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Accelerating NVMe-oF* for VMs with the Storage Performance Development Kit

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NVMe over Fabrics* Software Overhead

- NVMe Specification enables highly optimized drivers
  - Multiple I/O queues allows lockless submission from CPU cores in parallel
- But even the best kernel mode drivers have non-trivial software overhead
  - 3-5us of software overhead per I/O
  - 500K+ IO/s per SSD, 4-24 SSDs per server, 100Gb+ RDMA
  - <10us latency with latest media (i.e. Intel Optane$^{\text{TM}}$ SSD)
- Virtualization adds additional overhead
  - NVMe-oF typically not configured in virtual machine
- Enter the Storage Performance Development Kit
  - Includes polled-mode and user-space drivers for NVMe and NVMe-oF

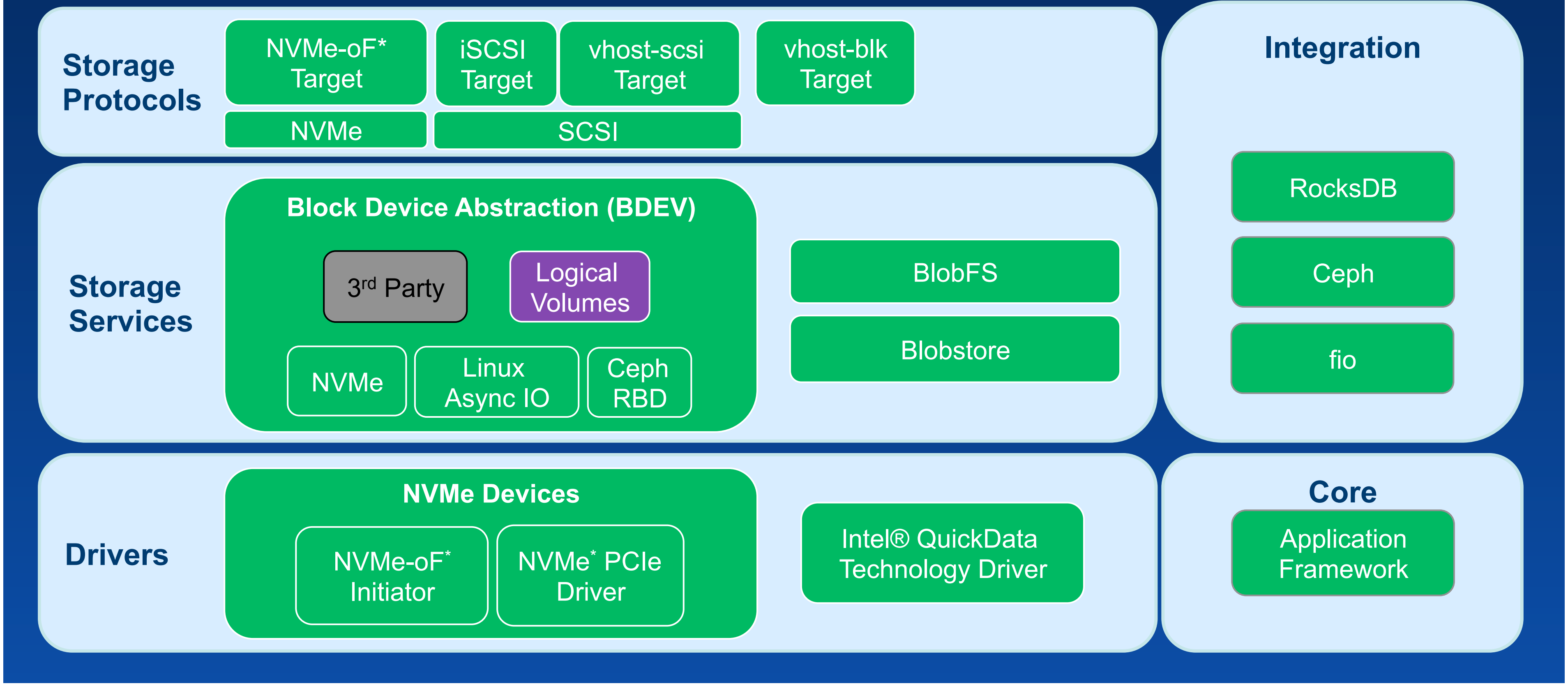
Storage Performance Development Kit (SPDK)

- Open Source Software Project
  - BSD licensed
  - Source code: http://github.com/spdk
  - Project website: http://spdk.io
- Set of software building blocks for scalable efficient storage applications
  - Polled-mode and user-space drivers and protocol libraries
- Designed for current and next generation NVM media latencies

Architecture

🟩 Released

🟪 Q4'17



Storage Protocols

NVMe-oF* Target

iSCSI Target

vhost-scsi Target

vhost-blk Target

NVMe

SCSI

Storage Services

Block Device Abstraction (BDEV)

3rd Party

Logical Volumes

NVMe

Linux Async IO

Ceph RBD

BlobFS

Blobstore

Integration

RocksDB

Ceph

fio

Drivers

NVMe Devices

NVMe-oF* Initiator

NVMe* PCIe Driver

Intel® QuickData Technology Driver

Core

Application Framework

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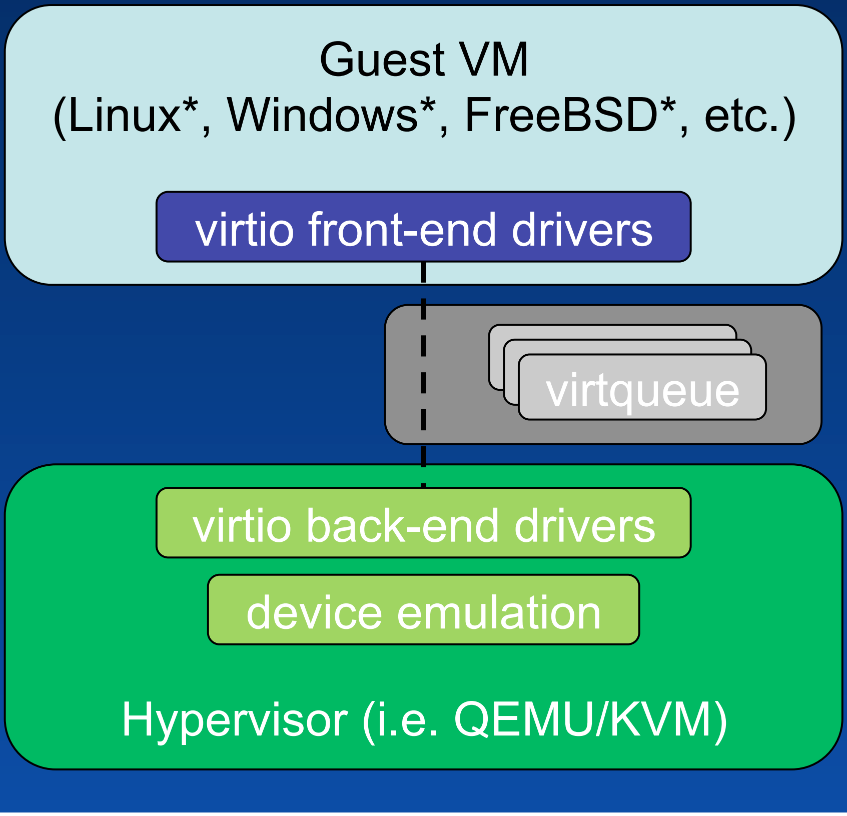
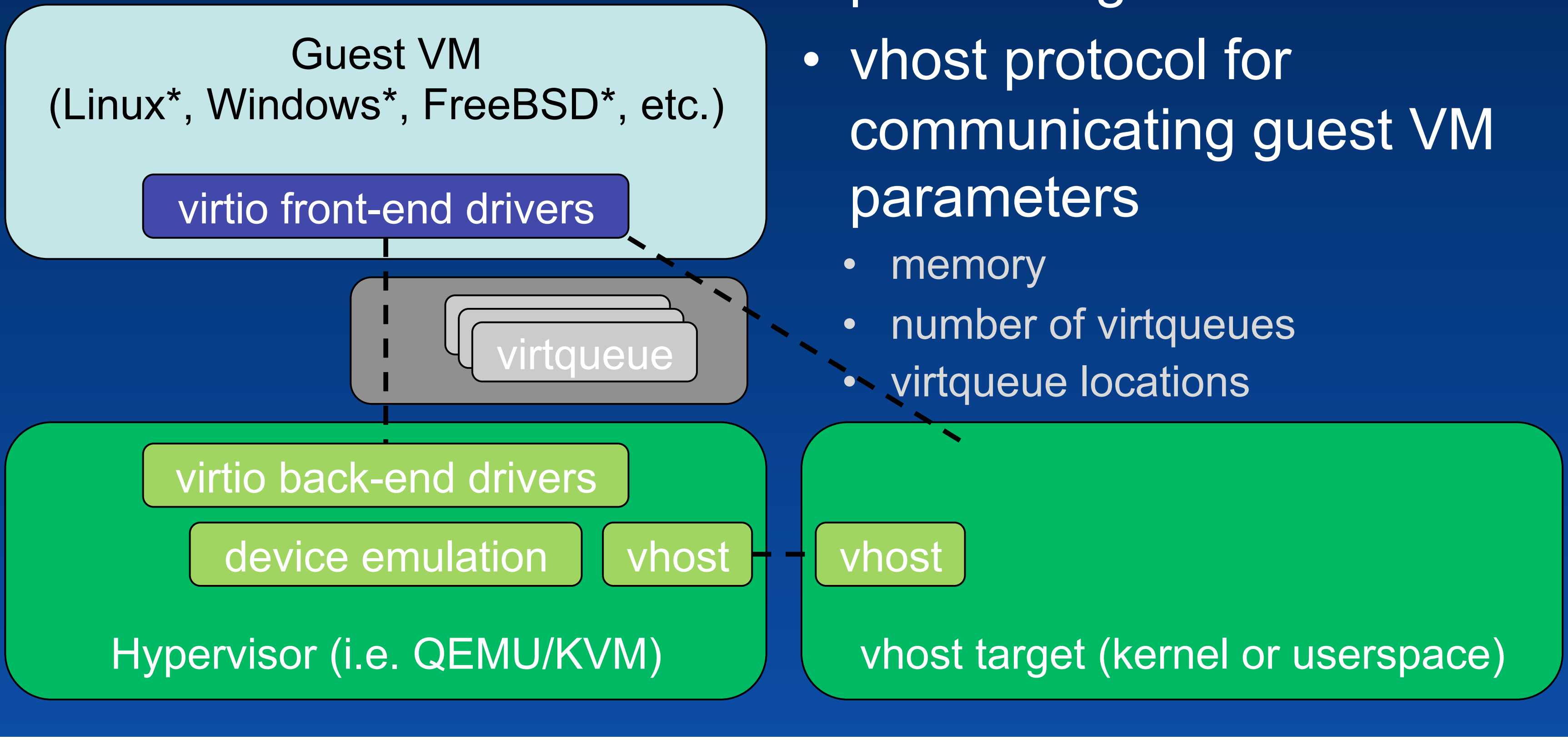
virtio



- Paravirtualized driver specification
- Common mechanisms and layouts for device discovery, I/O queues, etc.
- virtio device types include:
  - virtio-net
  - virtio-blk
  - virtio-scsi
  - virtio-gpu
  - virtio-rng
  - virtio-crypto

vhost


Guest VM
(Linux*, Windows*, FreeBSD*, etc.)
virtio front-end drivers
virtqueue
virtio back-end drivers
device emulation
vhost
vhost
Hypervisor (i.e. QEMU/KVM)
vhost target (kernel or userspace)

- Separate process for I/O processing
- vhost protocol for communicating guest VM parameters
  - memory
  - number of virtqueues
  - virtqueue locations

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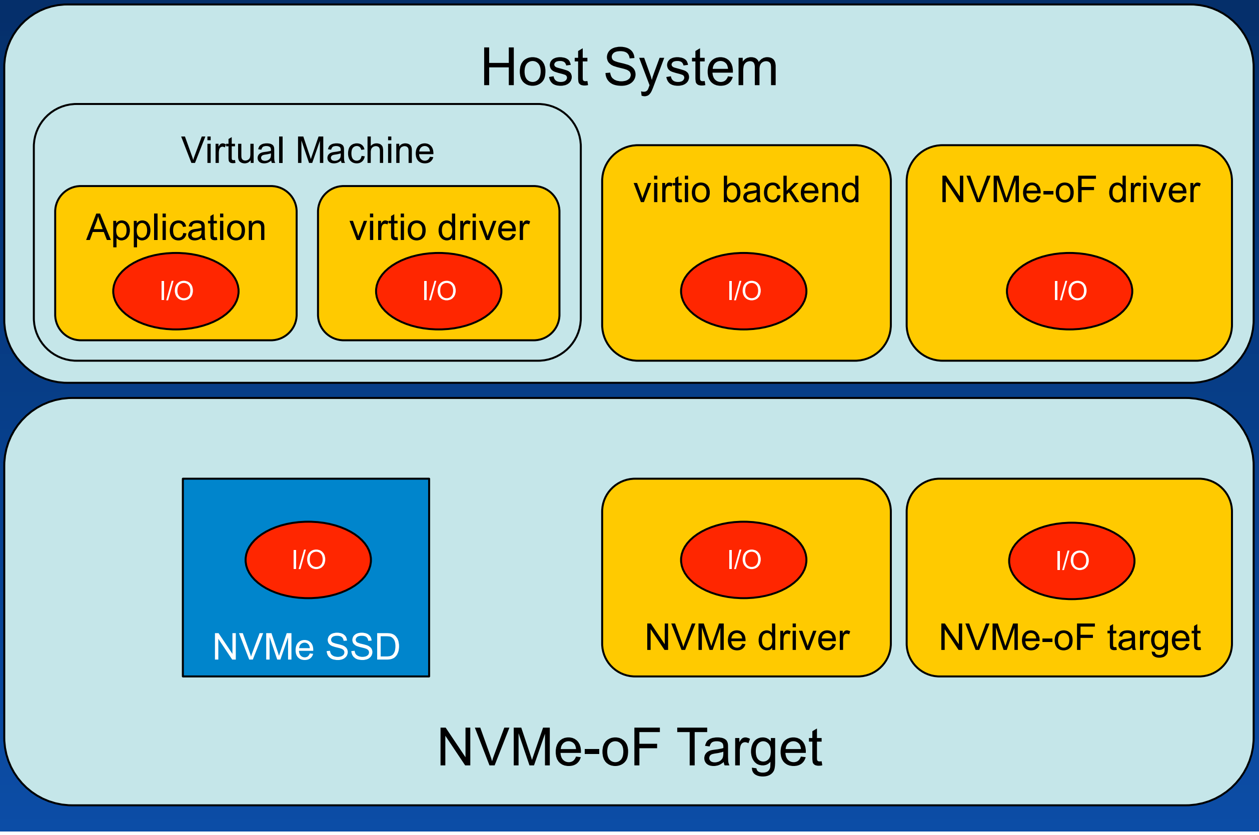
I/O Path



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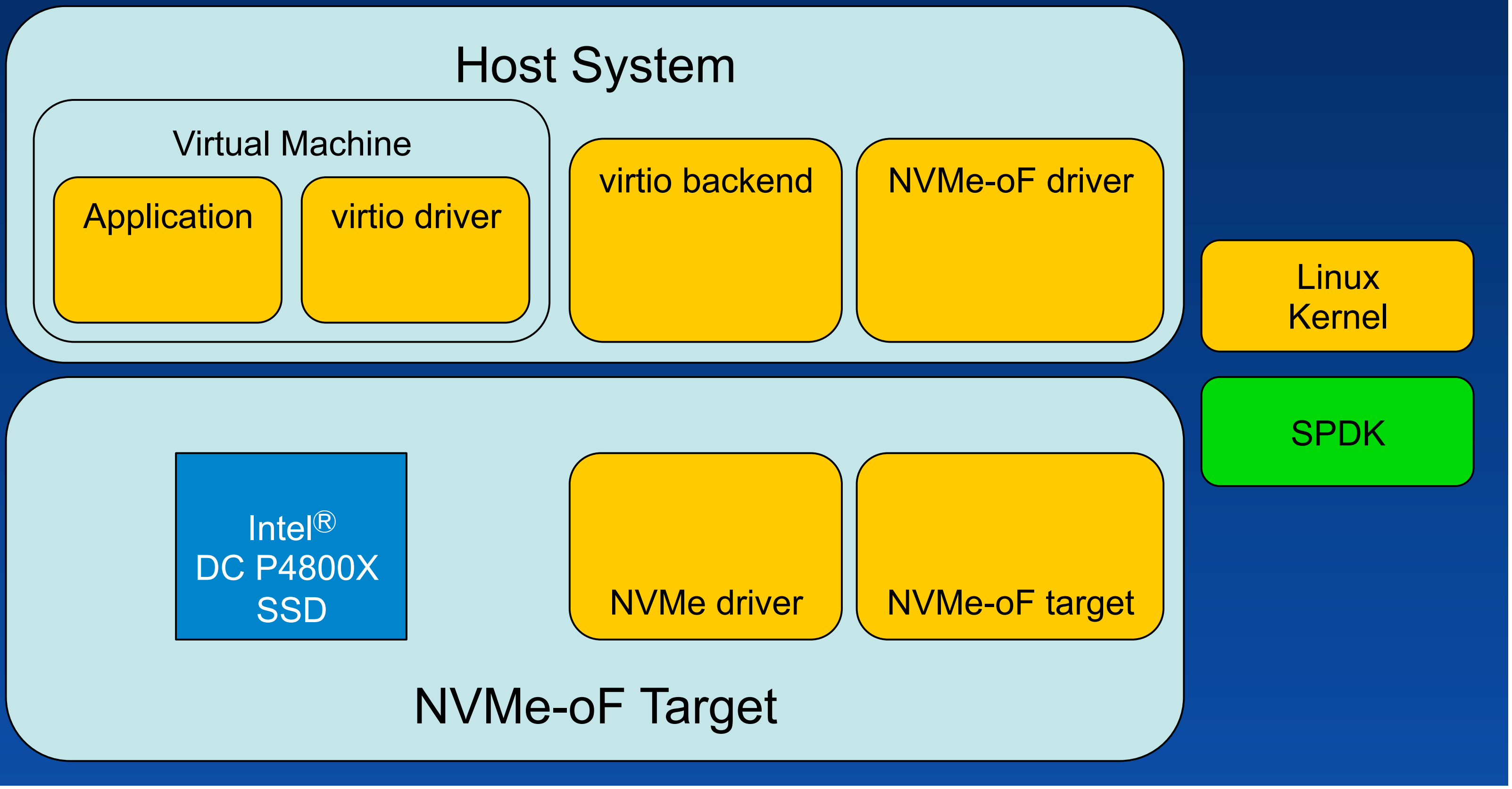
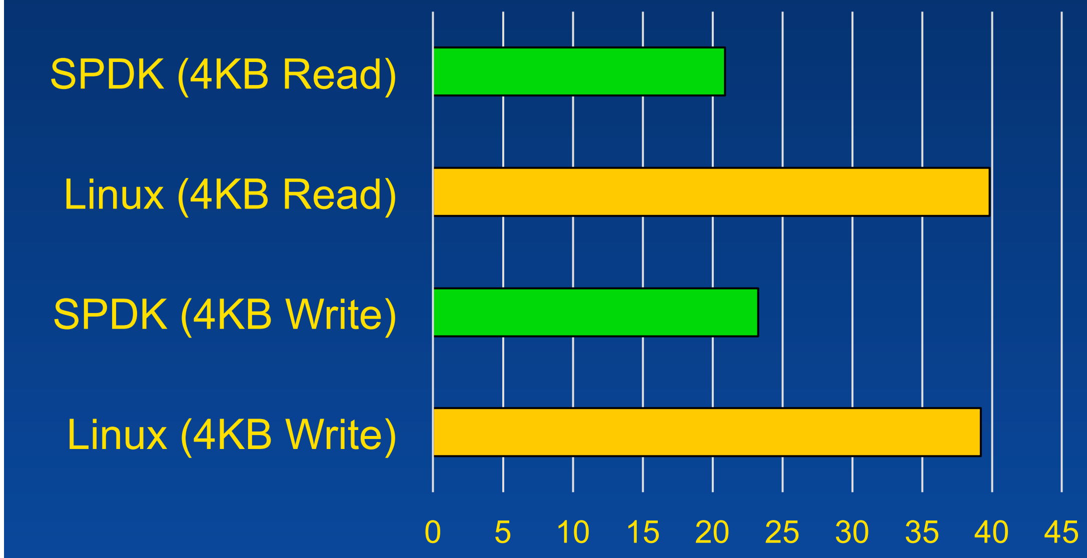
Performance Comparison



Performance Comparison

QD=1 Latency (microseconds)



- Configuration
  - 4KB Random I/O
  - Queue Depth 1
  - Intel® P4800X SSD
  - Mellanox® LX-710 25Gb
  - Measured from VM (fio)

SPDK cuts latency almost in half!

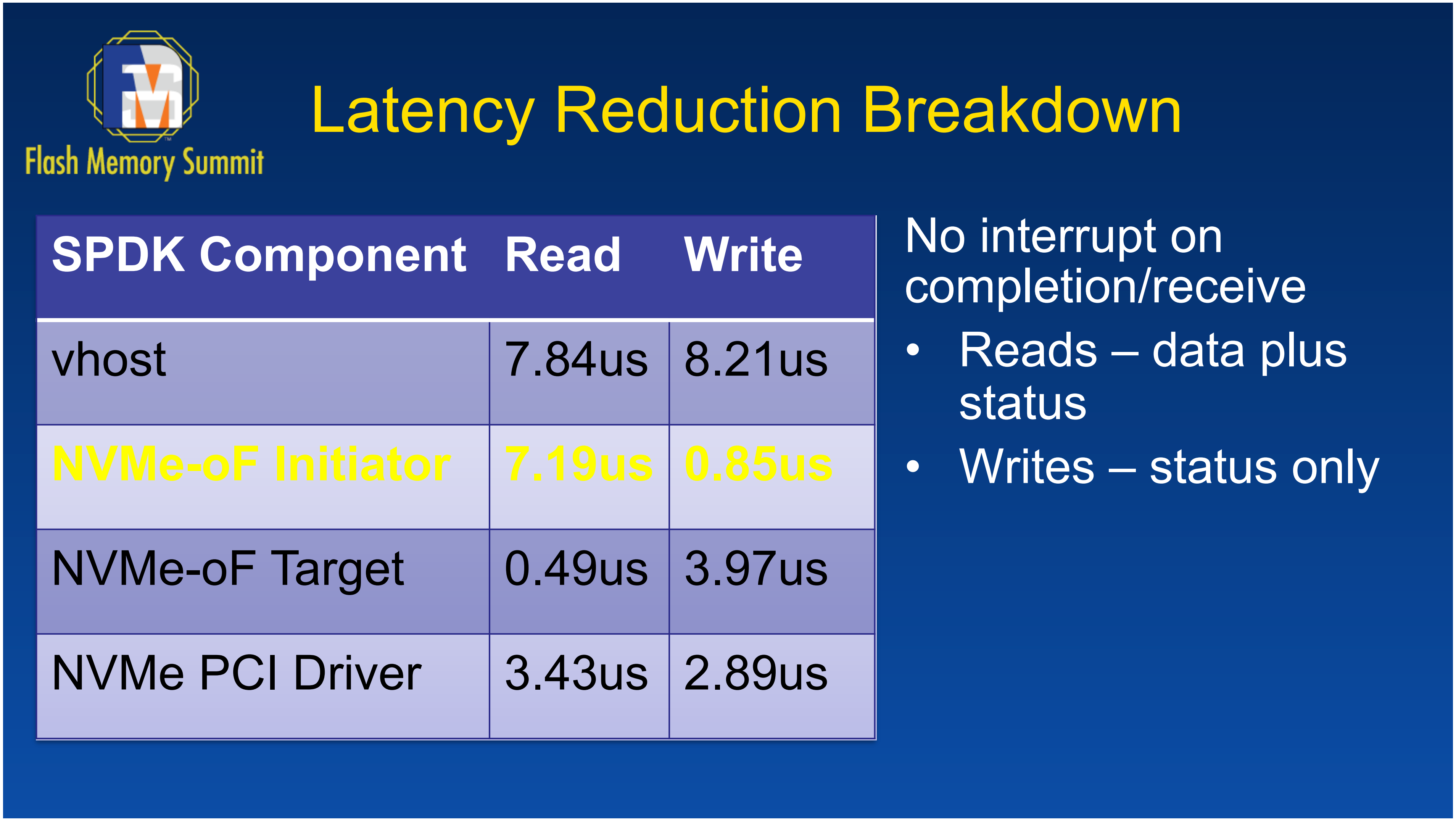
System Configuration: NVMe-oF Target: OS: Ubuntu 17.04 Linux Kernel: 4.10.0-19-generic x86_64, 187 GB Intel P4800X SSD, 2x E5-2695 v4 @ 2.10GHz, Hyperthreading disabled, 16x4GB DRAM, SPDK commit ID 7fedfb48, Mellanox LX-710 25Gb/s (SFP+) **VM Host System:** OS: Ubuntu 17.04 Linux Kernel: 4.10.0-19-generic x86_64, 2x E5-2699 v3 @2.30GHz Hyperthreading enabled, 16x8GB DRAM, SPDK commit 1e2aed0a, Mellanox LX-710 25Gb/s (SFP+) Link Speed **QEMU VM:** OS: CentOS Linux release 7.3.1611 Linux Kernel: 3.10.0-514.21.1.el7.x86_64

Latency Reduction Breakdown

SPDK Component	Read	Write
vhost	**7.84us**	**8.21us**
NVMe-oF Initiator	7.19us	0.85us
NVMe-oF Target	0.49us	3.97us
NVMe PCI Driver	3.43us	2.89us

No VMEXIT on submission

No context switch to wake SPDK thread



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No interrupt on completion/receive

- Reads – data plus status
- Writes – status only

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- Reads – command only
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Latency Reduction Breakdown

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No interrupt on I/O completion

Pinned hugepages

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Software Overhead

- Not just a latency improvement
- Reducing software overhead means:
  - Fewer I/O processing cores => More cores for VMs
  - Fewer VMEXITs in VMs => More cycles for application

SPDK vhost Hyper-Converged Demo

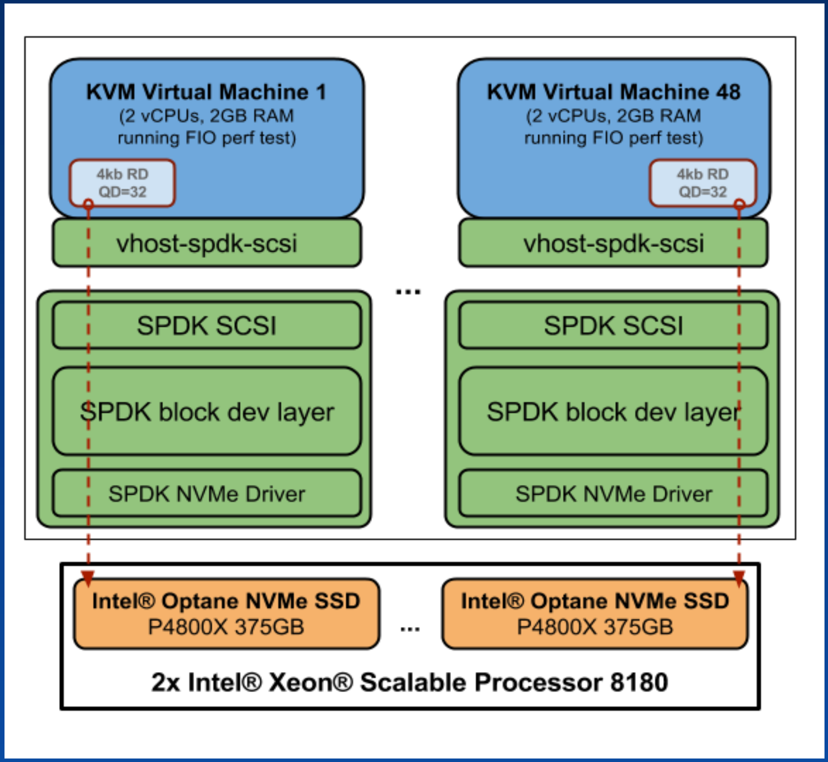
Use case

Software accelerated Virtual Machine Storage

Configuration

Hyper-converged Server Node

- Intel® Xeon® Scalable Processor node running 48 virtual machines with 24x direct-attached Intel® NVMe SSDs



KVM Virtual Machine 1
(2 vCPUs, 2GB RAM
running FIO perf test)

4kb RD
QD=32

vhost-spdk-scsi

SPDK SCSI

SPDK block dev layer

SPDK NVMe Driver

...

KVM Virtual Machine 48
(2 vCPUs, 2GB RAM
running FIO perf test)

4kb RD
QD=32

vhost-spdk-scsi

SPDK SCSI

SPDK block dev layer

SPDK NVMe Driver

Intel® Optane NVMe SSD
P4800X 375GB

...

Intel® Optane NVMe SSD
P4800X 375GB

2x Intel® Xeon® Scalable Processor 8180

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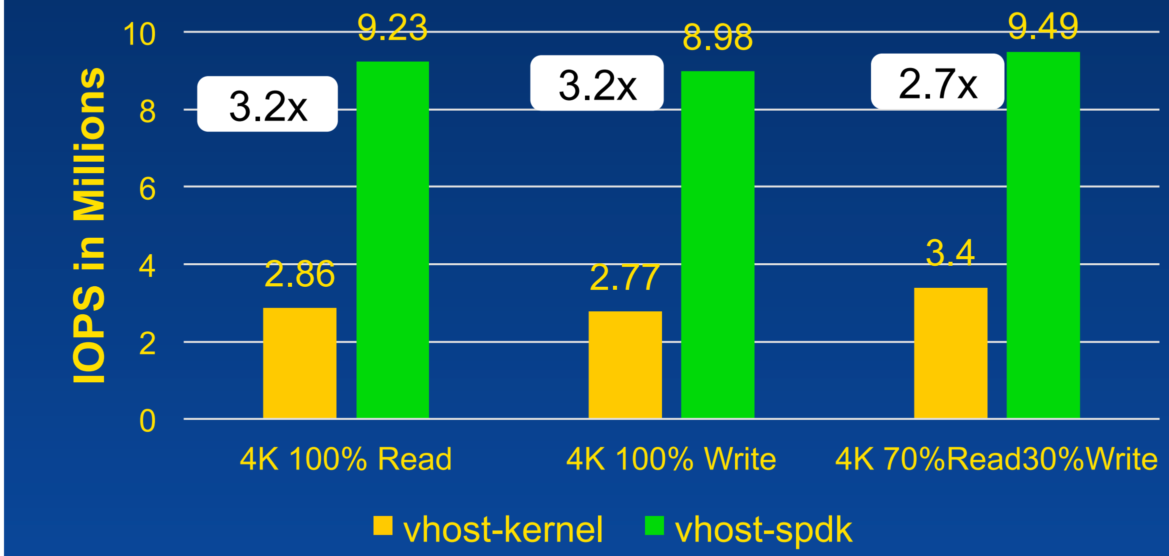
vhost-scsi performance – 48 VMs (SPDK vs. Kernel)



- 2x Intel Xeon Platinum 8180 Processor
- 24x Intel P4800x 375GB
- 10 vhost I/O processing cores

SPDK vhost yields up to 3.2x more IOPs

System Configuration:Intel Xeon Platinum 8180 @ 2.5GHz. 56 physical cores 6x 16GB, 2667 DDR4, 6 memory Channels, SSD: Intel P4800x 375GB x24 drives, Bios: HT disabled, p-states enabled, turbo enabled, Ubuntu 16.04.1 LTS, 4.11.0 x86_64 kernel, 48 VMs, number of partition: 2, VM config : 1core 1GB memory, VM OS: fedora 25, blk-mq enabled, Software packages: Qemu-2.9, libvirt-3.0.0, spdk (3bfecec994), IO distribution: 10 vhost-cores for SPDK / Kernel. Rest 46 cores for QEMU using cgroups, FIO-2.1.10 with SPDK plugin, io depth=1, 8, 32 numjobs=1, direct=1, block size 4k

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Summary

- Significant software overhead in virtualization usage models with NVMe-oF
- Software overhead impacts performance and CPU efficiency
- SPDK can reduce this software overhead by up to 20us per I/O
- Check out SPDK at http://spdk.io