PM Support in Linux and Windows

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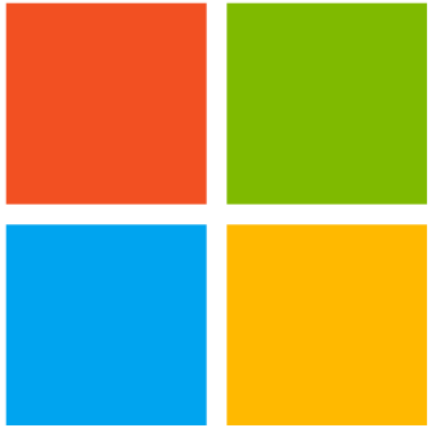


Windows Support for Persistent Memory

Availability of Windows PM Support

- Client Workstation:
  - August, 2016: Windows 10 Anniversary Update
  - April, 2017: Windows 10 Creators Update
  - October, 2017: Windows 10 Fall Creators Update
  - April, 2018: Windows 10 April 2018 Update
  - October, 2018: Windows 10 October 2018 Update
- Server:
  - September, 2016: Windows Server 2016
  - November, 2019: Windows Server 2019
- Supported Hardware:
  - JEDEC NVDIMM-N
  - HPE Scalable Persistent Memory

DAX Support

- Supported since Windows Server 2016
- Advantages:
  - Improved IO performance by eliminating OS overhead
- Disadvantages:
  - Functionality loss due to elimination of OS hook points, examples:
    - Software Encryption
    - Software Compression
- Only NTFS supports DAX

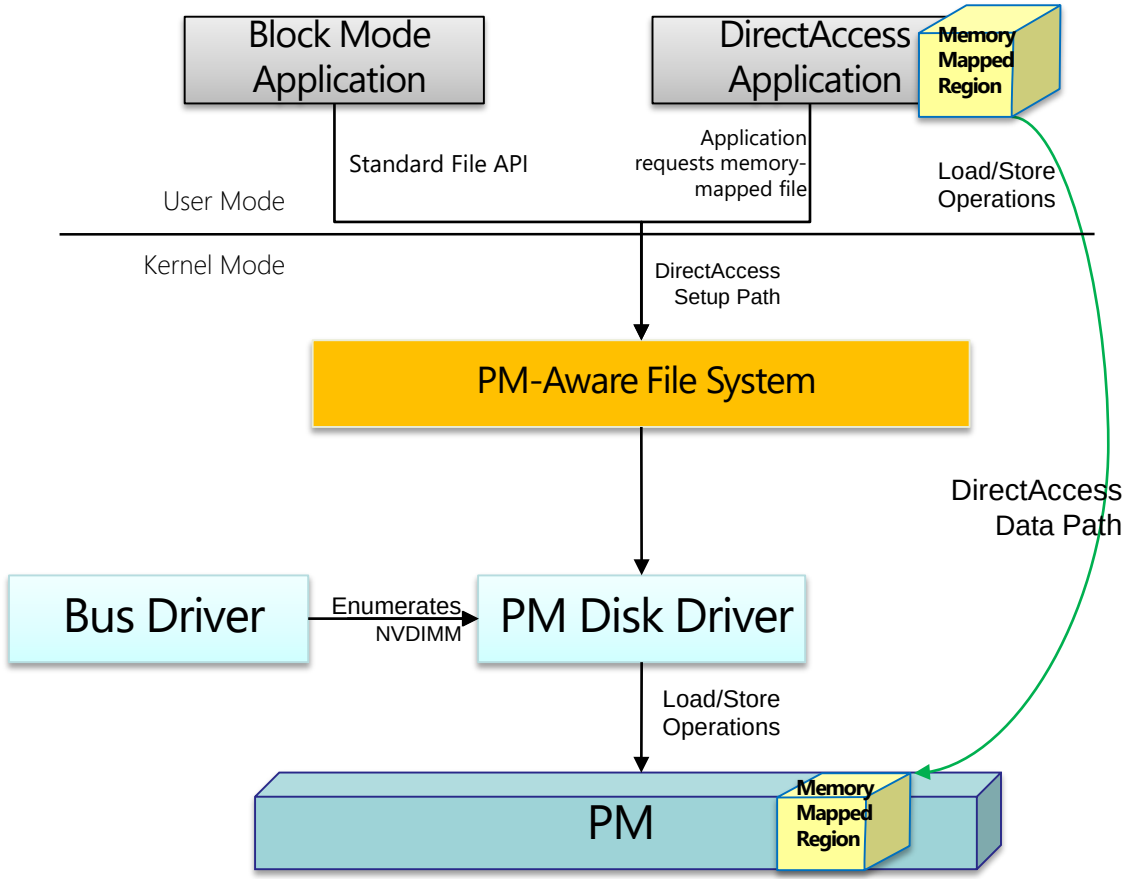
How DAX Works

The Idea

- App has direct access to PM via existing memory-mapping semantics
- Updates directly modify PM
  - Storage Stack not involved

Characteristics

- True device performance (no software overhead)
- Byte-Addressable



IO on Windows DAX Volumes

- Non-Cached IO
  - Is converted to cached IO by the file system
- Cached IO
  - Cache Manager maps directly to persistent memory
  - Copies directly between user's buffer and persistent memory
- Memory Mapped IO
  - Memory mapped sections point directly to PM hardware
  - Provides applications with zero-copy access to PM hardware

Is fully backwards compatible

- Maintains existing storage semantics
  - Sector atomicity supported by the PM disk driver
- Fully compatible with existing applications and filter drivers
- Supported by all Windows file systems

Windows Hyper-V PM Support

- Available in Windows Server 2019
- Windows & Linux guests in generation 2 VMs see virtual PMEM (vPMEM) devices
  - Memory mapped files in the guest have direct access to PM hardware on the host
  - Full Win32 and PMDK support
- New VHD file type: .VHDPMEM

What are Large and Huge Pages

- Modern CPUs manage memory using 4K pages
- An applications memory usage is managed via page tables controlled by the operating systems memory manager
- CPU's contain a mapping table cache called the TLB (translation lookaside buffer) that caches page table mappings
- For applications with a large memory footprint -- the CPU can spend a lot of time reading page table entries into the TLB
- A Large Page allows a contiguous 2mb region to be described with a single TLB entry
  - Applications typically see a significant performance improvement
- A Huge Page allows a contiguous 1gb region to be described with a single TLB entry

Windows PM support for Large & Huge Pages

- Available in Windows Server 2019
- DAX partitions are aligned to 2mb boundaries
- NTFS now supports cluster sizes up to 2mb (in powers of 2)
  - In Server 2016 the limit was 64K
- A memory mapped file on a DAX volume with a 2mb cluster size is guaranteed to be mapped using at least Large Pages
- Large and Huge page alignment is supported on cluster sizes <2mb

Windows PM Management Support

- Windows Server 2019 introduces Powershell support for managing physical and logical persistent memory devices
  - Ability to enumerate, create and delete logical persistent memory devices
  - Ability to enumerate and initialize physical persistent memory devices
  - Example cmdlets:
    - Get-PmemDisk
    - New-PmemDisk
    - Remove-PmemDisk
    - Get-PmemPhysicalDevice
    - Initialize-PmemPhysicalDevice
    - Get-PmemUnusedRegion

Windows PMDK Support

- Available since Windows Server 2016
- Defines a set of application API's for efficient use of PM hardware
  - Abstracts out OS specific dependencies
  - Underlying implementation uses memory mapped files
  - Makes its own atomicity guarantees
  - Works in both PM and non-PM environments
  - Simpler application development model
- Open source library available for Windows and Linux via GitHub
  - https://github.com/pmem/pmdk/

Examples uses of PM on Windows

- **SQL Server 2016**
  - **Tail-of-the-Log**: Transactions committed to DAX volume
  - 2X performance gain by:
    - **Halving** the transaction latency
    - De-serializing the SQL logging threads

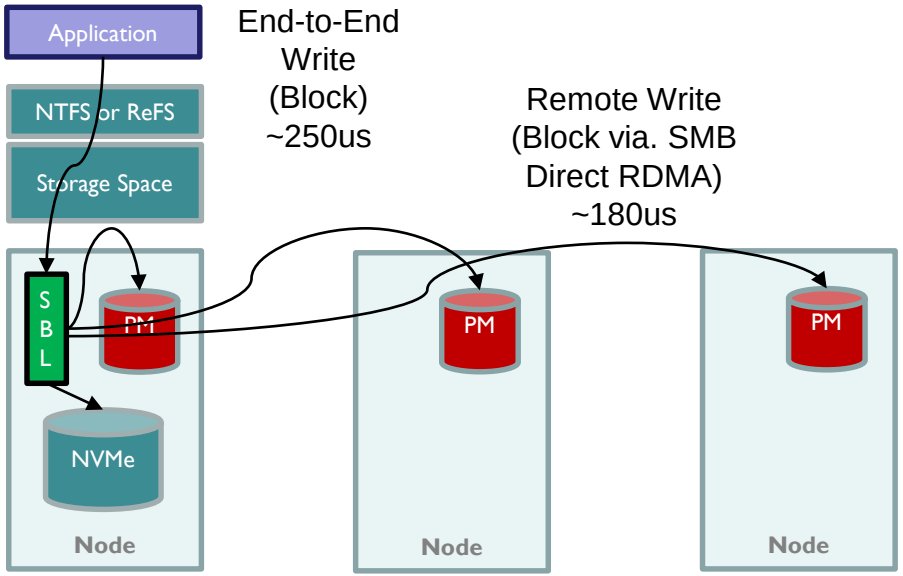
Write Caching for HCI with Storage Spaces Direct & Windows Server 2019

- Ultra-low-latency write caching (SBL) for all-NVMe deployments
- Industry record performance demonstrated at Ignite '18

Benchmark	Performance
4K 100% Rand Read	13.8 Million IOPs
4K 90/10% Rand R/W	9.45 million IOPs
2MB Sequential Read	549 GB/s Throughput

12-nodes with Triple-Mirrored Scoped Spaces with ReFS

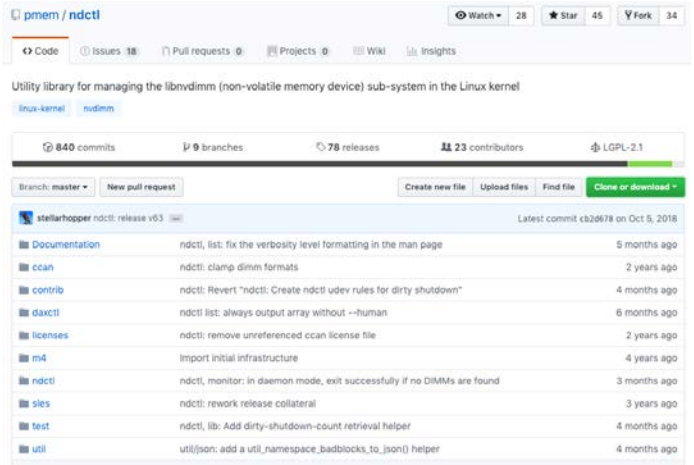
12 x Intel® S2600WFT, **384 GiB** memory, **2 x 28-core "**CascadeLake", **1.5 TB** Intel® Optane™ DC persistent memory as cache, **32 TB** NVMe (4 x 8TB Intel® DC P4510) as capacity, **2** x Mellanox ConnectX-4 25 Gbps



Linux Support for Persistent Memory

Managing PM in Linux: **ndctl**

- How do you determine if you have PM in your system?
- How do you manage the PM in your system?
- How do you determine the health of PM in your system?



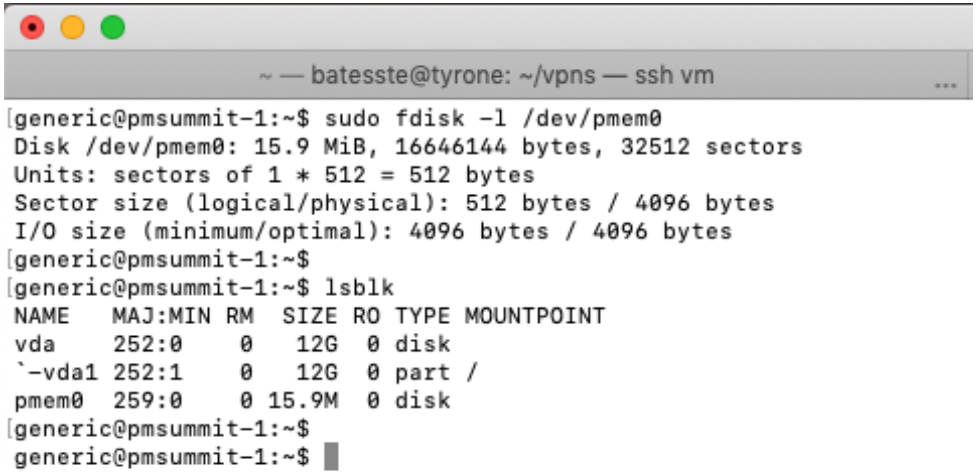
- Ties into physical layer specifications like NFIT and HMAT [1].

```
generic@pmsummit1:~$ ndctl list
{
  "dev":"namespace0.0",
  "mode":"raw",
  "size":16646144,
  "sector_size":512,
  "blockdev":"pmem0",
  "numa_node":0
}
generic@pmsummit1:~$
```

[1] http://www.uefi.org/sites/default/files/resources/ACPI_6_2.pdf

Using PM in Linux: **A block device**

- PM can be consumed by Linux applications using a block interface.
- Useful when a file-system is not required.
- Not super-efficient as block device changes on sector, not byte granularity.
- All your favourite block-device tools can be used.



[1] http://www.uefi.org/sites/default/files/resources/ACPI_6_2.pdf

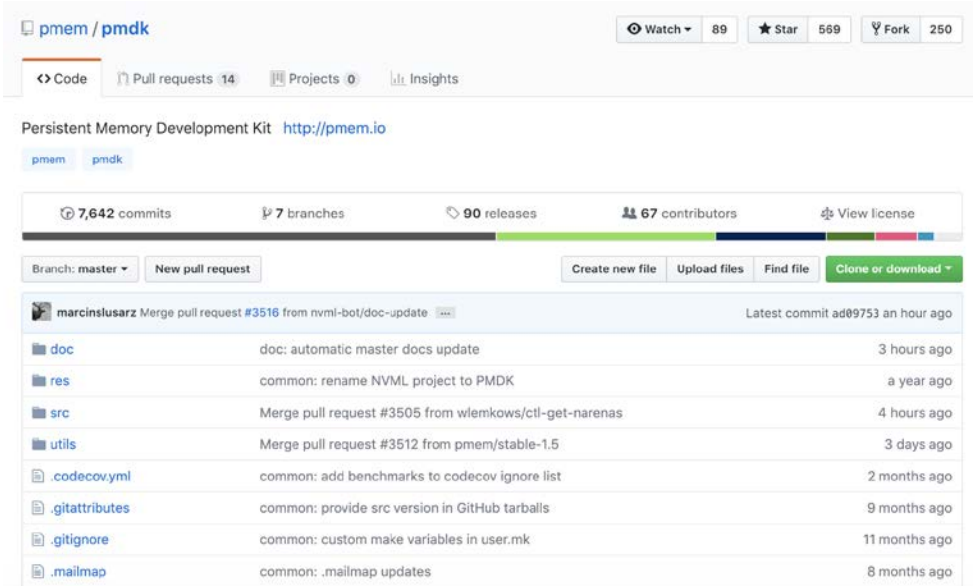
Using PM in Linux: **A filesystem**

- Like any standard block device we can put a filesystem over it.
- In this case we can put ANY filesystem we like on top.
- But if we use a DAX aware filesystem we get added benefits (PM optimizations).
- Now we can have files and directories and all that good stuff!
- In Linux both EXT4 and XFS have DAX support.

```
guest@pmsummit-1:~$ mkfs.xfs -f /dev/pmem0
mkfs.xfs: cannot open /dev/pmem0: Permission denied
guest@pmsummit-1:~$ sudo mkfs.xfs -f /dev/pmem0
[sudo] password for guest:
meta-data=/dev/pmem0             isize=512    agcount=4, agsize=56320 blks
         =                       sectsz=4096  attr=2, projid32bit=1
         =                       crc=1        finobt=1, sparse=0, rmapbt=0, reflink=0
data     =                       bsize=4096   blocks=225280, imaxpct=25
         =                       sunit=0      swidth=0 blks
naming   =version 2              bsize=4096   ascii-ci=0 ftype=1
log      =internal log           bsize=4096   blocks=1605, version=2
         =                       sectsz=4096  sunit=1 blks, lazy-count=1
realtime =none                   extsz=4096   blocks=0, rtextents=0
guest@pmsummit-1:~$ sudo mount -o dax /dev/pmem0 /mnt/
guest@pmsummit-1:~$ dmesg | tail
[   16.212472] pmem0: detected capacity change from 0 to 130023424
[  184.699585] pmem0: detected capacity change from 0 to 134217728
[  203.539578] pmem0: detected capacity change from 0 to 939524096
[  210.083474] pmem0: detected capacity change from 0 to 922746880
[  232.851656] random: crng init done
[  232.851694] random: 7 urandom warning(s) missed due to ratelimiting
[10604.527337] SGI XFS with ACLs, security attributes, realtime, no debug enabled
[10604.588508] XFS (pmem0): DAX enabled. Warning: EXPERIMENTAL, use at your own risk
[10604.588563] XFS (pmem0): Mounting V5 Filesystem
[10604.627537] XFS (pmem0): Ending clean mount
guest@pmsummit-1:~$
```

Using PM in Linux: **mmap()**

- Now we have files that live in a PM-aware filesystem on a PM-aware block device on physical PM.
- mmap() has been around for a while ;-). Maps the file into the Virtual Address space of the running process.
- Now the world becomes our oyster (see PMDK for more!)



git clone https://github.com/pmem/pmdk.git

Thank You