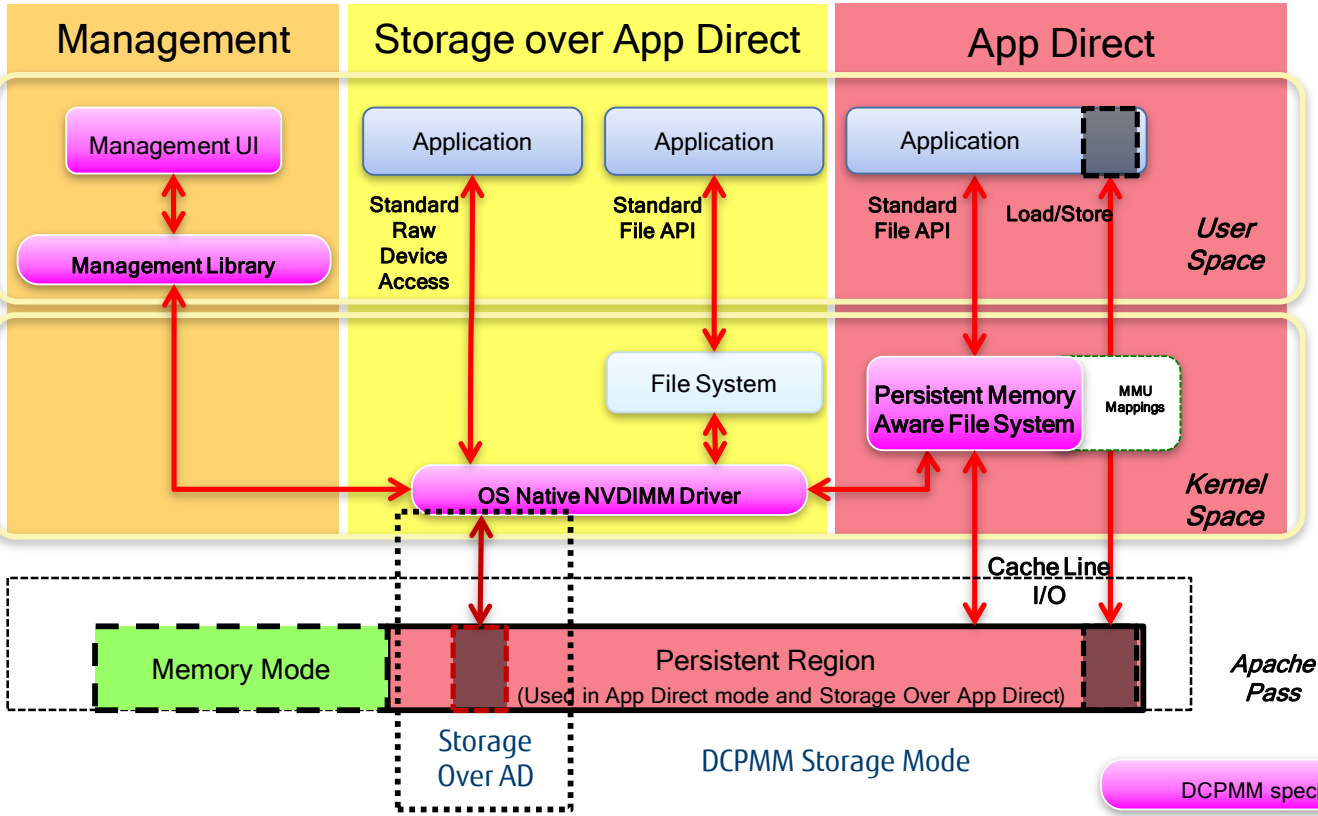
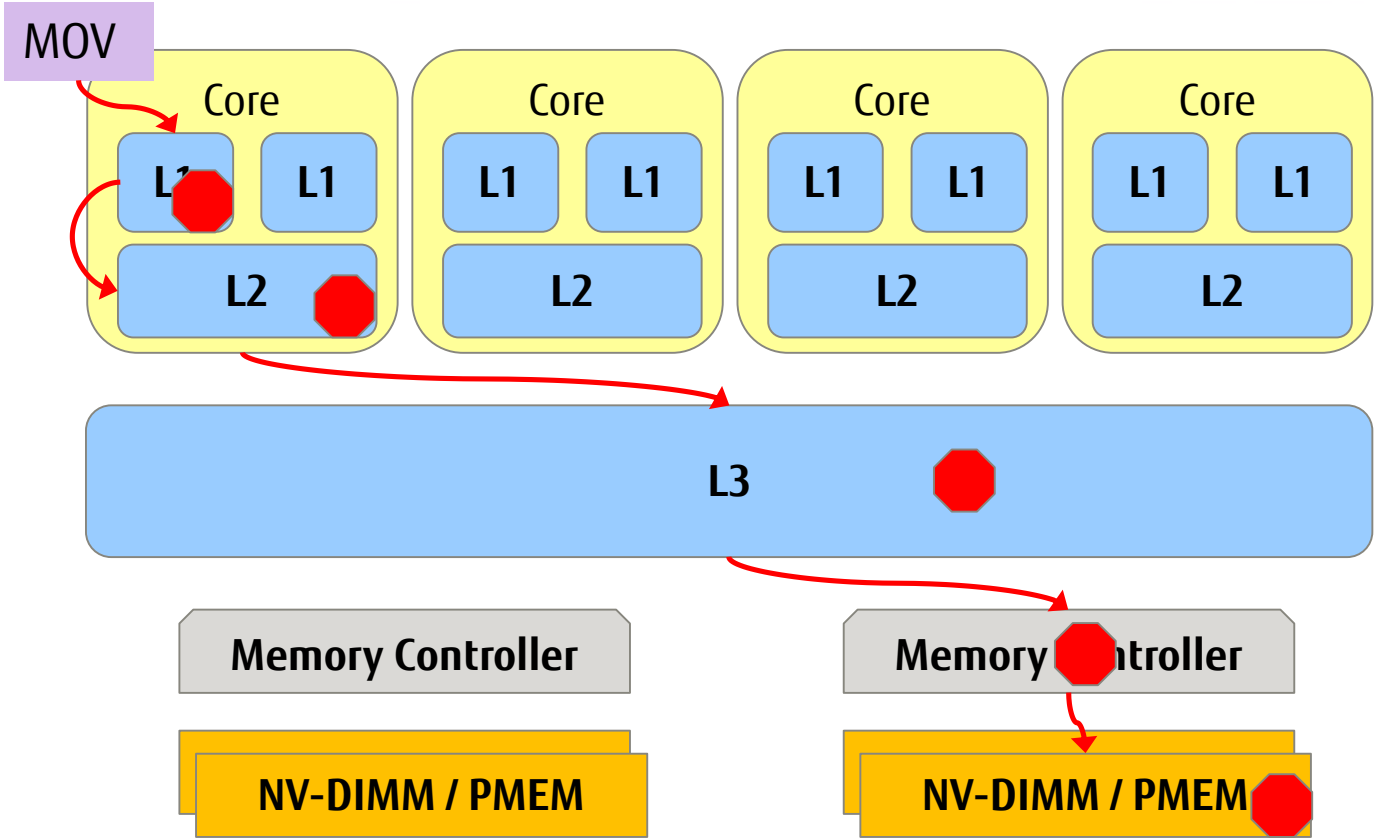
I/O with OS Buffer cache

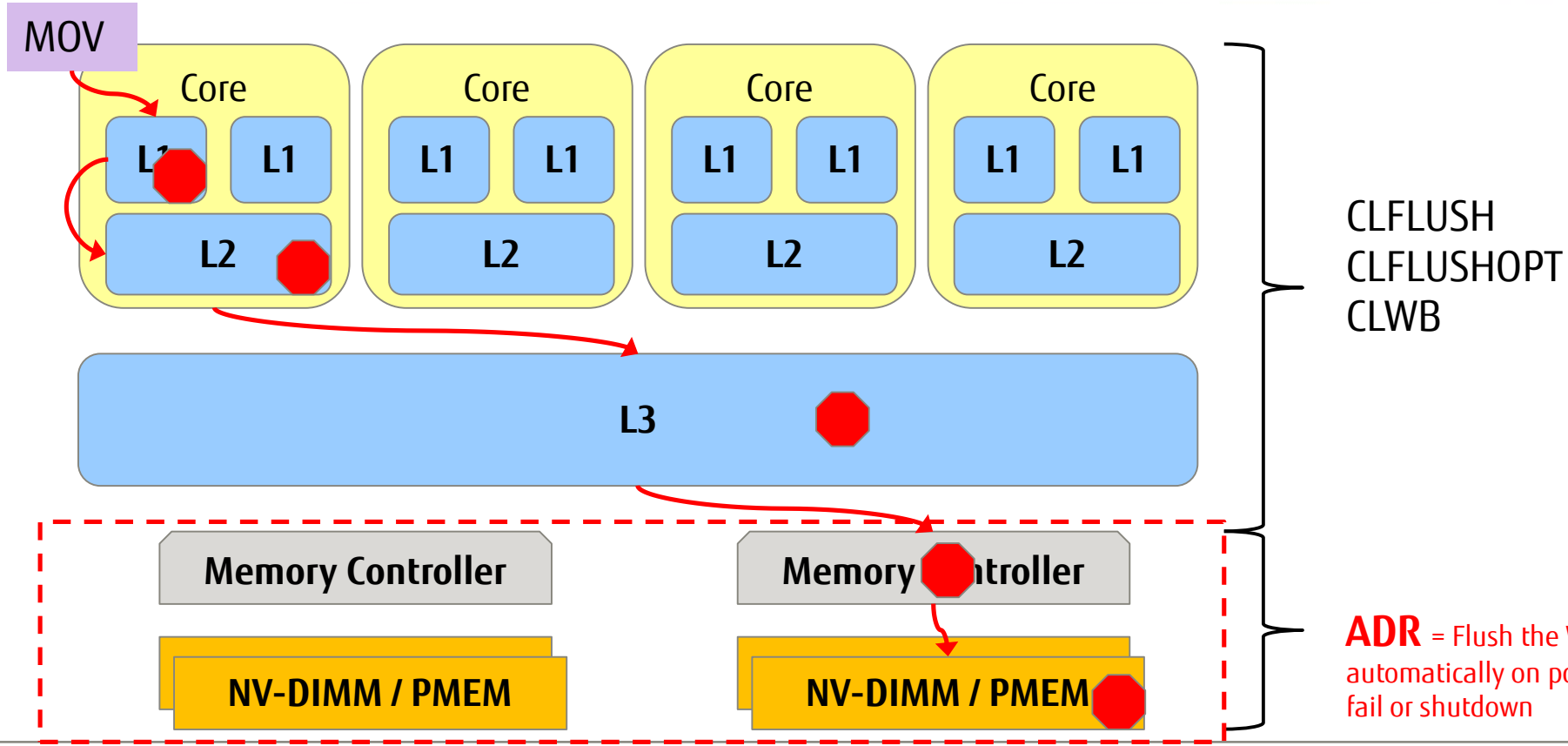


mov with CPU Lx cache

The Data Path



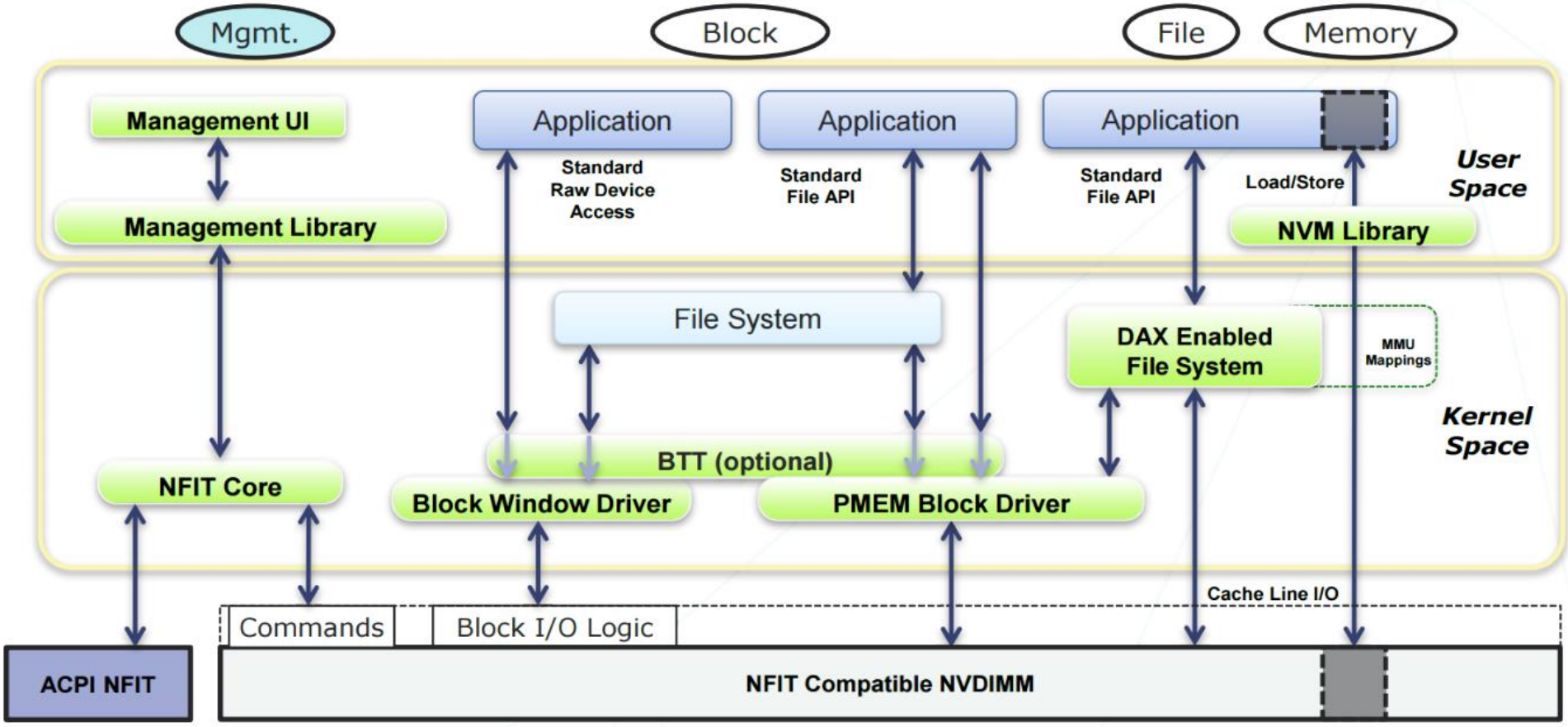
The Data Path



Caskade Lake CPU - lscpu

```
Model name:          Intel(R) Xeon(R) Platinum 8270 CPU @ 2.70GHz
CPU(s):              104
Thread(s) per core:  2
Core(s) per socket:  26
Socket(s):           2
CPU MHz:             1000.061
CPU max MHz:         4000.0000
CPU min MHz:         1000.0000
BogoMIPS:            5400.00
L1d cache:           32K
L1i cache:           32K
L2 cache:            1024K
L3 cache:            36608K
NUMA node0 CPU(s):   0-3,7-9,13-15,20-22,52-55,59-61,65-67,72-74
(…)
Flags:               fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat pse36 clflush dts acpi mmx fxsr
sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology
nonstop_tsc cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx smx est tm2 ssse3 sdbg fma cx16 xtpr pdcm pcid dca
sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault
epb cat_l3 cdp_l3 invpcid_single intel_ppin ssbd mba ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid fsgsbase
tsc_adjust bmi1 hle avx2 smep bmi2 erms invpcid rtm cqm mpx rdt_a avx512f avx512dq rdseed adx smap clflushopt clwb
intel_pt avx512cd avx512bw avx512vl xsaveopt xsavec xgetbv1 xsaves cqm_llc cqm_occup_llc cqm_mbm_total cqm_mbm_local
dtherm ida arat pln pts hwp hwp_act_window hwp_epp hwp_pkg_req pku ospke avx512_vnni flush_l1d arch_capabilities
```

Linux Kernel Layers for PMEM



Linux Kernel 4.4+ NVDIMM OS support

- Linux 4.2 + subsystems added support of NVDIMMs. Mostly stable from 4.4
- NVDIMM modules presented as device links: /dev/pmem0, /dev/pmem1
- QEMO support (experimental)
- XFS-DAX and EXT4-DAX available

DAX

File system extensions to bypass the page cache and block layer to memory map persistent memory, from a PMEM block device, directly into a process address space.

BTT (Block, Atomic)

`nd_btt.ko` Block Translation Table: Persistent memory is byte addressable. Existing software may have an expectation that the power-fail-atomicity of writes is at least one sector, 512 bytes. The BTT is an indirection table with atomic update semantics to front a PMEM/BLK block device driver and present arbitrary atomic sector sizes.

PMEM

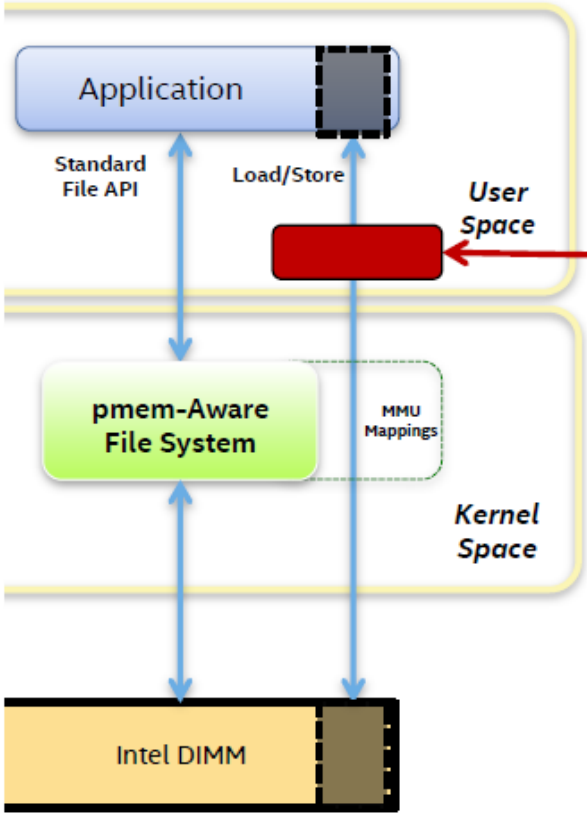
`nd_pmem.ko` A system-physical-address range where writes are persistent. A block device composed of PMEM is capable of DAX. A PMEM address range may span an interleave of several DIMMs.

BLK

`nd_blk.ko` A set of one or more programmable memory mapped apertures provided by a DIMM to access its media. This indirection precludes the performance benefit of interleaving, but enables DIMM-bounded failure modes.

NVM Library: pmem.io

64-bit Linux* Initially



NVM Libraries (optional)

- Open Source
  - https://pmem.io/pmdk
- libpmem
- libpmemobj
- libpmemblk
- libpmemlog

Transactional

- libvmem
- libvmmalloc

Programming example with libpmem

pmdk/src/examples/libpmem/manpage.c

```
int main(int argc, char *argv[])
{ (…)   /* create a pmem file and memory map it */
        if ((pmemaddr = pmem_map_file(“/mnt/pmem0/my-file”, 4096, PMEM_FILE_CREATE,
                                0666, &mapped_len, &is_pmem)) == NULL) {
                perror("pmem_map_file");
                exit(1);
        }

        /* store a string to the persistent memory */
        strcpy(pmemaddr, "hello, persistent memory");

        /* flush above strcpy to persistence */
        if (is_pmem)
                pmem_persist(pmemaddr, mapped_len);
        else
                pmem_msync(pmemaddr, mapped_len);

        /* Delete the mappings. The region is also automatically unmapped when the process is terminated. */
        pmem_unmap(pmemaddr, mapped_len);
}
```

Original libart art_insert routine

FUJITSU

```
void*
art_insert(art_tree *t, const unsigned char *key, int key_len, void *value)
{
    int old_val = 0;
    void *old = recursive_insert(t->root, &t->root, key, key_len, value, 0, &old_val);
    if (!old_val) t->size++;
    return old;
}
```

libart art_insert routine … ported to libpmemobj

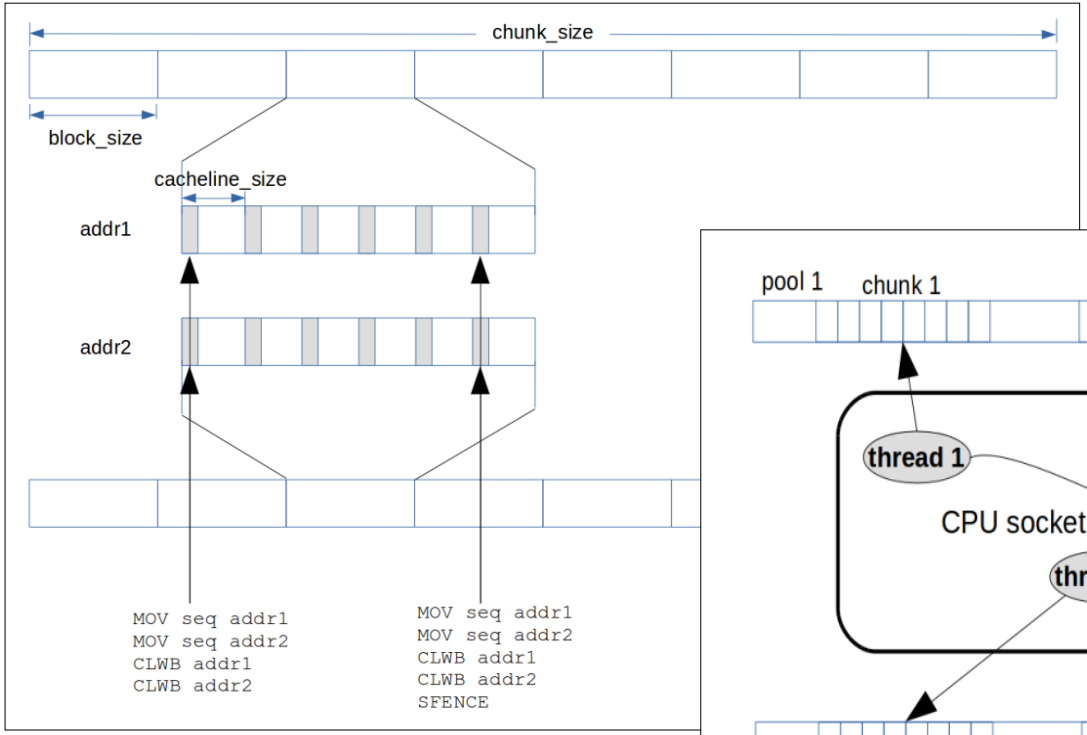
FUJITSU

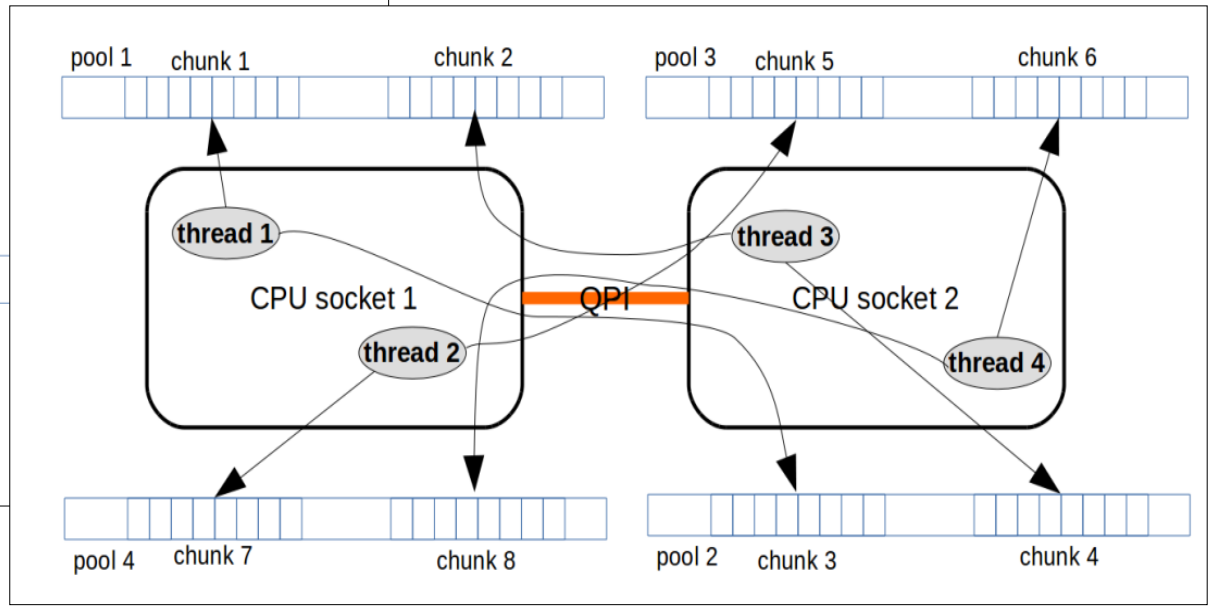
```
TOID(var_string)
art_insert(PMEMobjpool *pop, const unsigned char *key, int key_len, void *value, int val_len)
{
    int old_val = 0;
    TOID(var_string) old;
    TOID(struct art_tree_root) root;

    TX_BEGIN(pop) {
        root = POBJ_ROOT(pop, struct art_tree_root);
        TX_ADD(root);

        old = recursive_insert(pop, D_RO(root)->root, &(D_RW(root)->root), (const unsigned char *)key,
key_len, value, val_len, 0, &old_val);
        if (!old_val) D_RW(root)->size++;
    } TX_ONABORT {
        abort();
    } TX_END

    return old;
}
```

FUJITSU

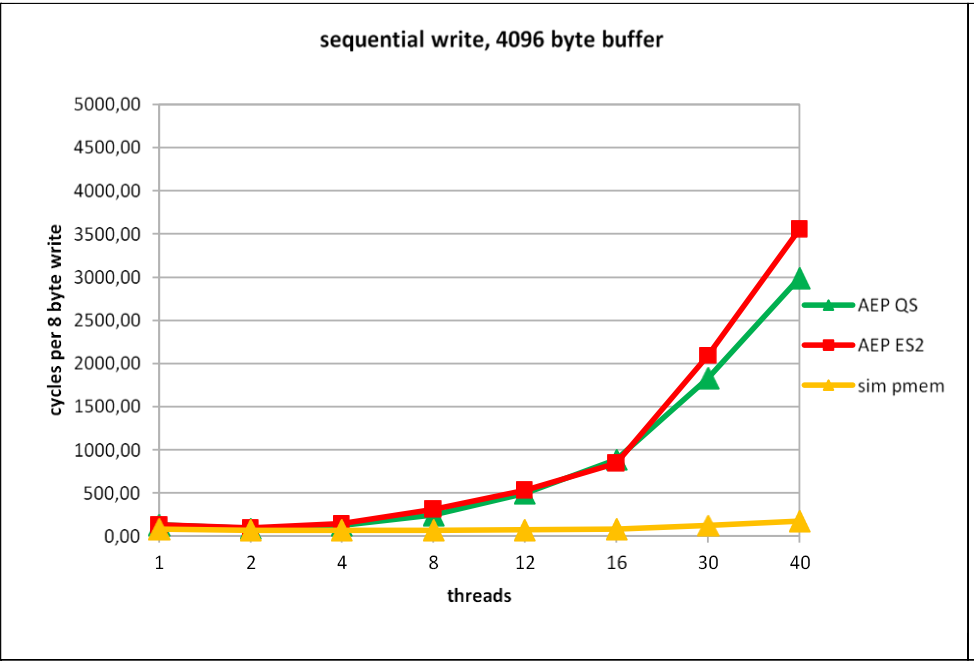
- Technology
- Setup and Configuration
- Software Programming Stack
- **Measurements**

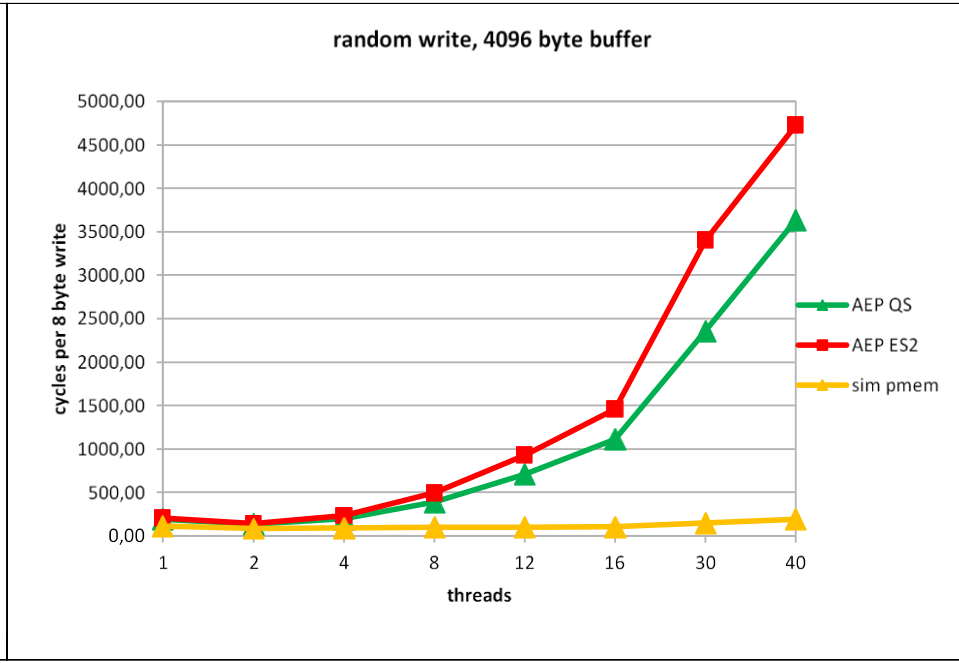
addr-test





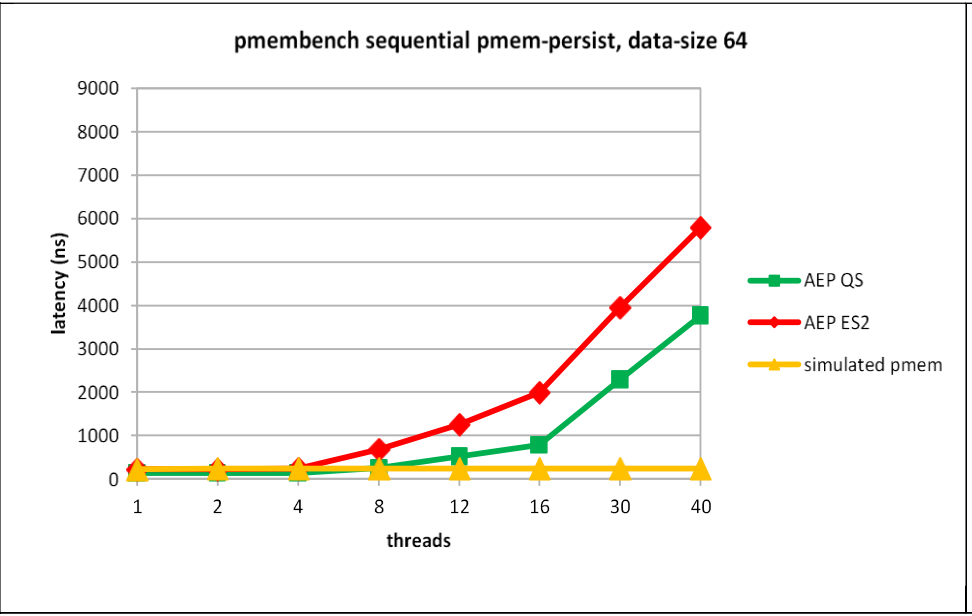
addr-test – 1x DCPMM vs. DRAM

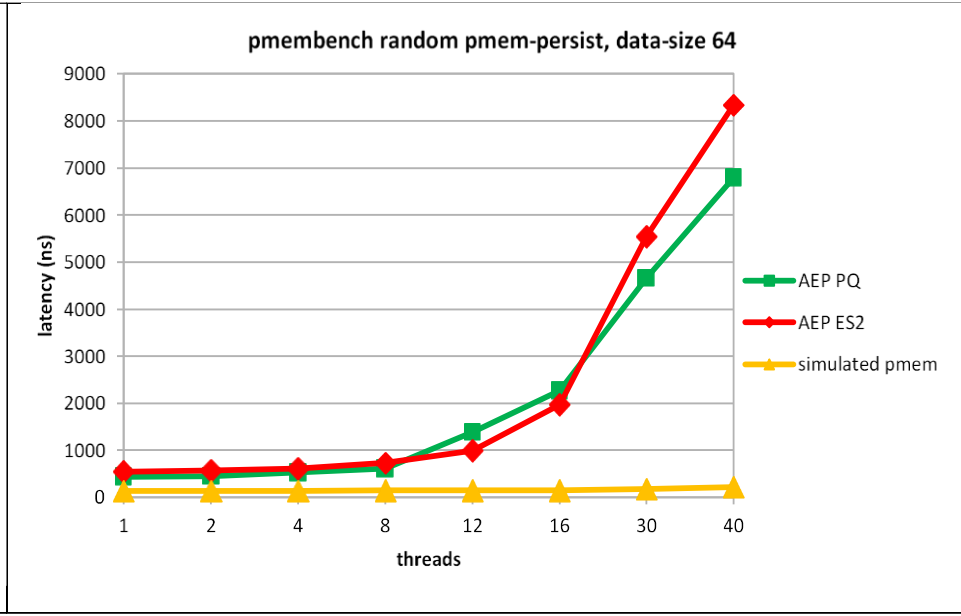




Measurement on pre-production HW

pmdk pmembench – 1x DCPMM vs. DRAM





Measurement on pre-production HW

Test system PRIMERGY

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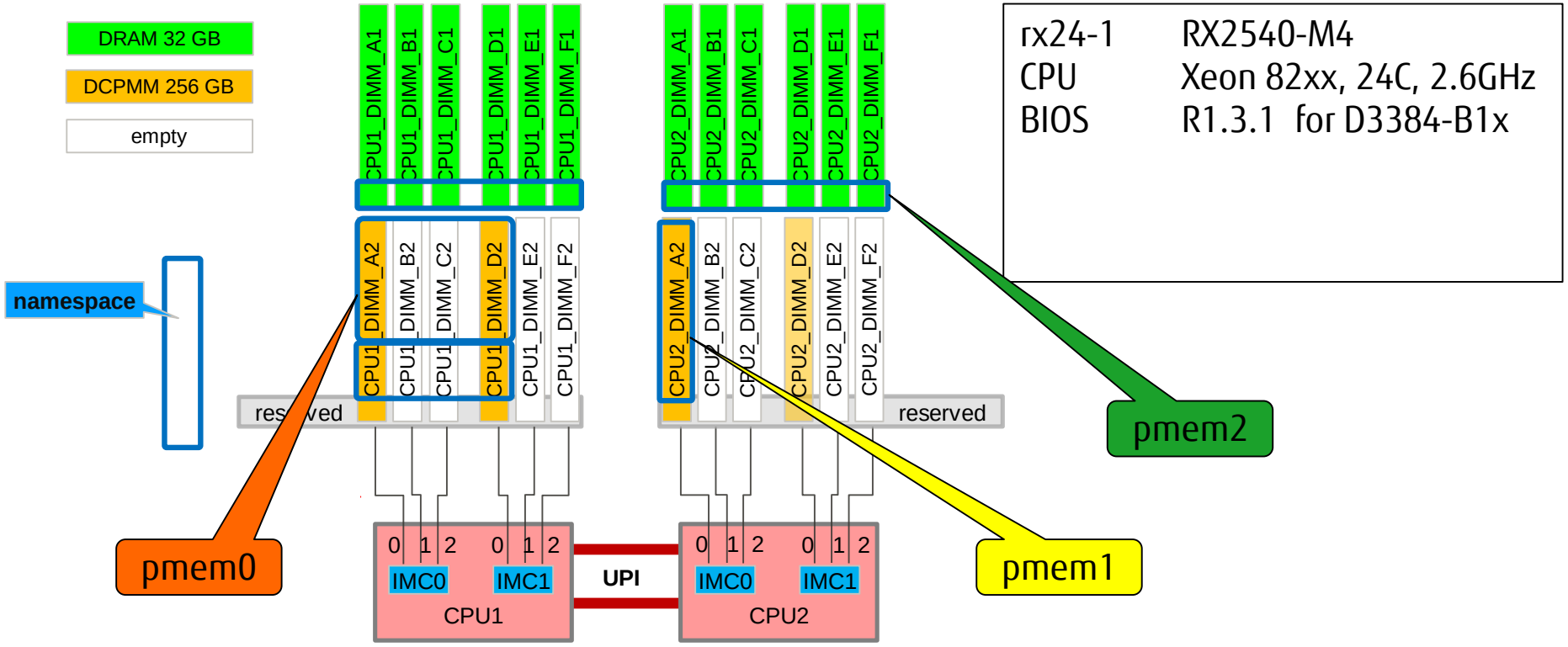
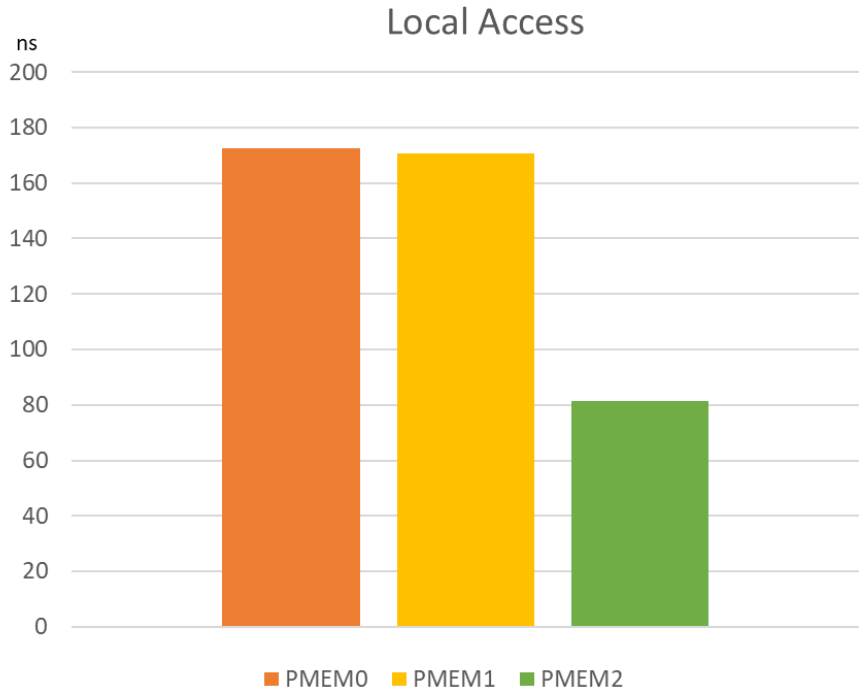
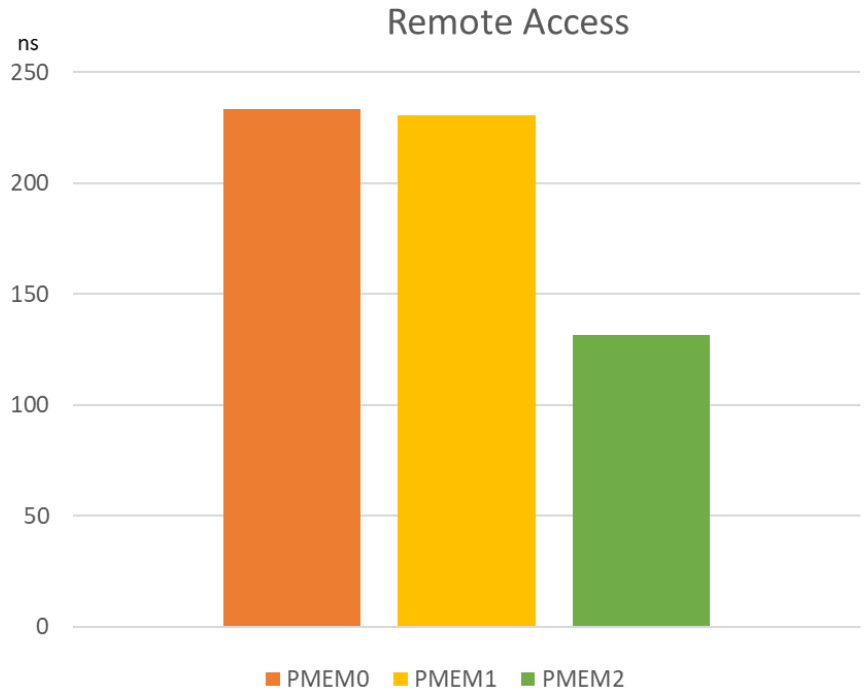


rx24-1	RX2540-M4
CPU	Xeon 82xx, 24C, 2.6GHz
BIOS	R1.3.1 for D3384-B1x

mlc – idle_latency



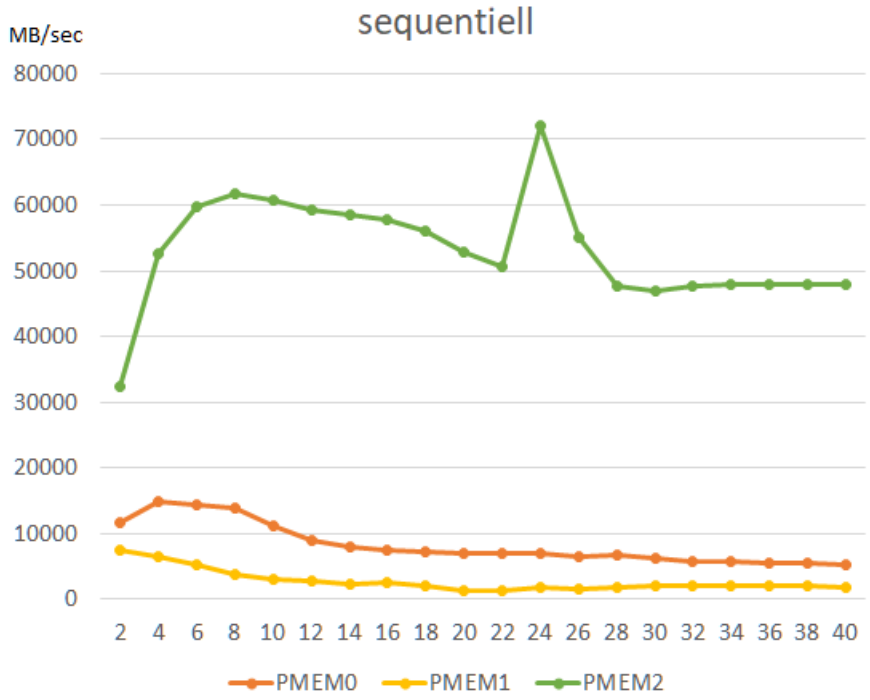


mlc -c30 --idle_latency -J/mnt/pmem[012] -p36,6

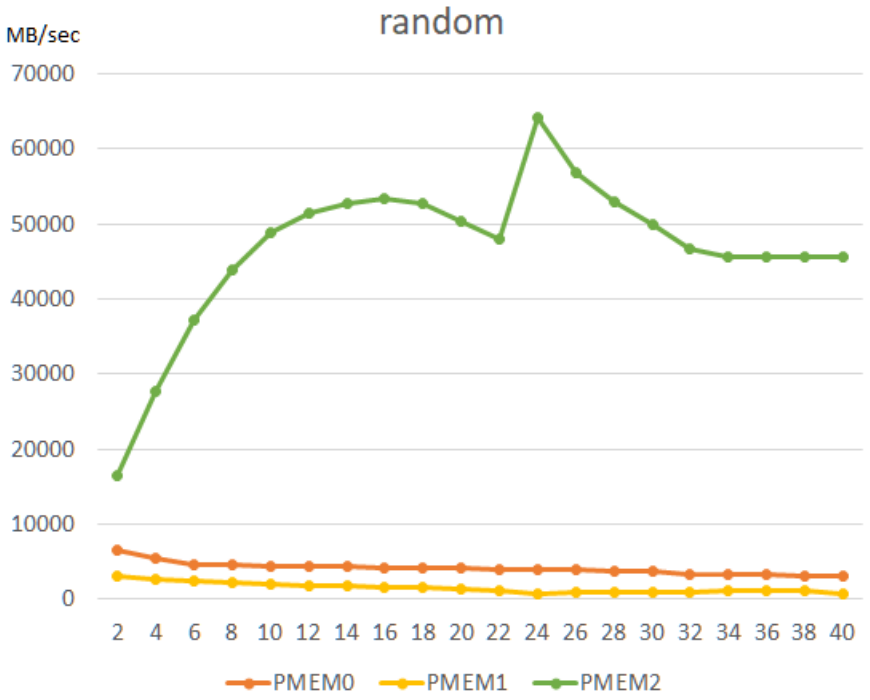
mlc –c2 --idle_latency -J/mnt/pmem[012] -p36,6

Measurement on pre-production HW

mlc – loaded_latency 100% read - bandwidth



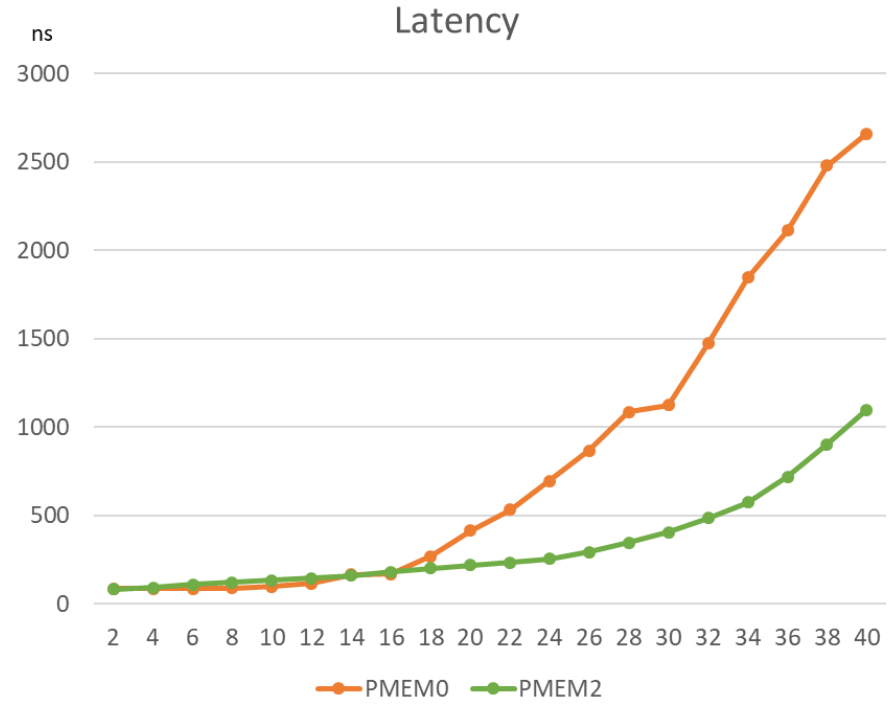
mlc --loaded_latency -d0 -g<perthreadfile>
<perthreadfile>: 1-[2/4/.../40] R seq pmem /mnt/pmem[0/1/2]



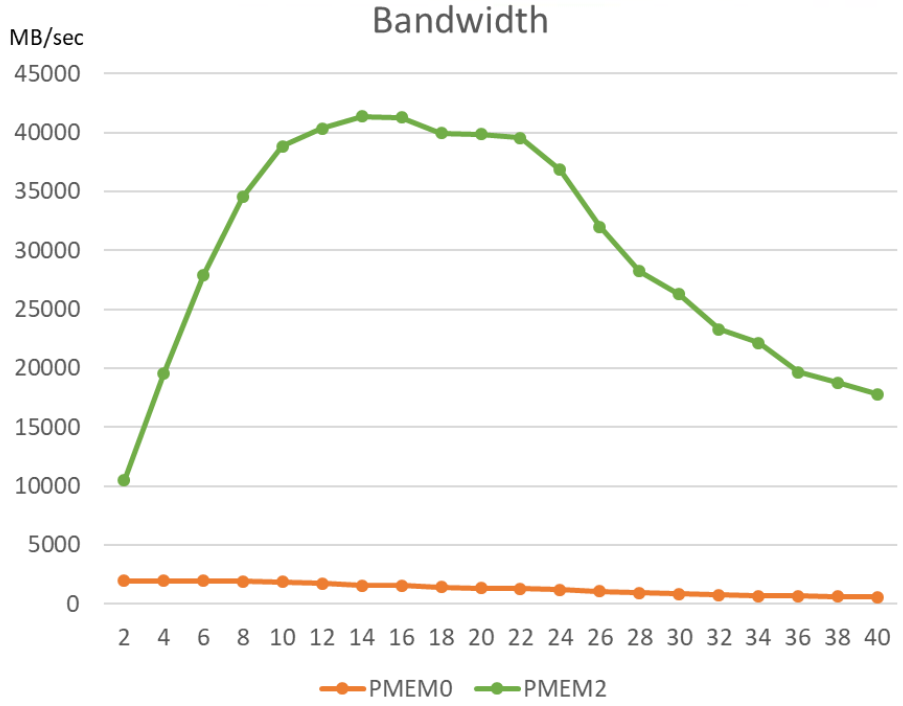
mlc --loaded_latency -d0 -g<perthreadfile>
<perthreadfile>: 1-[2/4/.../40] R rand pmem /mnt/pmem[0/1/2]

Measurement on pre-production HW

mlc – loaded_latency 100% random write



mlc --loaded_latency -d0 -g<perthreadfile>
<perthreadfile>: 1-[2/4/…/40] W6 rand pmem /mnt/pmem[0/1/2]



mlc --loaded_latency -d0 -g<perthreadfile>
<perthreadfile>: 1-[2/4/…/40] W6 rand pmem /mnt/pmem[0/1/2]

Measurement on pre-production HW

Improvements of pmdk and AEP generations

FUJITSU

- Libart3: adaptive radix tree as an example with libpmemobj
- Single threaded application
- DIMM access on local / far socket

		pmdk 1.2			pmdk 1.3			pmdk 1.4			pmdk 1.5	
		local	far		locat	far		local	far		local	far
simulated pmem	**insert**	**15965**	26448	35,1	**10359**	17415	5,6	**9774**	16318	-1,8	**9946**	15255
	re-insert	1046	1141		1097	1232		1101	1235		1096	1234
	lookup	788/747	773/737		793/752	754/750		785/747	777/746		794/760	784/754
AEP ES2	**insert**	**34273**	41197	31,9	**23356**	28031	10,6	**20888**	26899	11,5	**18482**	27542
	re-insert	1514	1671		1622	1771		1603	1776		1621	1802
	lookup	811/848	807/853		831/878	823/891		826/887	819/884		829/871	785/912
AEP QS	**insert**	**35269**	40531	35,1	**22881**	27064	13,6	**19760**	25493	15,3	**16739**	25840
	re-insert	1479	1651		1508	1686		1510	1692		1496	1699
	lookup	810/831	841/859		810/879	866/904		831/885	822/897		812/852	832/895

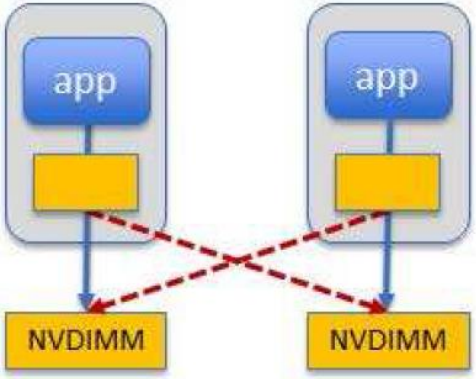
(in CPU cycles)

Measurement on pre-production HW

FUJITSU

- Technology
- Setup and Configuration
- Software Programming Stack
- Measurements
- **Direction, Vision, Outlook**

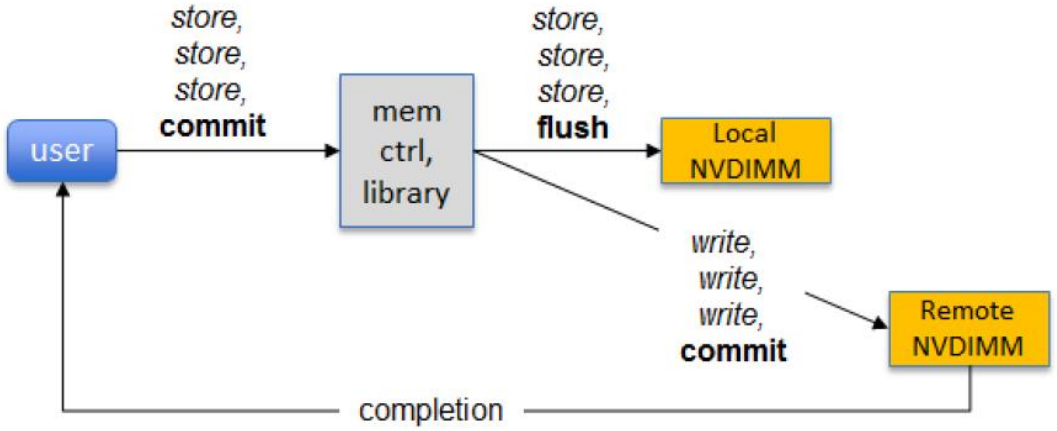
Use Case: High Availability, Replication



What it looks like

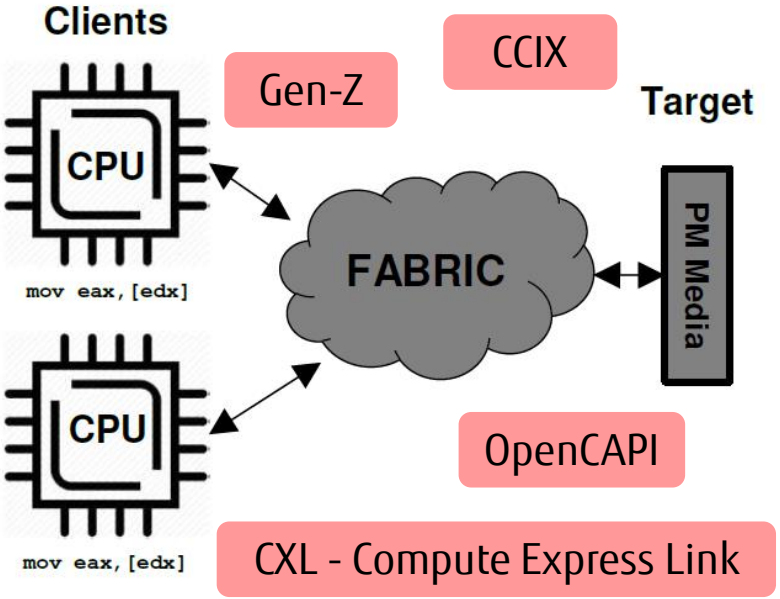
Usage: replicate data that is stored in local PM across a fabric and store it in remote PM

How it works



PMoF

The Holy Grail of PMoF



Loads and stores on a client CPU affect Persistent Memory across the fabric!

The knights that say "c"!

We are a loooong way from here!

Open issues and open questions

FUJITSU

- DCPMMs support encryption, but today manual entry in BIOS at startup
  - Future (?): Key-Mgmt, integrate DIMM unlock in Kernel boot
- With direct load/store all block based tools can no longer be used (Virus detection, delta backup based on modified blocks, ...)
- DCPMM re-configuration (extension, replacement)
- Hierarchical memory management ... does not exist today
- How can write (CPU store) errors be detected and mapped to the related process without I/O logic ?
  - In Linux EDAC (Error Detection And Correction) would map a MCE to a DIMM
- How to handle malware in persistent memory ?
- All pmdk libraries today are heavily overweight and hardly show the advantage of store/load to advantage
- Security, performance and manageability of PMoF

Summary (1)

FUJITSU

- DCPMM can be shipped in April 2019 for all Cascade Lake systems
  - attractive price compared to DRAM
  - ~ 4x higher capacity as DRAM
  - ~ 10x higher latency as DRAM
  - Accessible as DRAM: load(address), store(address)
- Available on all Fujitsu x86 Server PRIMERGY and PRIMEQUEST with SLES12-SP4 and SLES15-SP1
- Version1 of a new Technology, Speed and capacity will improve
- Usability
  - All mandatory interfaces (setup, monitor, error detection, programming model, C-Libraries, encryption, PMoF) are available today

Summary (2)

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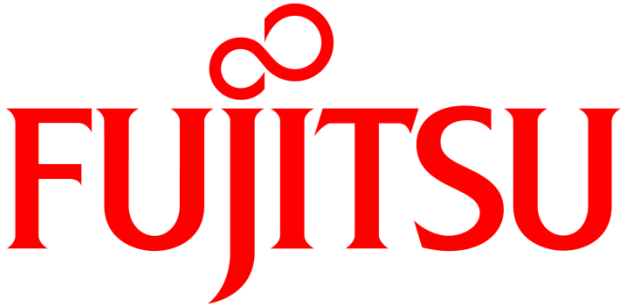
- Many open issues and question especially in the area of error detection / recovery, setup, configuration, security, manageability
- Inefficient and heavily overweighed C-Libraries
- How to replace the behaviour and tools that today depend on the block device ?
- Security, performance and manageability of PMoF
- Hierarchical memory management (near, far, remote, persistent, volatile, shared ... memory)



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