Western Digital

ZNS: Avoiding the Block Interface Tax for Flash-based SSDs

Matias Bjørling, Abutalib Aghayev, Hans Holmberg, Aravind Ramesh, Damien Le Moal, Gregory R. Ganger, George Amvrosiadis

July 14-16

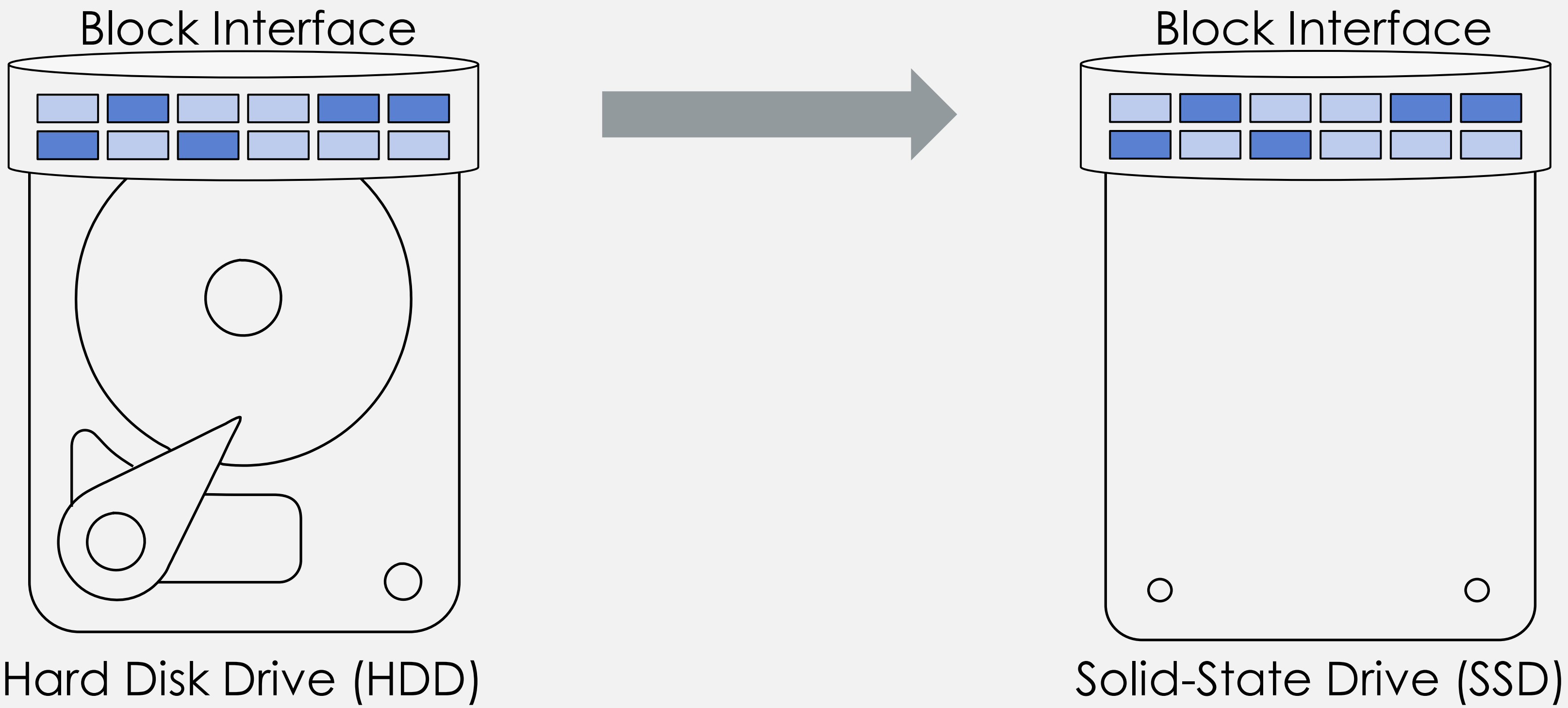
USENIX ATC 2021

Western Digital
Carnegie Mellon University
PennState

The Block Interface Tax

For several decades storage software has been built atop the block interface

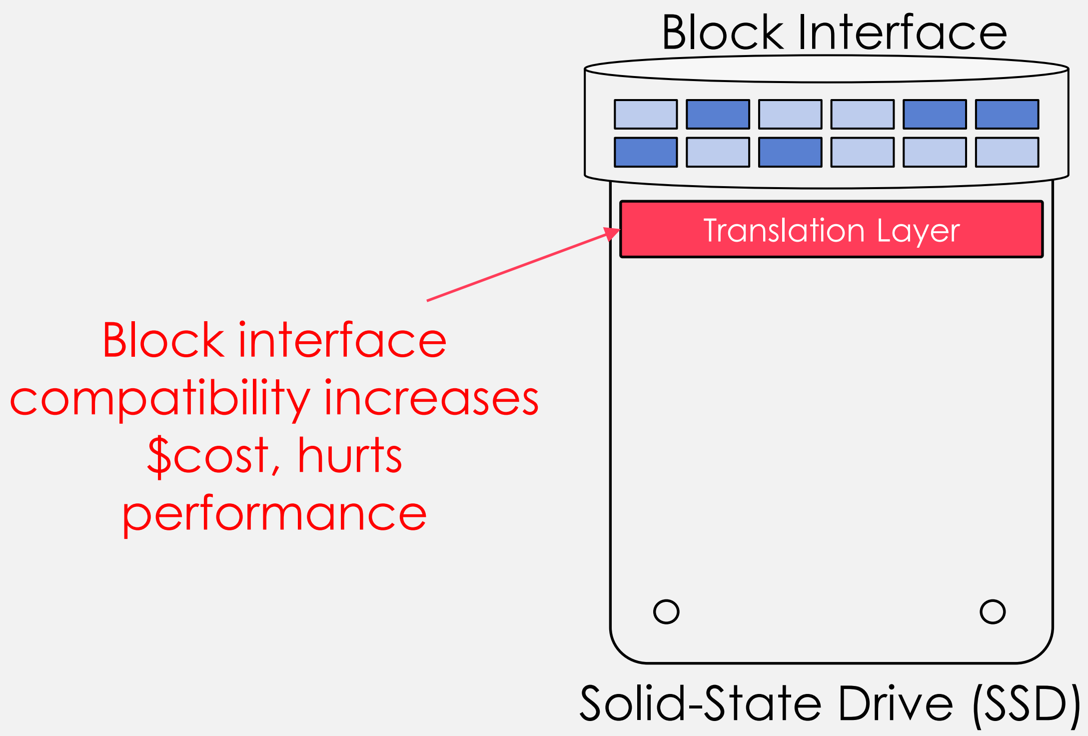
- Storage represented as an array of fixed-size blocks
- Each block can be read, written, and overwritten atomically
- Adopted for HDDs as well as SSDs



The Block Interface Tax

The inherent properties of flash-based SSDs have made the block interface a poor fit

- SSDs “append” pages to erase blocks, need to erase whole block before rewriting
- Data placement overhead: **media over-provisioning (7-28%), higher $cost and lower performance**

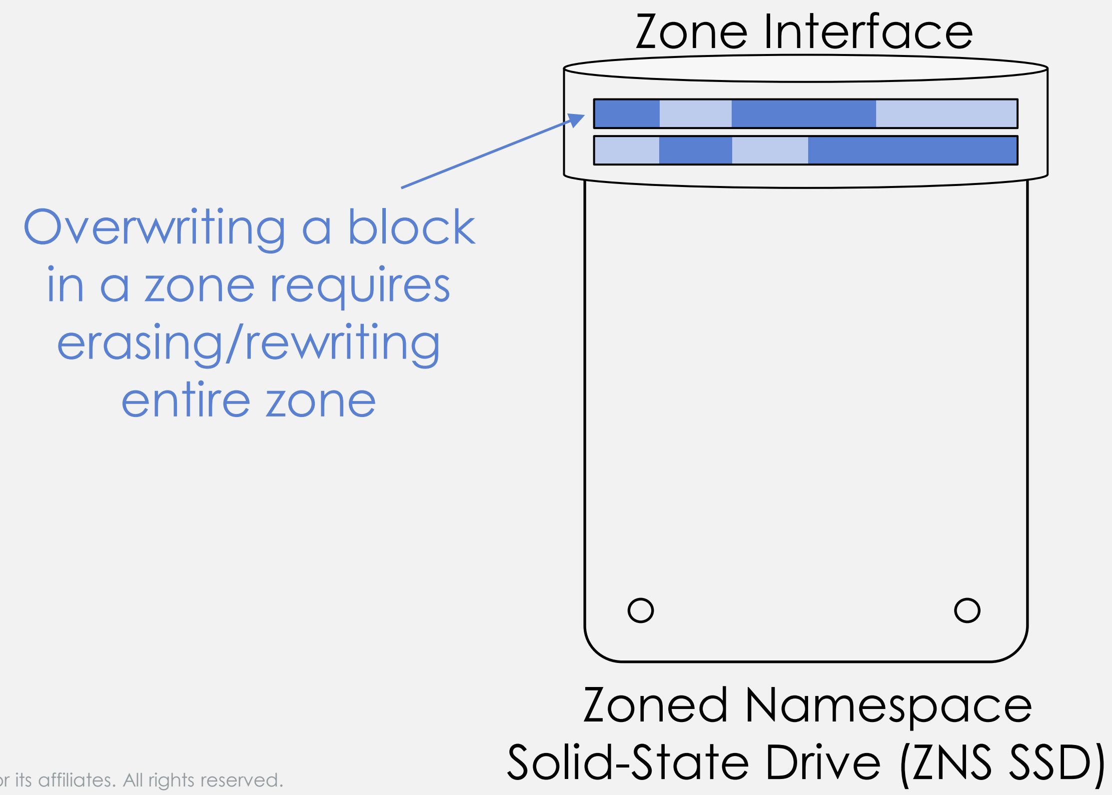


Zoned Namespace SSDs

Getting rid of the block interface tax

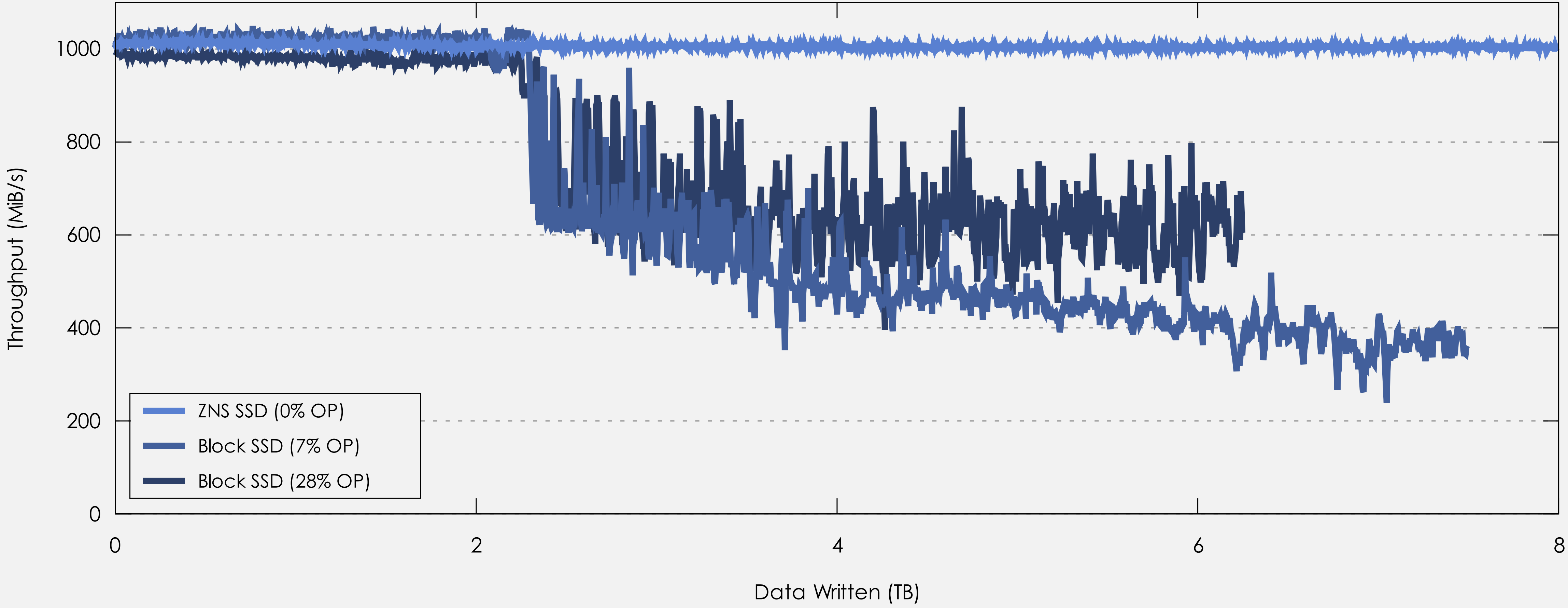
What if the host could write data onto the flash-based SSD through append-only regions (zones)? → ZNS exposes them!

- No fine-grained data placement in SSDs: **+7-28% capacity**, **lower $cost**, **predictable high performance**



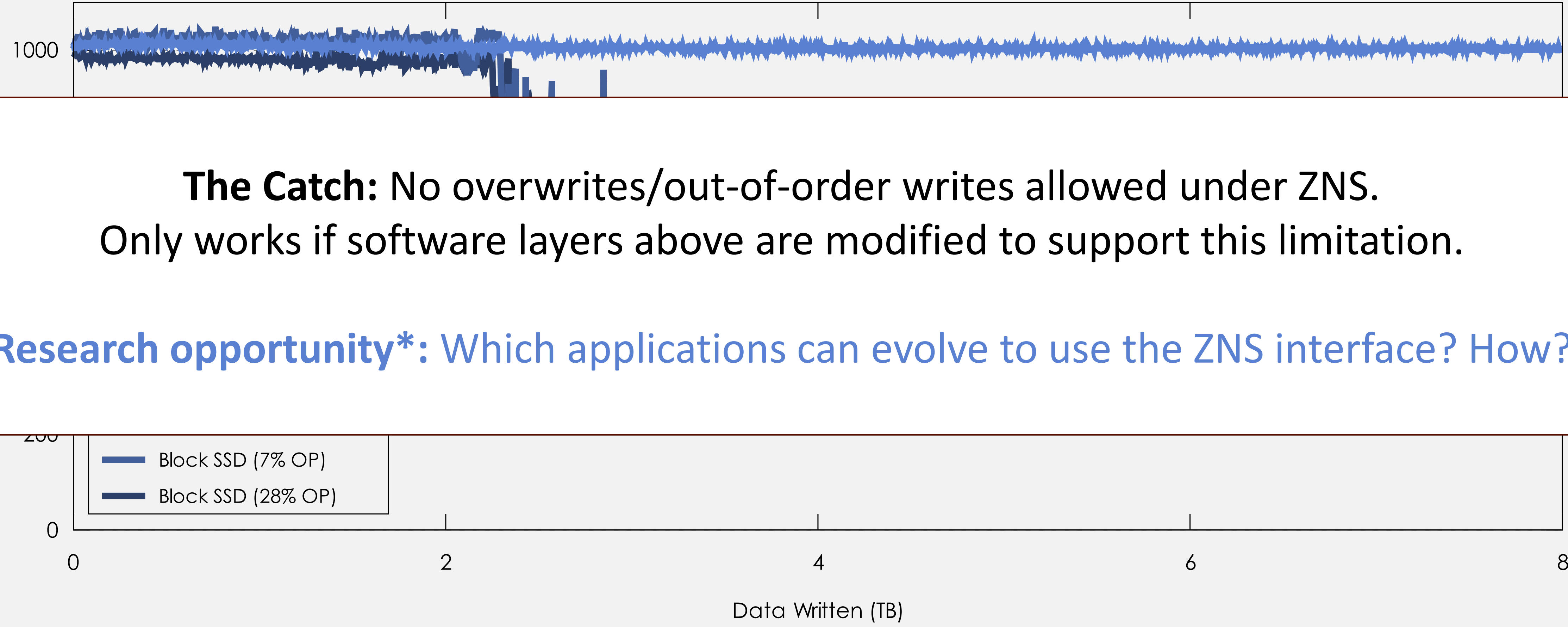
Zoned Namespace SSDs

Getting rid of the block interface tax



Zoned Namespace SSDs

Getting rid of the block interface tax



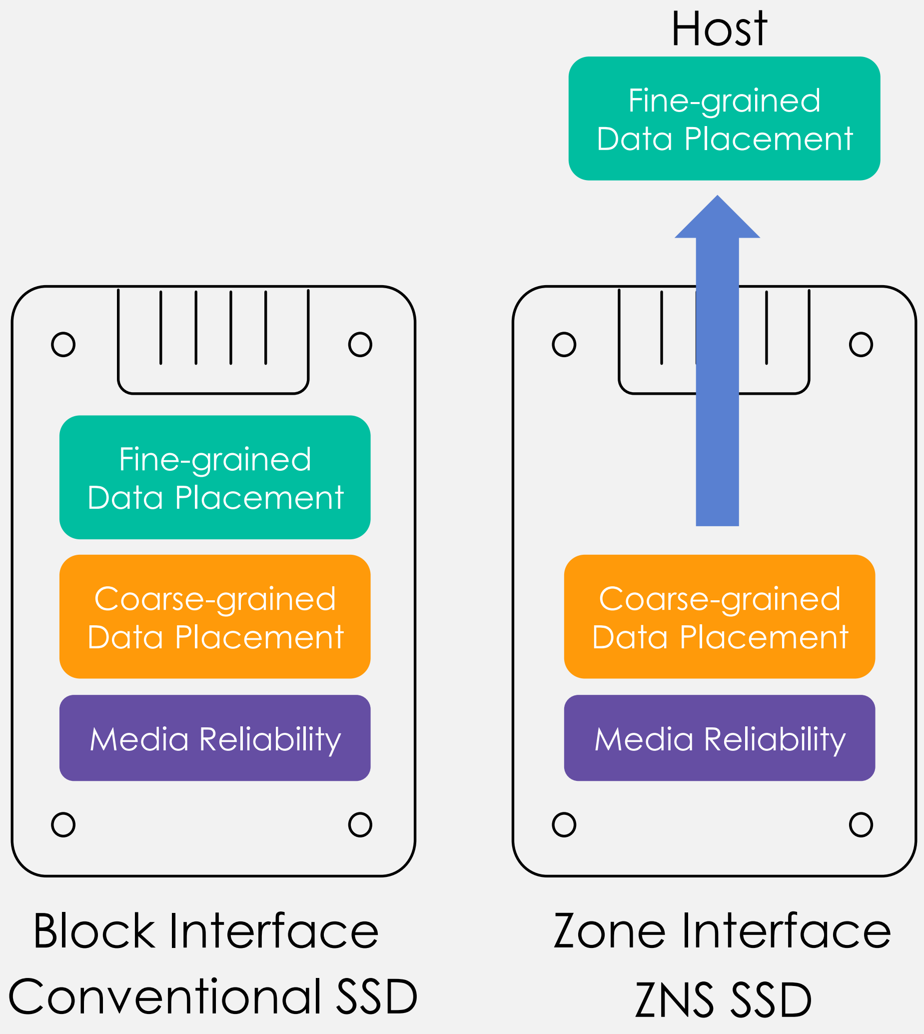
The Catch: No overwrites/out-of-order writes allowed under ZNS.
Only works if software layers above are modified to support this limitation.

Research opportunity*: Which applications can evolve to use the ZNS interface? How?

*Stavrinos et. al., **Don't be a Blockhead: Zoned Namespaces Make Work on Conventional SSDs Obsolete**, HotOS, 2021

Evolving towards ZNS SSDs

- **ZNS SSDs relinquish GC responsibilities** traditionally carried out by the FTL
- The ZNS interface enables the SSD to translate **sequential zone writes onto distinct erase blocks**
- Since **random writes are disallowed** by the interface, and zones must be **explicitly reset by the host**, the **data placement occurs at the coarse-grained level of zones**
- **GC of zones becomes the responsibility of the host**
- **Media reliability continues to be the full responsibility of the SSD**



Adoption

Three ways to adopt ZNS SSDs

- Host-side FTL
  - Implement a host-side FTL that exposes the ZNS SSD as a block interface SSD.
  - High system overhead wrt to DRAM and CPU.
  - Enable workloads that specifically require random write characteristics.

- File Systems (**f2fs /w zones**)
  - Place data onto zones using the file system characteristics
  - Efficient use of resources, as the file system simply places data more efficiently
  - Layer of indirection away from the application, and therefore some inefficient data placement causes host GC.

- End-to-end Data Placement (**RocksDB /w ZenFS**)
  - Places data onto zones using the application characteristics
  - No indirection overhead cause by FTL data placement nor file system.
  - Highest performance and the lowest write amplification

Enabling the Linux Ecosystem

Adding support for ZNS SSDs

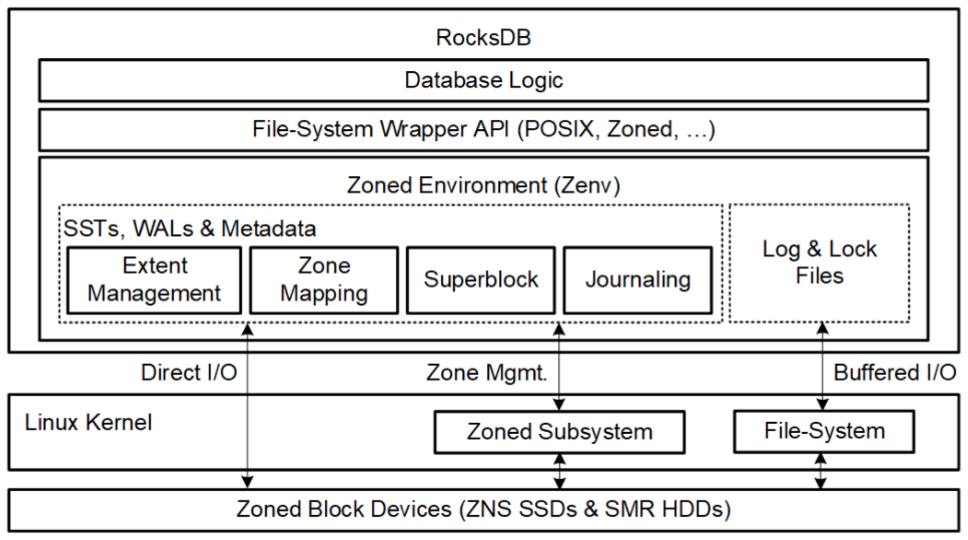
- General Linux Support thru the Zoned Block Device (ZBD) subsystem
- NVMe driver support for zone attributes (e.g., capacity)
- API support for exposing limit of active zones, which depends on device resources
- Linux file system support: extending **f2fs** to run on ZNS

	Lines Added	Lines Removed
Linux Kernel	647	53
f2fs (kernel)	275	37
f2fs (tools)	189	15
fio	342	58
ZenFS (RocksDB)	3276	2
Total	**4729**	**169**

ZenFS Architecture

A new storage backend for RocksDB

- Extent-based block-aligned contiguous region of file data
  - Multiple file extents per zone (no spanning)
- Journal data: appended to circular buffer of designated zones
  - Includes WAL data, file identifiers, in-memory allocation structures
  - Buffered writes handled by buffering in memory until flush event
- Zone management
  - User limit for internal fragmentation simplifies file size uncertainty (due to compression, compaction)
  - Write lifetime hints from RocksDB simplify Garbage Collection
  - Limits active zones based on device resources



Evaluation

Apples-to-apples comparison

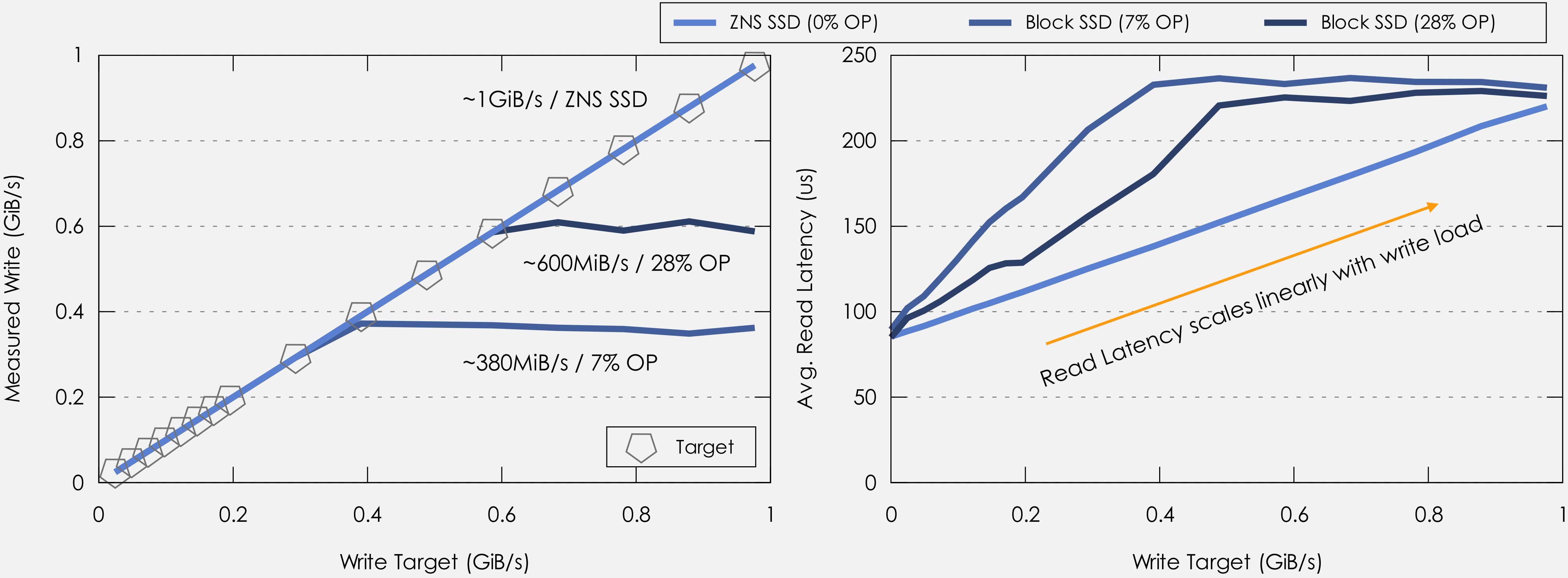
- Production hardware platform that can expose itself as either a block-interface SSD or a ZNS SSD.
- Methodology
  - Raw I/O performance
  - RocksDB Performance
    - XFS, F2FS (Block)
    - F2FS /w zone support (ZNS)
    - RocksDB /w ZenFS (ZNS)

Feature summary of the evaluated SSDs

SSD Interface	Block	Block	Zoned
Media Capacity	2TiB	2TiB	2TiB
Host Capacity	1.92TB	1.6TB	2TB
Over-provisioning	7%	28%	0%
Placement Type	None	None	Zones
Max Active Zones	N/A	N/A	14
Zone Size	N/A	N/A	2048 MiB
Zone Capacity	N/A	N/A	1077MiB

Raw I/O Characteristics

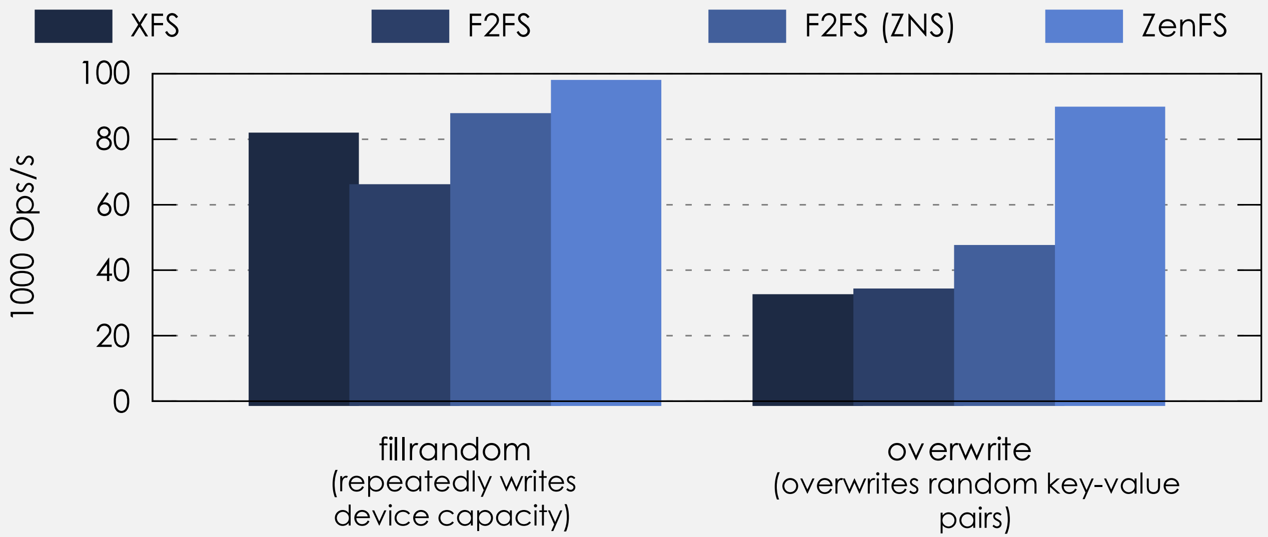
Improving Write Throughput & Read Latency



RocksDB: Writes

Double the throughput over 28% OP SSDs

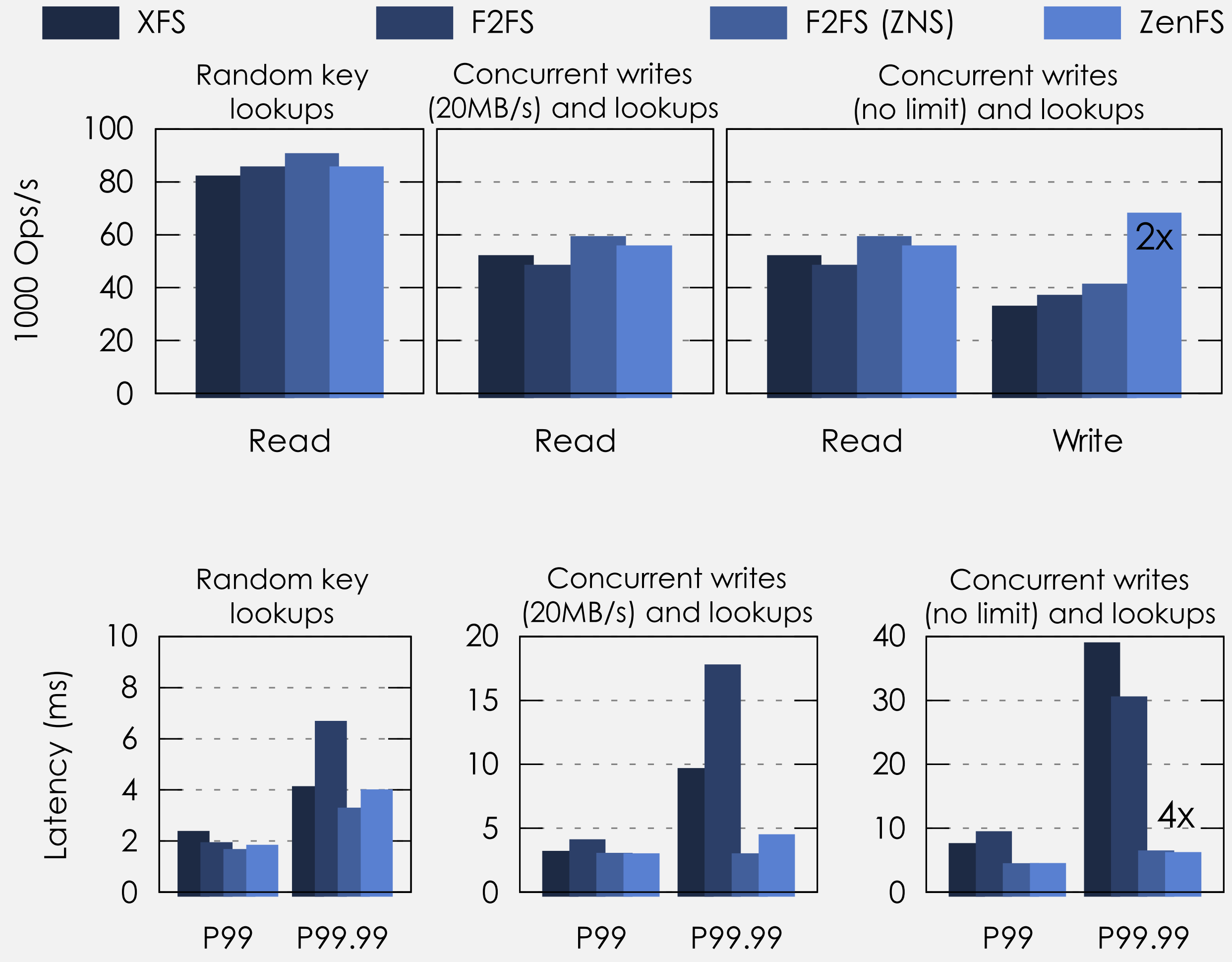
- XFS and F2FS overprovisioning at 28%
- Fillrandom begins at clean state. Overhead visible when overwriting
- Write Amplification for ZNS is 1.0x
  - XFS at 2.0x and vanilla F2FS at 2.4x



RocksDB: Reads and Writes

Improving Writes and Tail Latencies

- When writes are limited to 20MB/s
  - Only ZNS achieves write goal, others **15%** lower
- When writes are not limited
  - ZNS SSD write throughput **2x** higher
- RocksDB on ZNS achieves up to **4x** lower 99.99th-percentile read latency, **2x** write throughput



Summary

- ZNS SSDs enable **higher performance and lower-cost-per-byte flash-based SSDs**.
- By shifting responsibilities for managing data placement within erase blocks from FTLs to host software, ZNS **eliminates the need for fine-grained indirection table, garbage collection, and media over-provisioning.**
- We find that the 99.9th-percentile random-read latency for our **RocksDB /v ZenFS is at least 2-4x lower** on a ZNS SSD compared to a block-interface SSD, and the **write throughput is 2x higher**.
- All work is upstream and available through the appropriate open-source projects.

Thank You

Western Digital.
Carnegie Mellon University
PennState