Western Digital

Introduction to Open-Channel Solid State Drives

Matias Bjørling
Director, Solid-State System Software

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Flash Memory Summit

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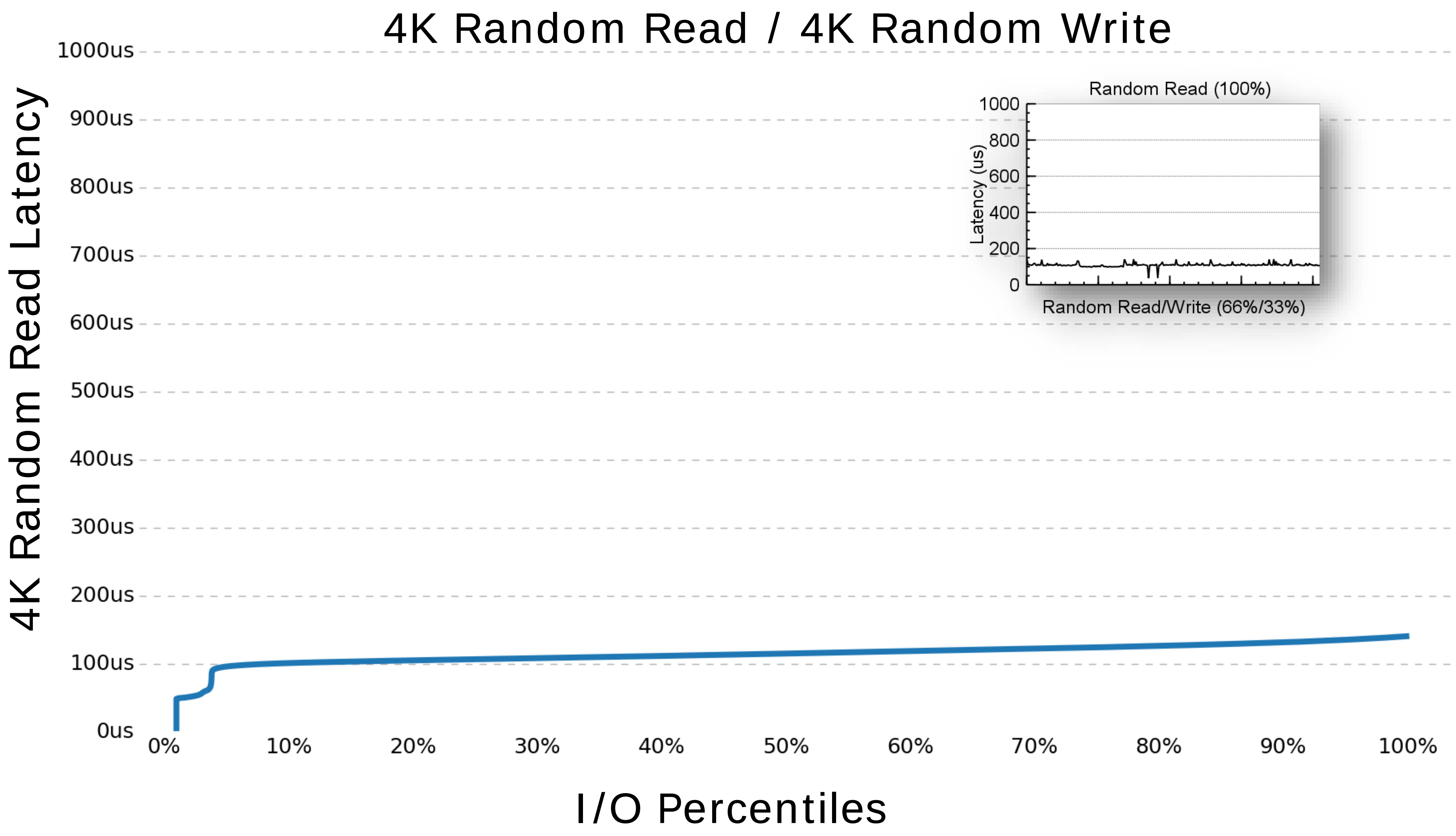
Agenda

1. Motivation
2. Interface
3. Eco-system
4. Open-Source Contributions

0% Writes - Read Latency



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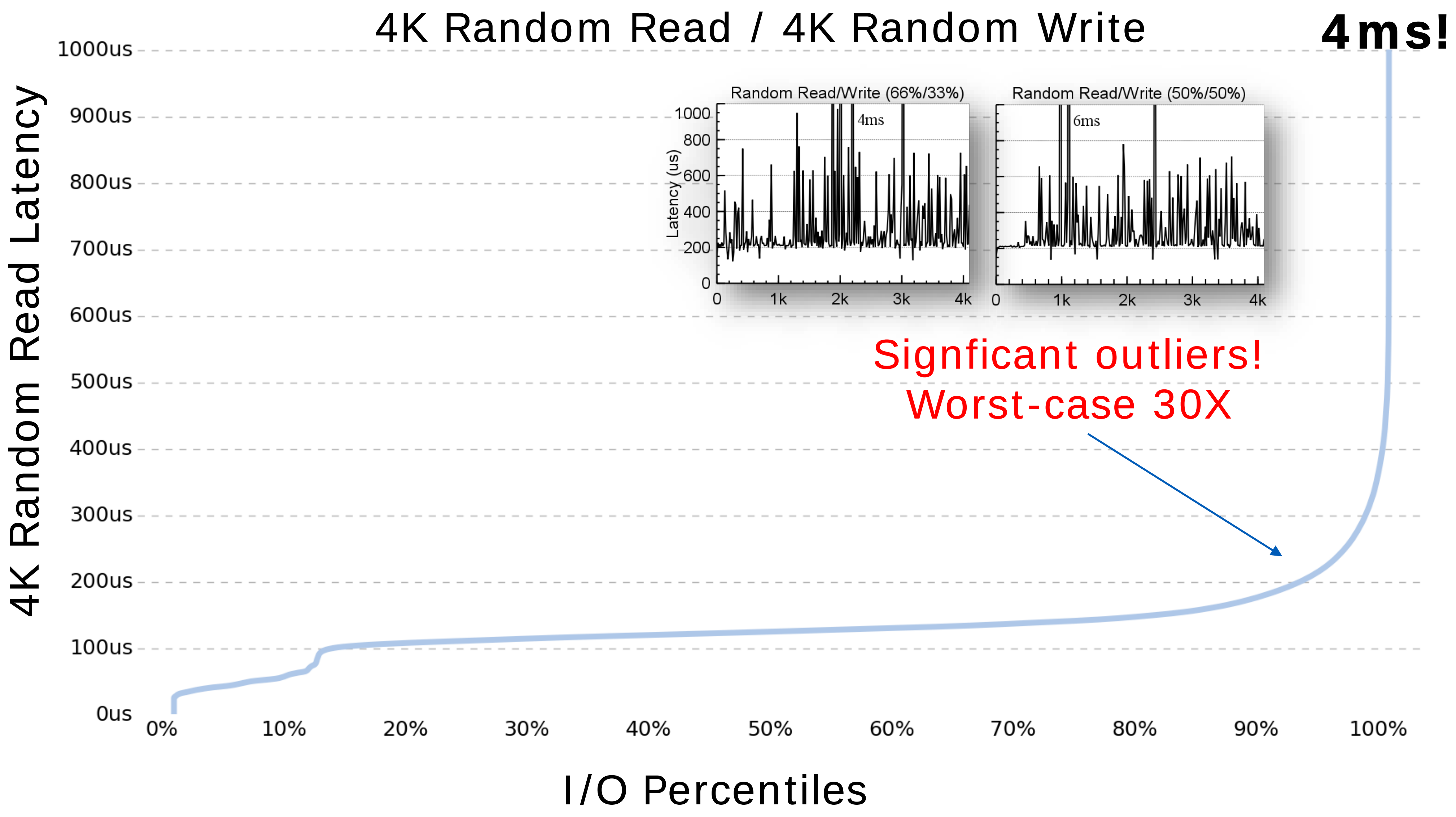
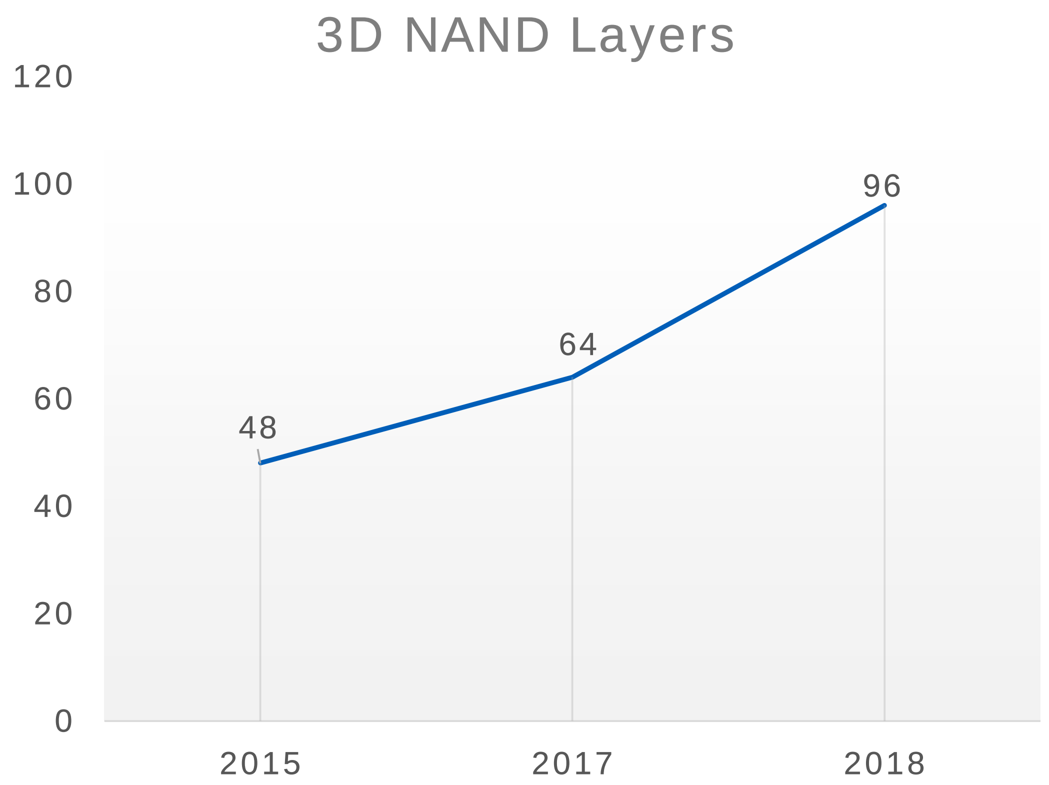
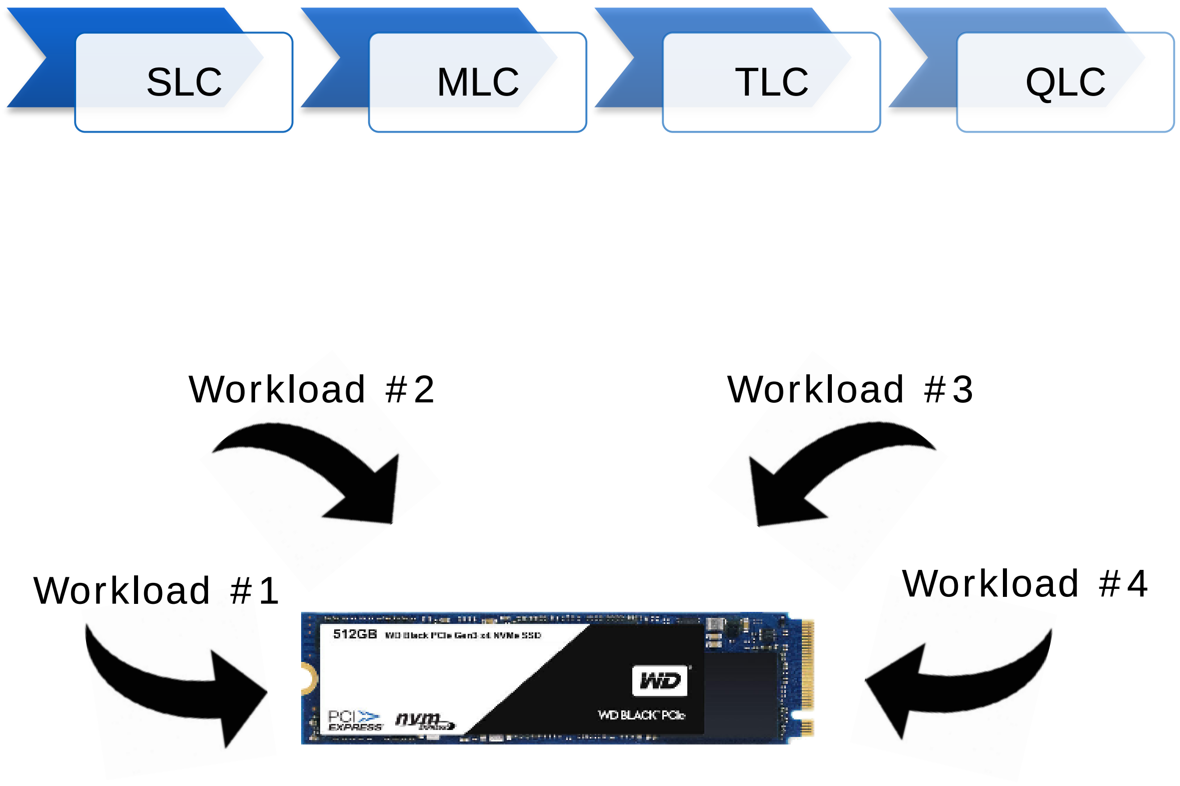
20% Writes - Read Latency



NAND Chip Density Continues to Grow

While Cost/GB decreases





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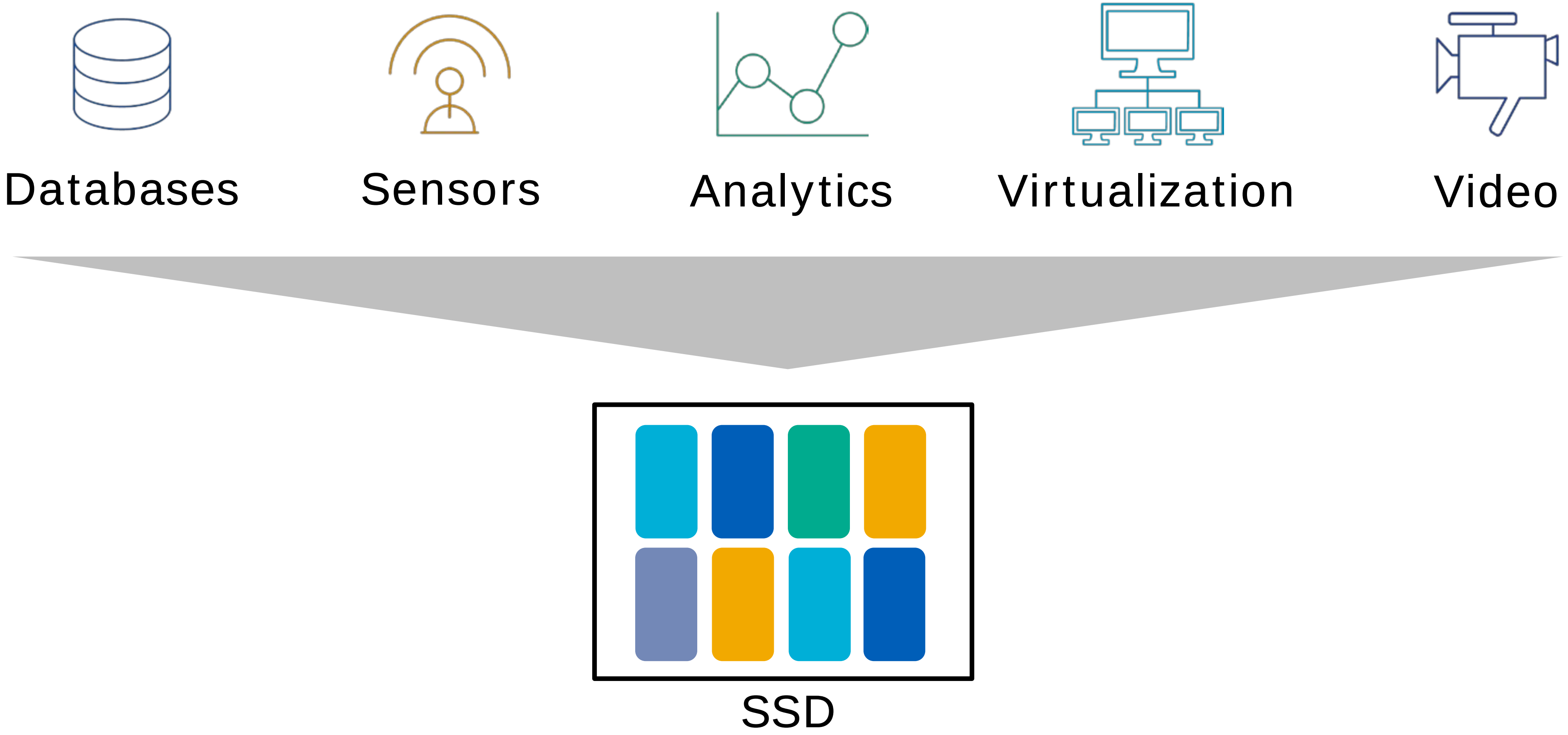
Ubiquitous Workloads

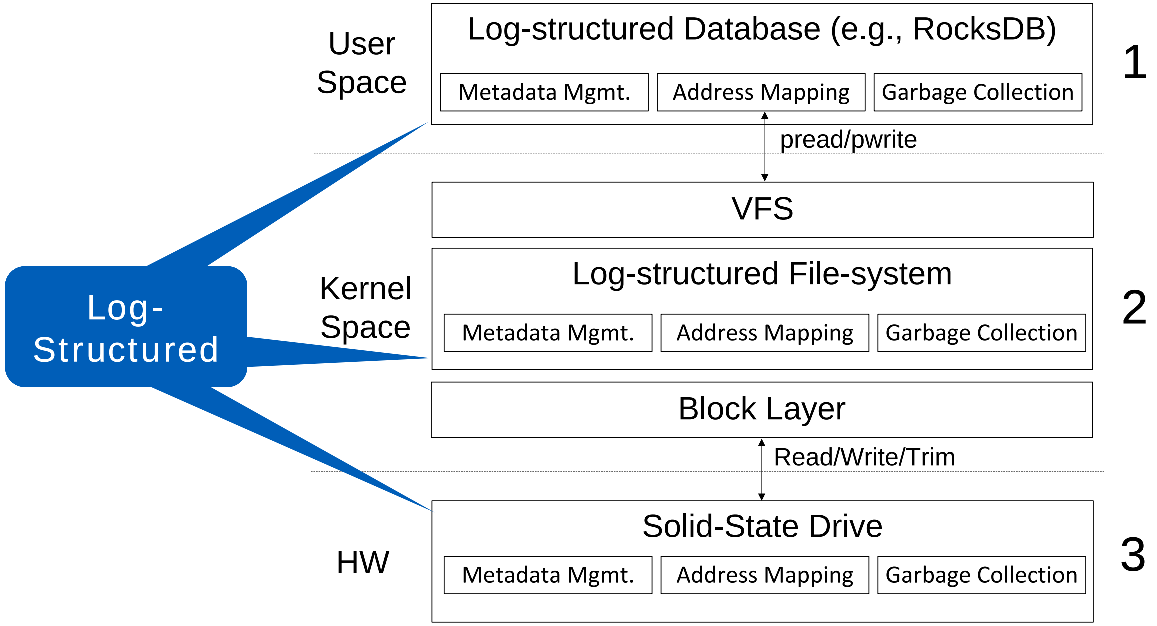
Efficiency of the Cloud requires many different workloads of a single SSD



Single-User Workloads

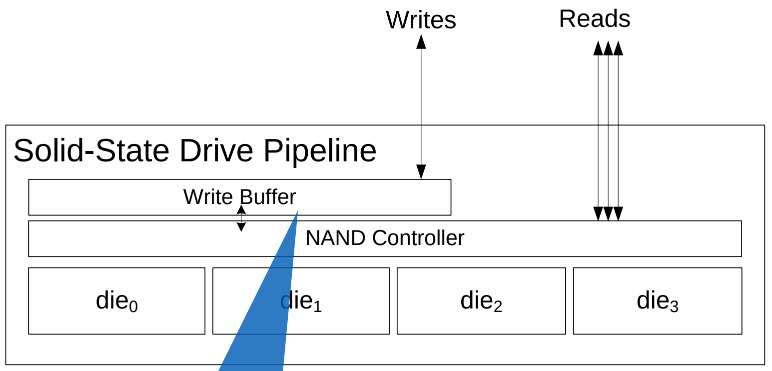
Indirection *and* ***Narrow Storage*** *interface is a main cause of outliers*

Host: Log-on-Log



Unable to align data logically = Write amplification increase + extra GC

Device: Write Buffering

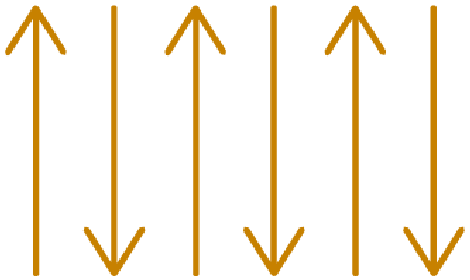


Buffered Writes

Drive maps logical data to the physical location with **Best Effort**

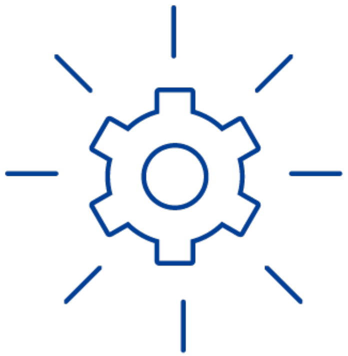
Host is oblivious to physical data placement due to indirection

Open-Channel SSDs



I/O Isolation

Predictable Latency



Data Placement &
I/O Scheduling

Concepts in an Open-Channel SSD

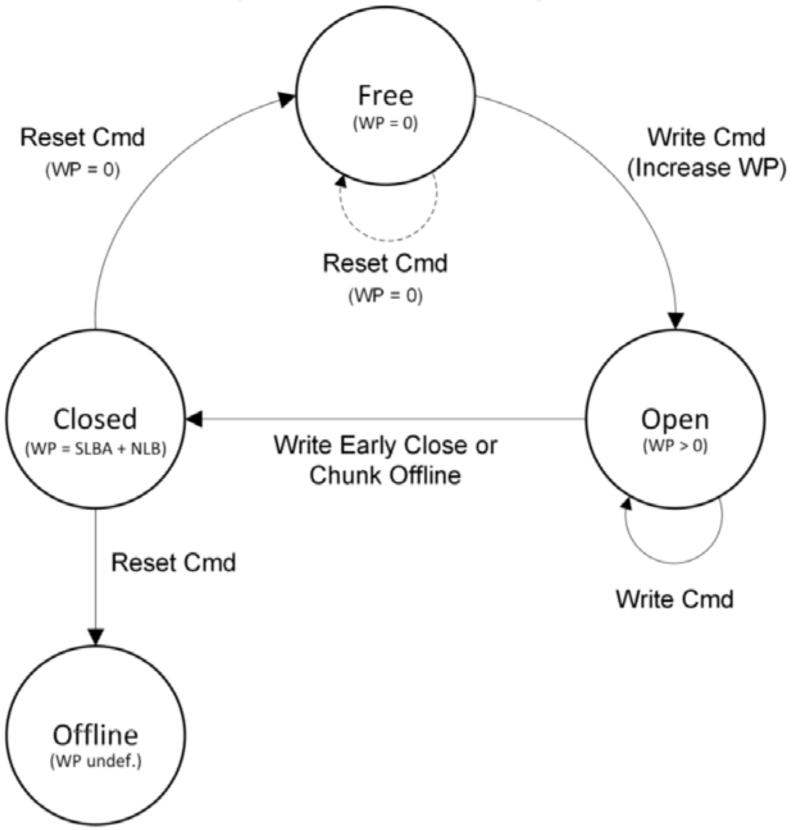
Interface Blocks

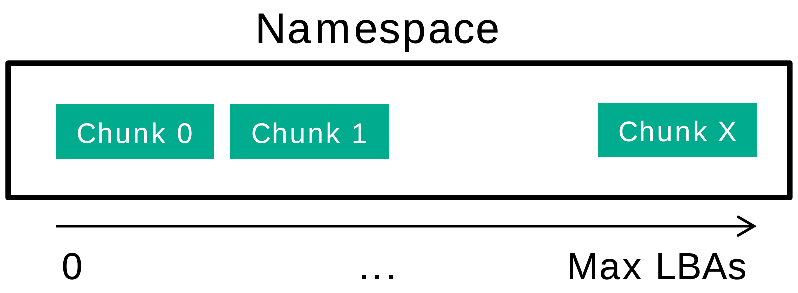
- Chunks
  - Sequential write only LBA ranges
- Hierarchical addressing
  - A sparse addressing scheme projected onto the NVMe™ LBA address space
- Direct-to-media min/opt write size
  - Eliminate write buffering
- Host-assisted Media Refresh
  - Improve I/O predictability
- Host-assisted Wear-leveling
  - Improve wear-leveling

Chunks

Enable orders of magnitude reduction of device-side DRAM

- A chunk is a range of LBAs where writes are required to be sequential.
- Reduces DRAM for L2P table by orders of magnitude
- Hot/Cold data separation
- Rewrite requires a reset
  - A chunk can be in one of four states (free/open/closed/offline)
  - If a chunk is open, there is a write pointer associated.
- Follows the same model as in the ZAC/ZBC standards.



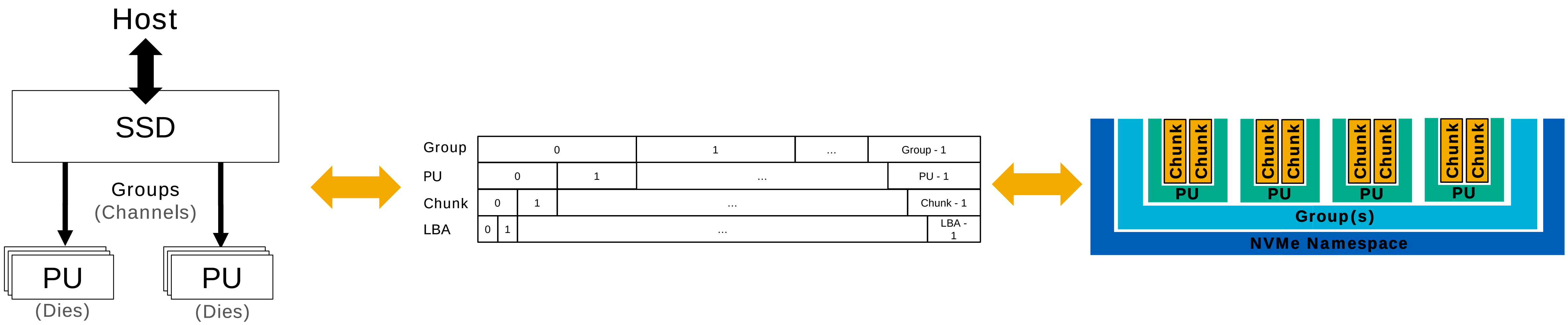


Hierarchical Addressing

Channels and Dies are mapped to Logical Groups and Parallel Units

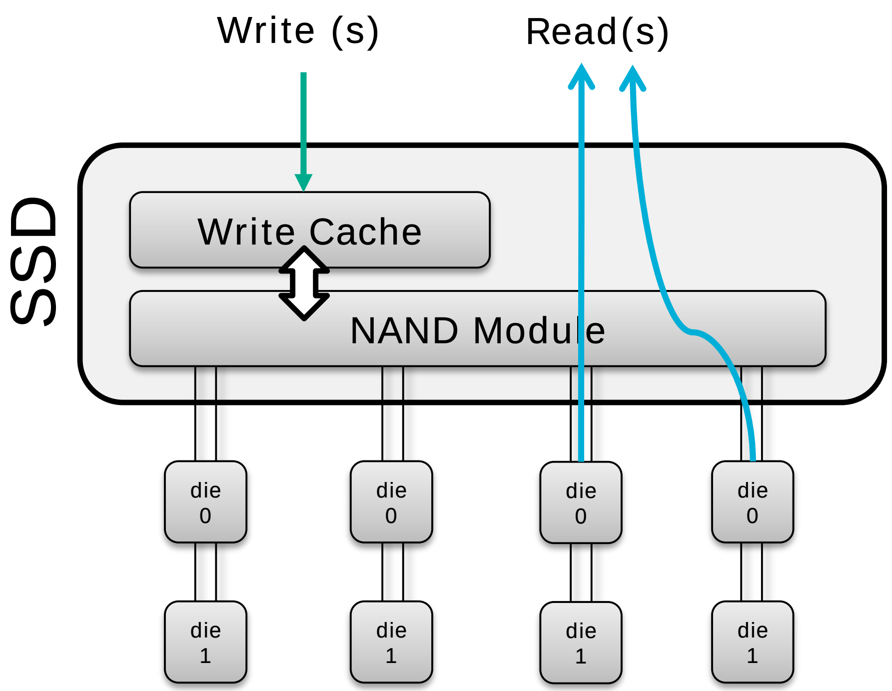
- Expose device parallelism through Groups/Parallel Units
  - One or a group of dies are exposed as parallel units to the host
  - Parallel units are a logical representation

Physical | **LBA Address Space** | **Logical**

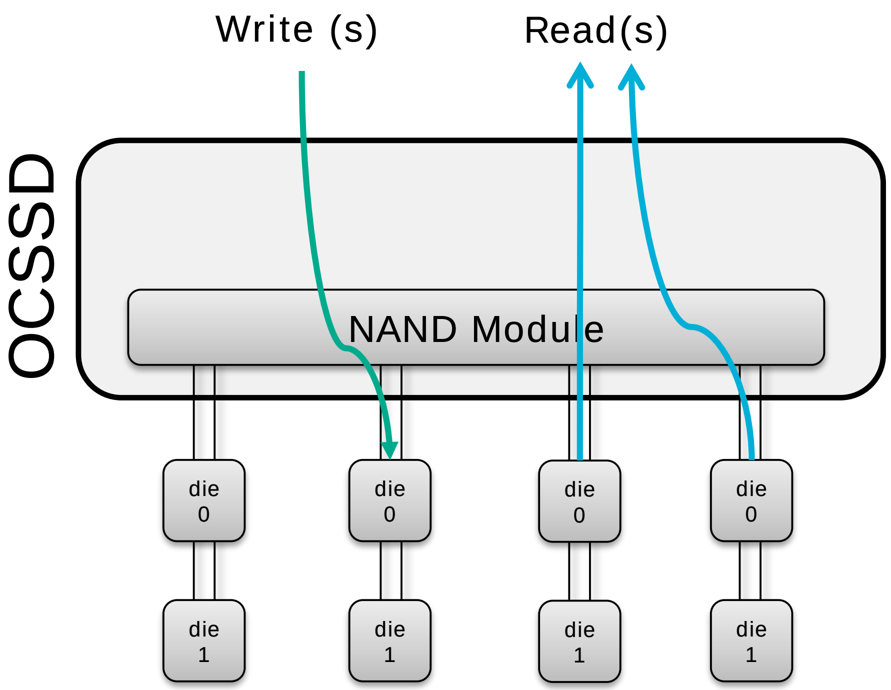


Direct-to-Media

Bypass device write cache and move data directly to NAND



Add unpredictability. When to flush?
Limited streams due to DRAM/SRAM requirements

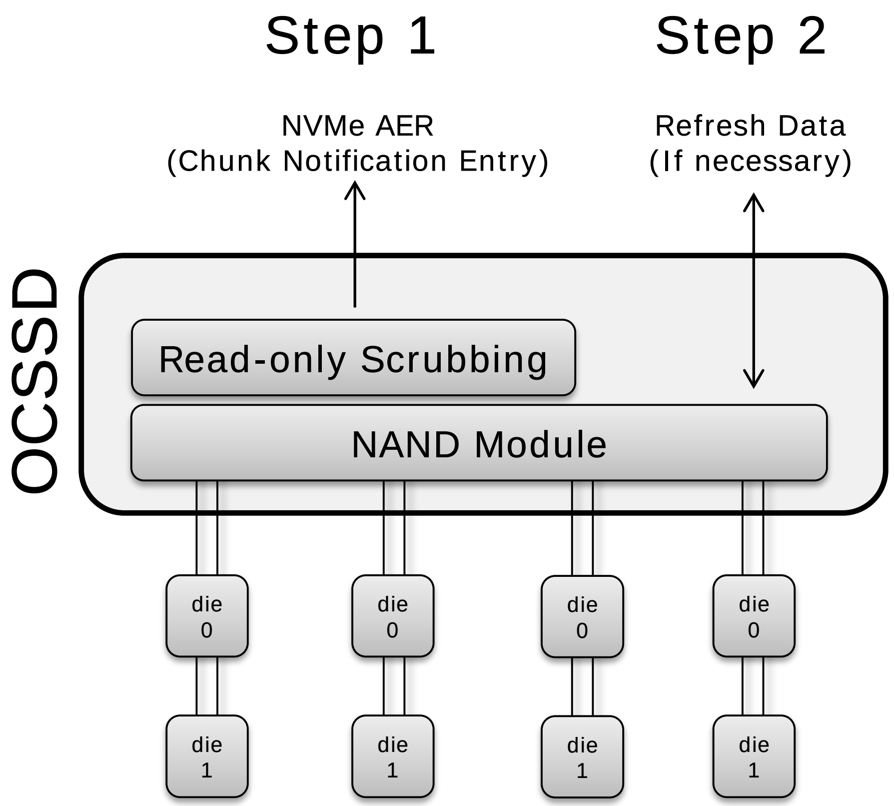


Synchrounous Write
Large Writes (Flash page size)
Large number of streams / open chunks

Host-assisted Media Refresh

Enable host to assist SSD data refresh

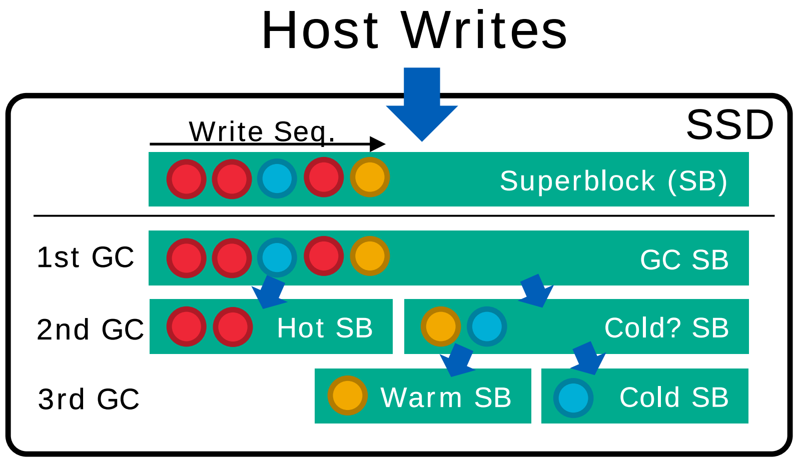
- SSDs refreshes its data periodically to maintain reliability. It does this through a data scrubbing process
  - Internal read and writes make the drive I/O latencies unpredictable.
  - Writes dominates I/O outliers
- 2-step Data Refresh
  - Device to only perform the data scrubbing read part - Data movement is managed by host
  - Increases predictability of the drive. Host manages refresh strategy
    - Should it refresh? Is there a copy elsewhere?

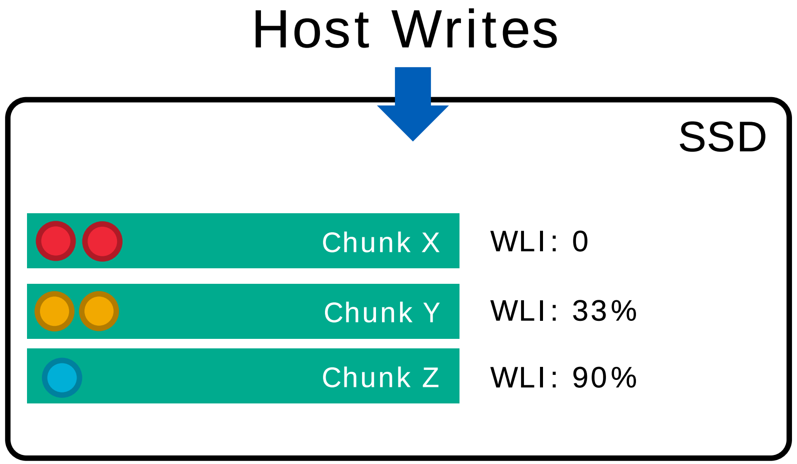


Host-assisted Wear-Leveling

Enable host to separate Hot/Cold data to Chunks depending on wear

- SSDs typically does not know the temperature of newly written data
  - Placing hot and cold data together increases write amplication
  - Write amplication is typical 4-5X for SSDs
- Chunk characteristics
  - Limited reset cycles (as NAND blocks has limited erase cycles)
  - Place cold data on chunks that are nearer end-of-life and use younger chunks for hot data
- Approach
  - Introduce per-chunk relative wear-level indicator (WLI)
  - Host knows workload and places data w.r.t. to WLI
  - No need to needlessly garbage collect chunks → **Increases lifetime, I/O latency, and performance**

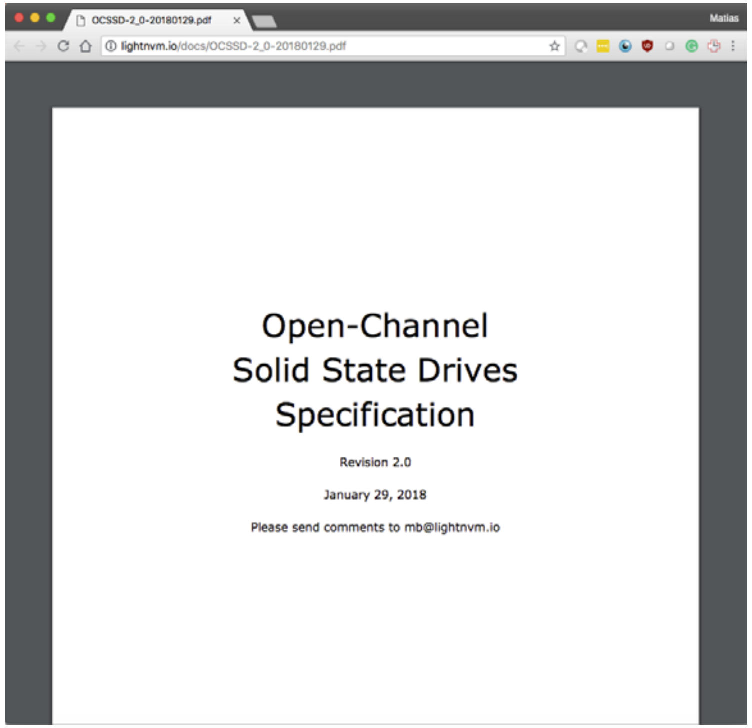




Interface Summary

The concepts together provide

- **I/O Isolation** through the use of Groups & Parallel Units
- **Fine-grained data refresh** managed by the host
- **Reduce write amplification** by enabling host to place hot/cold data efficiently
- **DRAM & Over-provisioning** reduction through append-only Chunks
- Direct-to-media to **avoid expensive internal data movement**

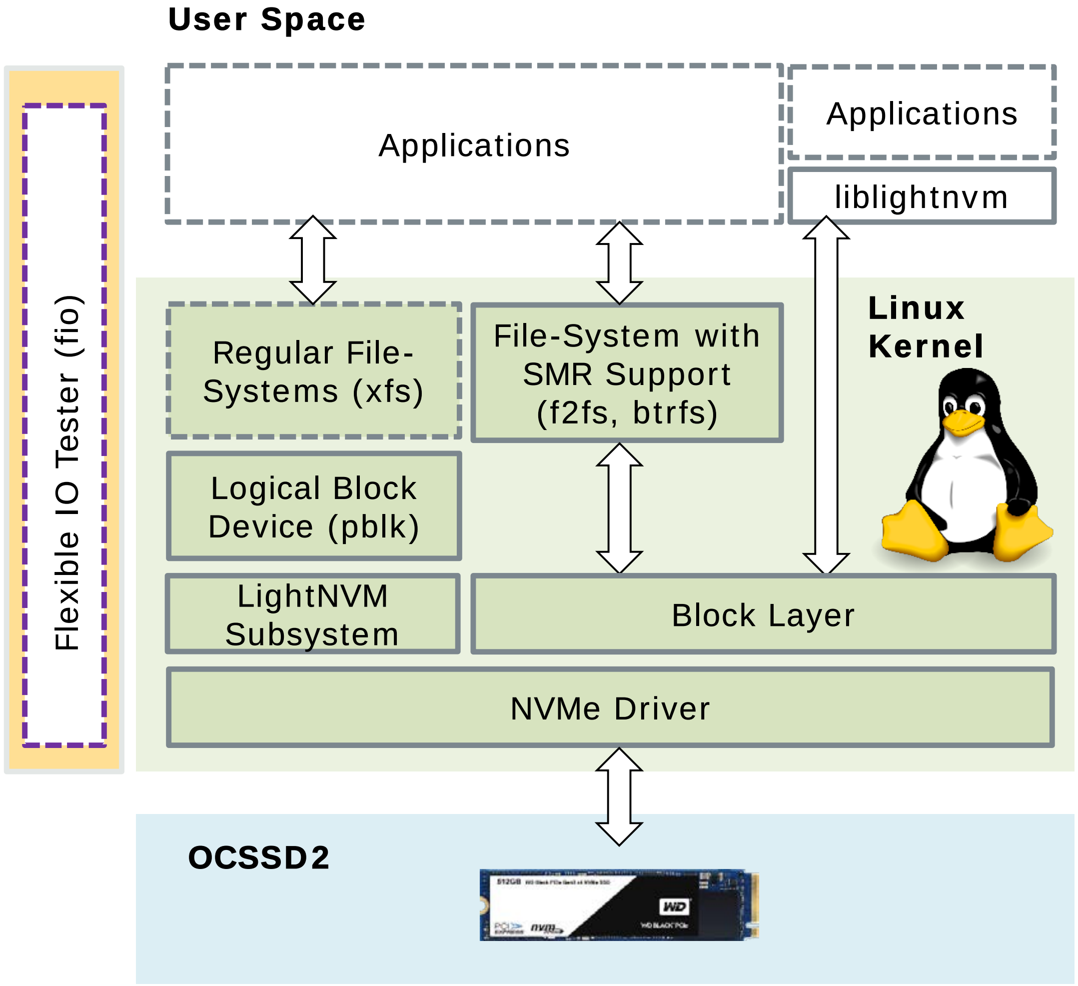


Specification available at http://lightnvm.io

Eco-system

Large eco-system through Zoned Block Devices and OCSSD

- Linux Kernel®
  - NVMe Device Driver
    - Detection of OCSSDs
    - Implements 1.2 and 2.0 specification
    - Registers as a ZBD and with LightNVM
  - LightNVM Subsystem
    - Provides core functionality
    - Target management
  - Target interface
    - Enumerate, get geometry, I/O interface, etc.
    - pblk host-side FTL – Map OCSSD to Block Device
- User-space
  - Libzbc, fio (ZBD support), liblightnvm
  - SPDK



Open-Source Software Contributions

- Initial release of subsystem with Linux kernel 4.4 (January 2016).
- User-space library (liblightnvm) support upstream in Linux kernel 4.11 (April 2017).
- pblk available in Linux kernel 4.12 (July 2017).
- Open-Channel SSD 2.0 specification released (January 2018) and support available from Linux kernel 4.17 (May 2018).
- SPDK Support for OCSSD (June 2018)
- Upcoming
  - OCSSD as Zoned Block Device (Patches available)
  - Fio with Zone support (Patches available)
  - 2.0a revision with fixes

Path to Standardization

The OCSSD interface combines several concepts

- Groups / Parallel Units = NVM Sets / Endurance Groups
- Direct-to-Media - Proposal in NVMe WG
- Chunks - Not yet defined
- Host-assisted Data Refresh
  - I/O Determinism: Deterministic Windows
  - **AER Feedback mechanism** – Fine-grained Host controlled Data Refresh
- Host-assisted WL
  - Endurance Groups with extended attributes
  - **Finer granularity through Chunks.** Improve hot/cold data placement → Dependent on the concept of chunks

OCSSD 2.0	NVMe
Parallelism Groups/PUs	NVM Sets + Endurance Groups
Direct-to-Media	In progress
Chunks	
Host-assisted Data Refresh	Deterministic Windows
Host-assisted WL	Endurance Groups

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LightNVM: The Linux Open-Channel SSD Subsystem

https://www.usenix.org/conference/fast17/technical-sessions/presentation/bjorling

LightNVM

http://lightnvm.io

LightNVM Linux kernel Subsystem

https://github.com/OpenChannelSSD/linux

liblightnvm

https://github.com/OpenChannelSSD/liblightnvm

QEMU NVMe with Open-Channel SSD Support

https://github.com/OpenChannelSSD/qemu-nvme

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