Towards an Unwritten Contract of Intel Optane SSD

Kan Wu, Andrea Arpaci-Dusseau, and Remzi Arpaci-Dusseau

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Outline

Background & Motivation

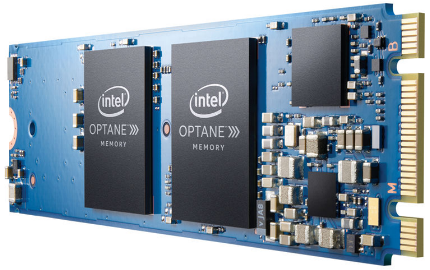
An Unwritten Contract of Intel Optane SSD

Implications from the Contract

Discussion

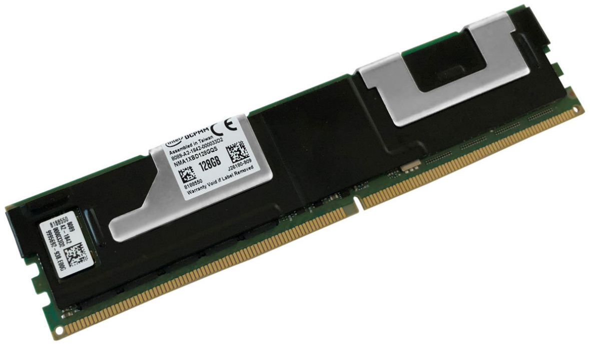
Background

New Non-volatile Memory technologies provide unprecedented performance for persistent storage



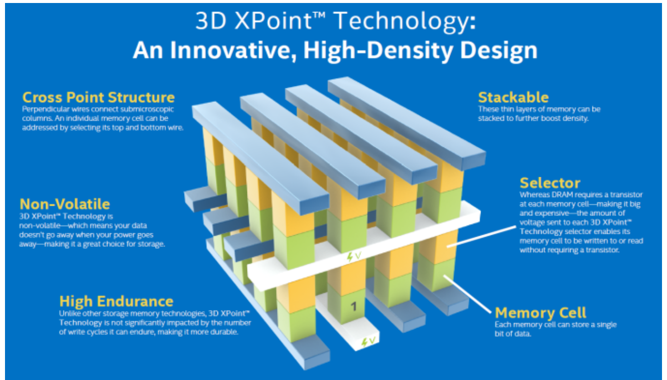
Intel Optane Memory

Intel Optane SSD



Intel Optane DC Persistent Memory

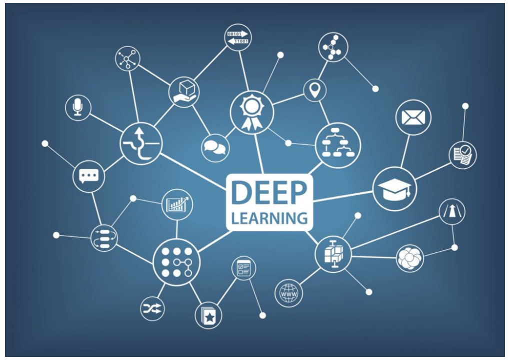
3D Xpoint Memory



Background: Intel Optane SSD

The most cost-effective and widely available option

Intel Optane SSD



Motivation

Intel Optane SSD

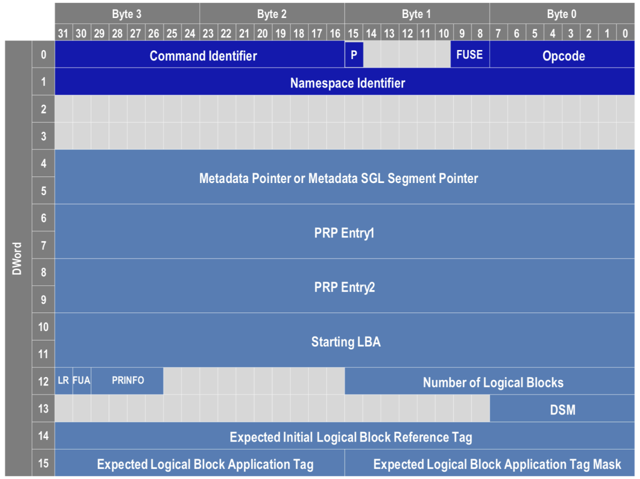
How to use it effectively?

How to use a device effectively?

The Written Contract

Register	7	6	5	4	3	2	1	0
Features(7:0)	Sector Count 7:0							
Features(15:8)	Sector Count 15:8							
Count(7:0)	TAG					Reserved		
Count(15:8)	PRIO(1:0)		Reserved					
LBA(7:0)	LBA 7:0							
LBA(31:24)	LBA 31:24							
LBA(15:8)	LBA 15:8							
LBA(39:32)	LBA 39:32							
LBA(23:16	LBA 23:16							
LBA(47:40)	LBA 47:40							
ICC	ICC(7:0)							
Device	FUA	1	Res	0	Reserved			
Command	60h							

Figure 205 – READ FPDMA QUEUED command definition



ATA EXPRESS®

PCI EXPRESS®

The Unwritten Contract

- ✓ HDD: (Steven et al.)
  "Sequential accesses are the best, much better than non-sequential."
- ✓ SSD : (Jun et al.)
  - Large Request Scale
  - Locality
  - Grouping by Death Time
  - …

Intel Optane SSD

An Unwritten Contract of Intel Optane SSD

An Unwritten Contract of Intel Optane SSD

Immediate performance: (6)

- Access with Low Request Scale Rule
- Random Access is OK Rule
- Avoid Crowded Accesses Rule
- Control Overall Load Rule
- Avoid Tiny Accesses Rule
- Issue 4KB Aligned Requests Rule

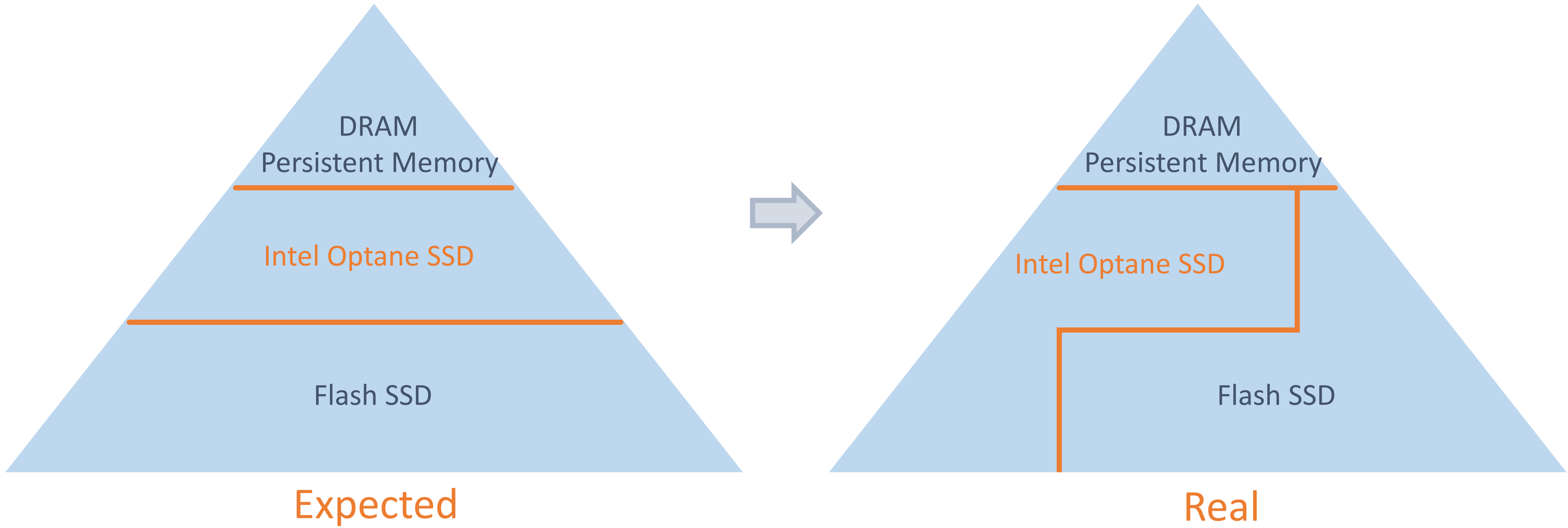
Sustainable performance: (1)

- Forget Garbage Collection Rule

An Unwritten Contract of Intel Optane SSD

Rule 1: Access with Low Request Scale

Rule 4: Control Overall Load



Storage Hierarchy

Rule 1: Access with Low Request Scale

Motivation:

- 3D XPoint Memory > NAND Flash (up to x1000 lower latency[2])
- Does Optane SSD always perform better than Flash SSD?

What is the rule?

- "To obtain low latency, Optane SSD users should issue small requests and maintain a small number of outstanding IOs"

Note: > stands for "is better than"

Rule 1: Access with Low Request Scale

Optane SSD vs. Samsung 970 Pro:

- What we do:
  - Random read-only / write-only workloads
  - Each workload has two variables: Request Size and Queue Depth

Rule 1: Access with Low Request Scale

Optane SSD vs. Samsung 970 Pro:

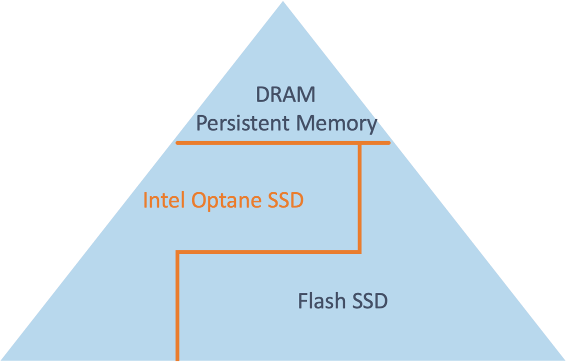
➡ What we observe:

- Similar Write Results (in paper)
- Optane SSD > / = / < Flash SSD

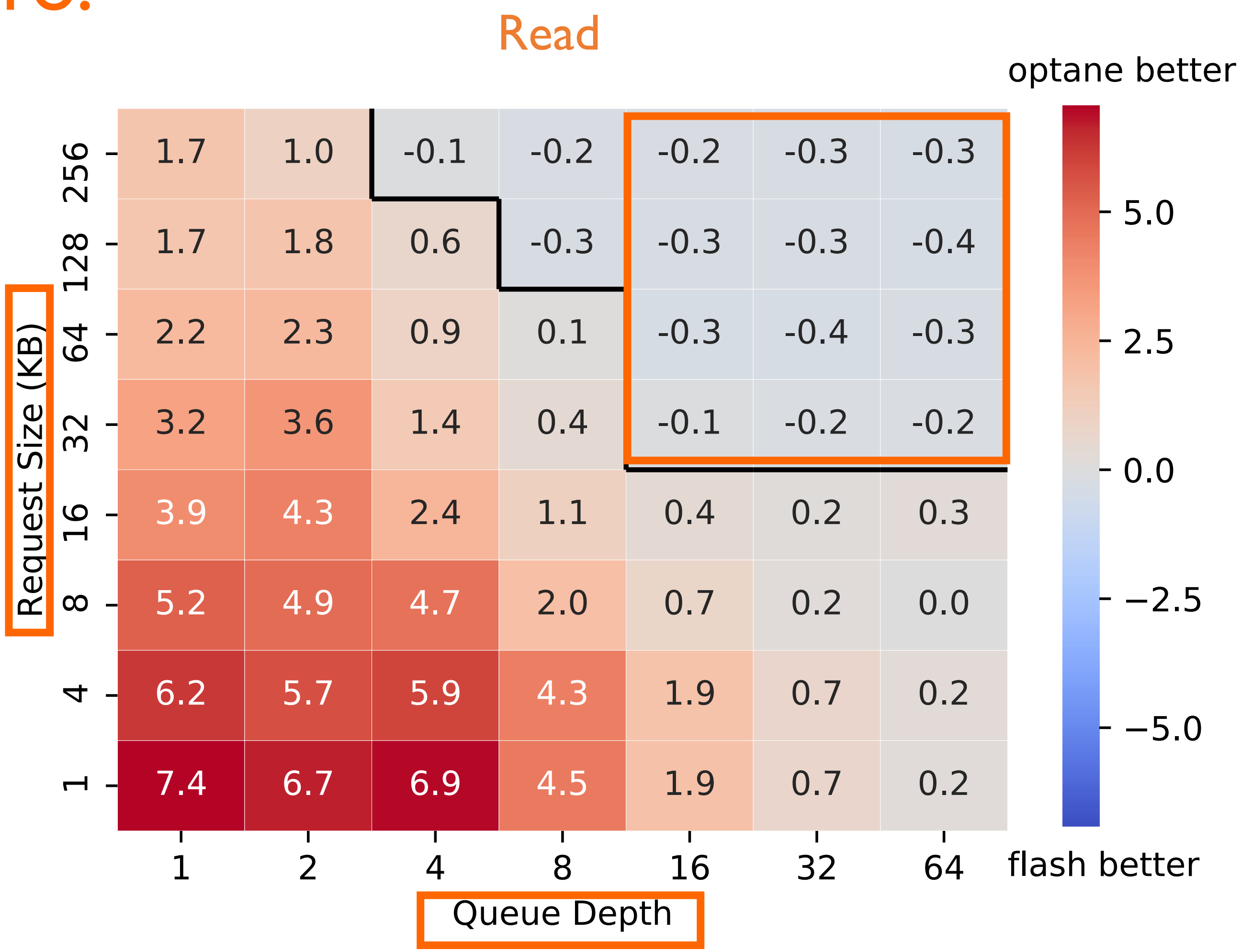
$$|T| = \frac{L_{higher} - L_{lower}}{L_{lower}}$$

T > 0 when Optane has smaller latency

T < 0 when Flash has smaller latency



Real

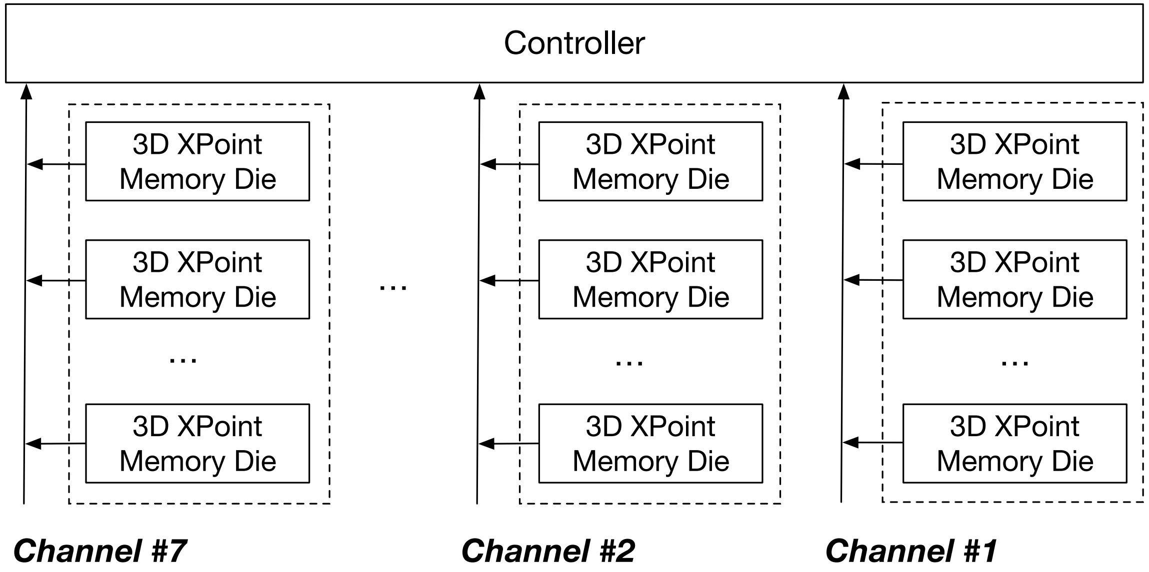


Avg Latency of random workloads, Optane vs. Flash

Rule 1: Access with Low Request Scale

Uncover the internals of the Optane SSD

- Internal parallelism
  dictates its behavior when serving workloads with high request scale
  - Optane SSD: RAID-like organization of memory dies
  - The interleaving degree (#channels)



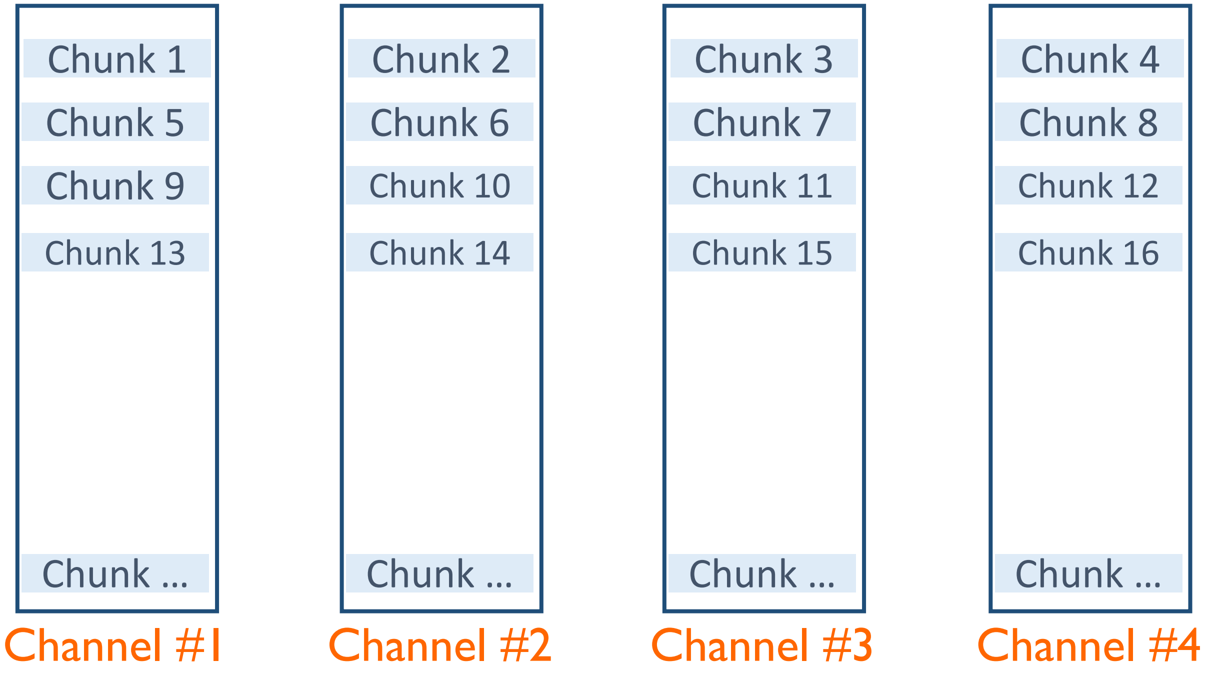
RAID-like Architecture in Optane SSD

Rule 1: Access with Low Request Scale

Detecting Interleaving Degree of Optane SSD:

- What we do: (Feng et al.(HPCA 11), Timothy et al.(ASPLOS 04))
  - Precondition: sequential writes => evenly distribute
  - 4KB (chunk) read stream with stride S (S = distance between consecutive chunks)

    Different S => Different throughput



Chunk Layout

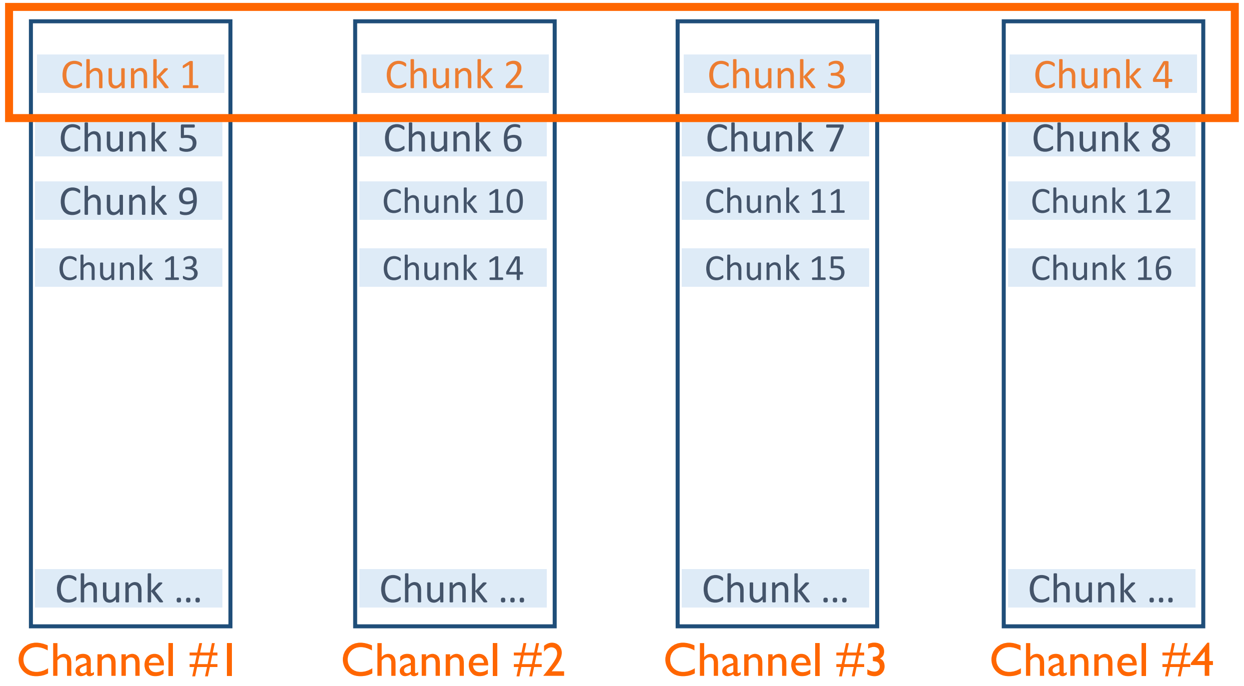
Rule 1: Access with Low Request Scale

Detecting Interleaving Degree of Optane SSD:

- What we do:
  - Precondition: sequential writes
  - 4KB (chunk) read stream with stride S (S = distance between consecutive chunks)

S = 0 (chunk), QD = 4

Performance ☺



Chunk Layout

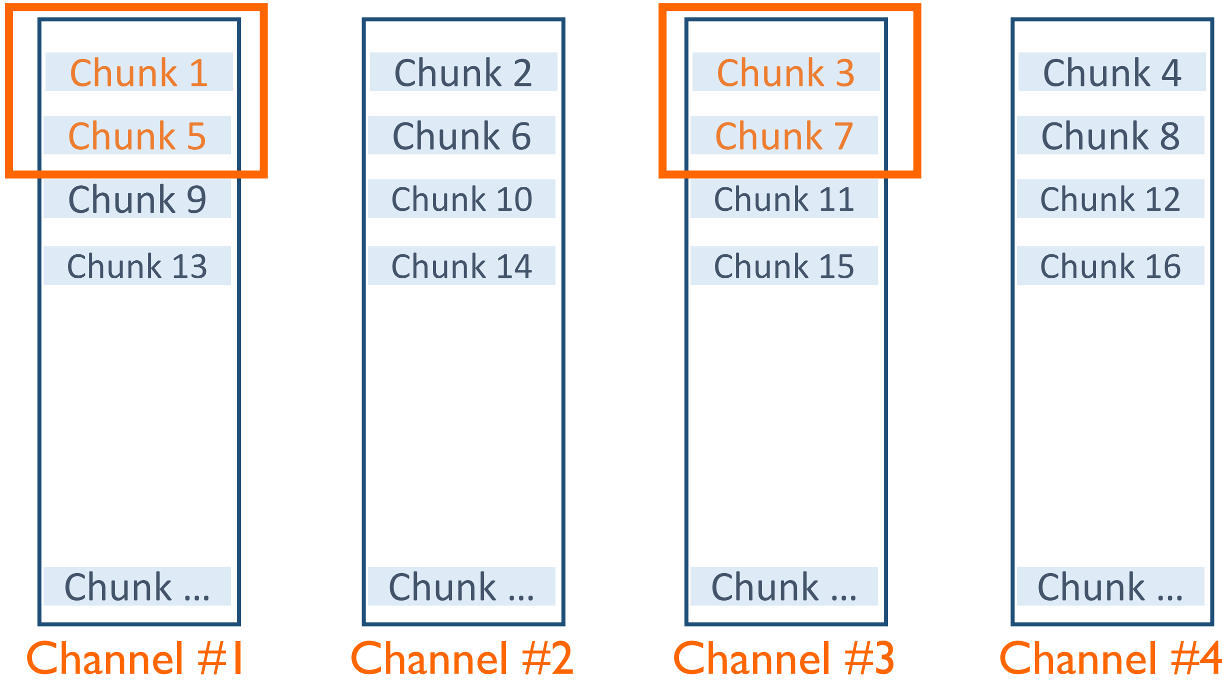
Rule 1: Access with Low Request Scale

Detecting Interleaving Degree of Optane SSD:

- What we do:
  - Precondition: sequential writes
  - 4KB (chunk) read stream with stride S (S = distance between consecutive chunks)

S = 1 (chunk), QD = 4

Performance 



Chunk Layout

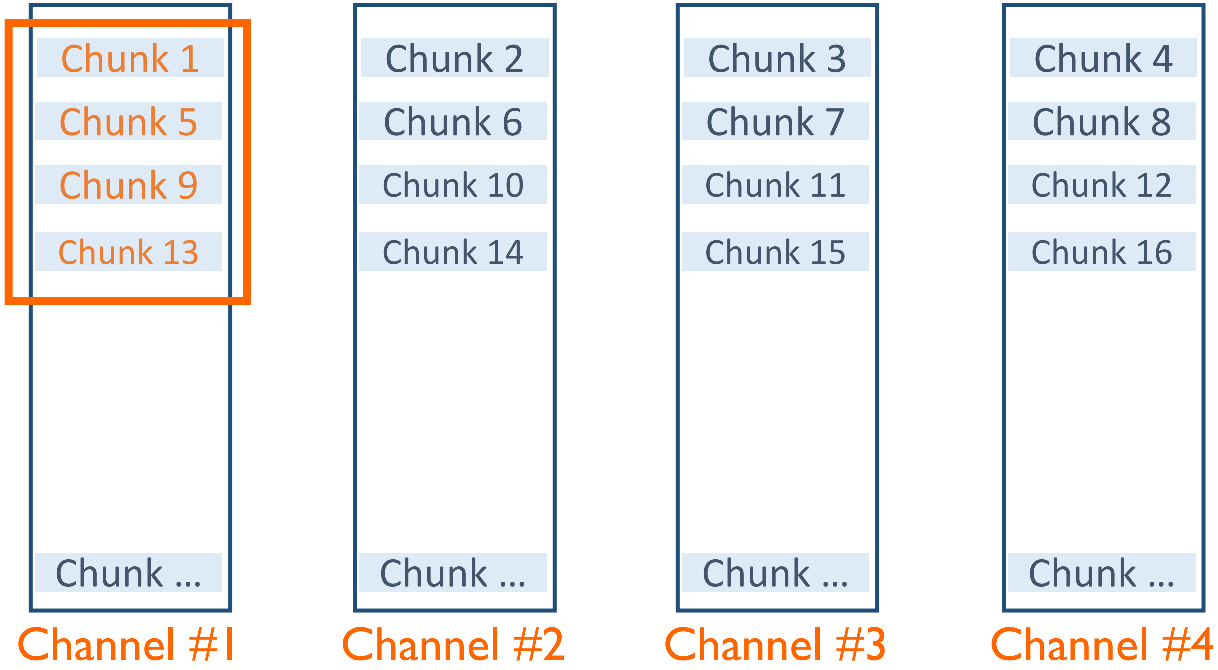
Rule 1: Access with Low Request Scale

Detecting Interleaving Degree of Optane SSD:

- What we do:
  - Precondition: sequential writes
  - 4KB (chunk) read stream with stride S (S = distance between consecutive chunks)

S = 3 (chunk), QD = 4

Performance



Chunk Layout

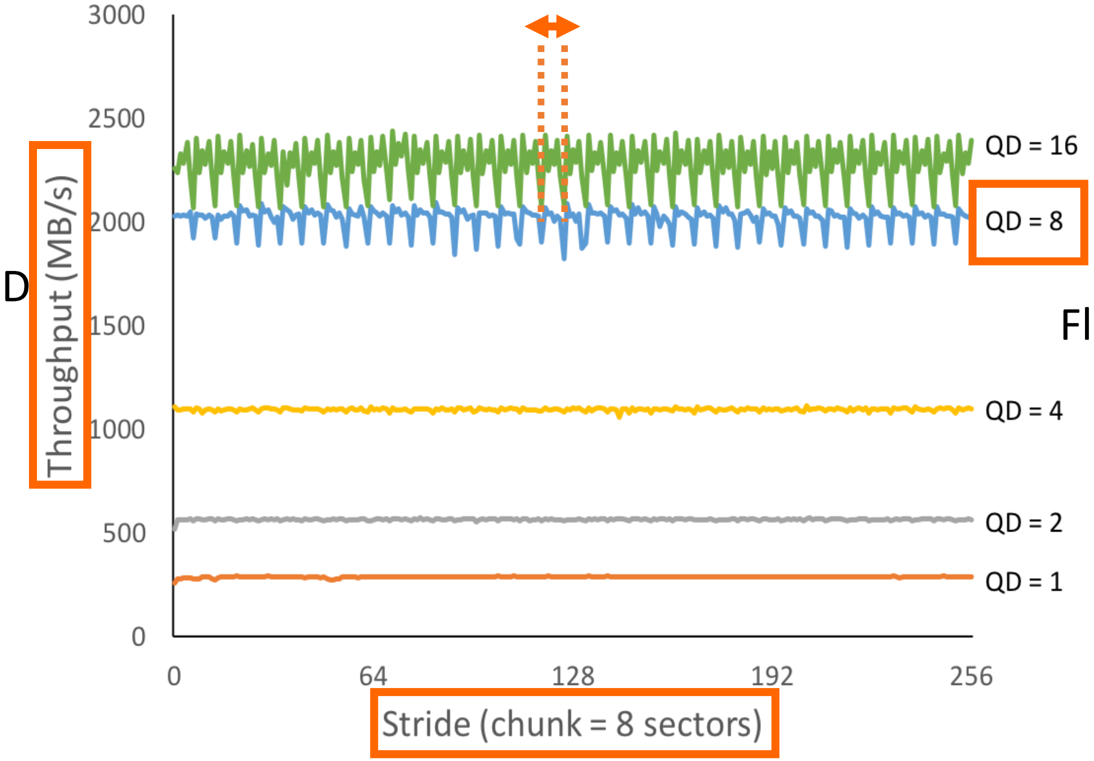
Rule 1: Access with Low Request Scale

Detecting Interleaving Degree of Optane SSD:

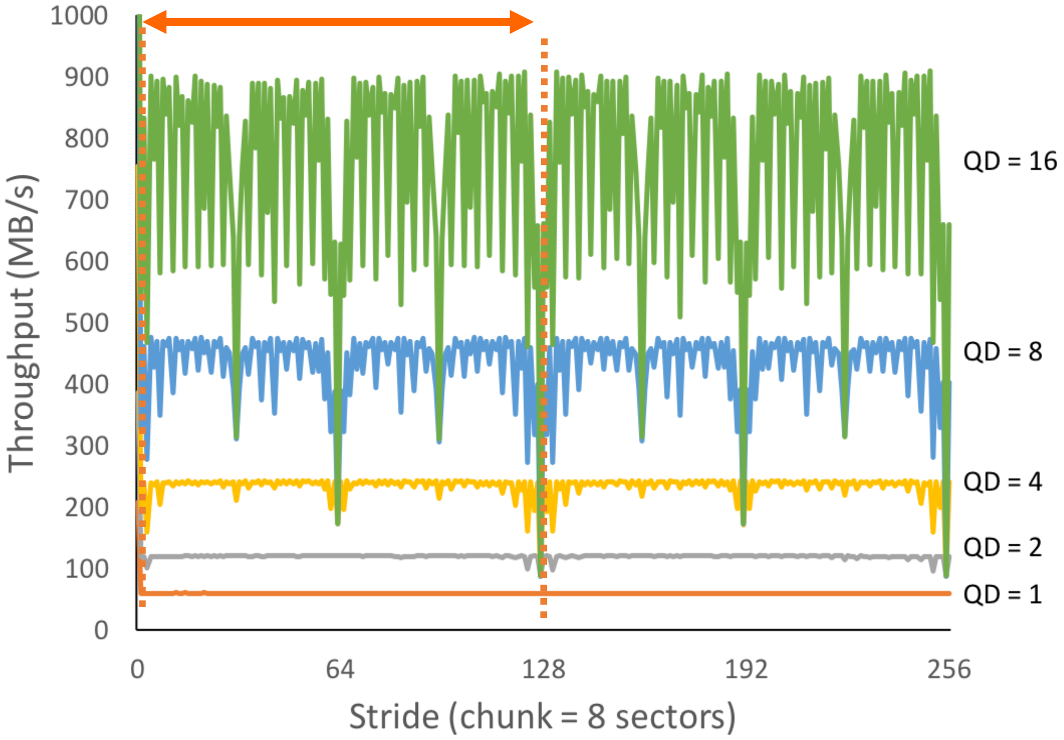
- What we observe:
  - Intuition:

    Distance between the lowest dips in each line => the interleaving degree

Optane SSD



Flash SSD

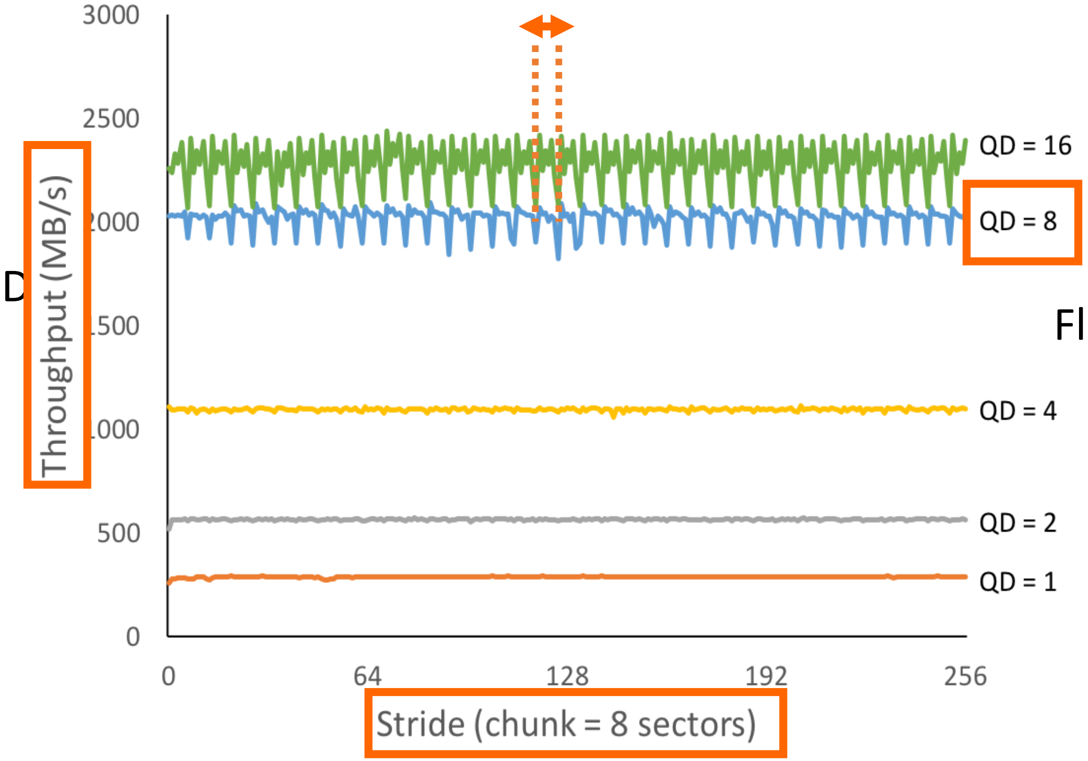


Rule 1: Access with Low Request Scale

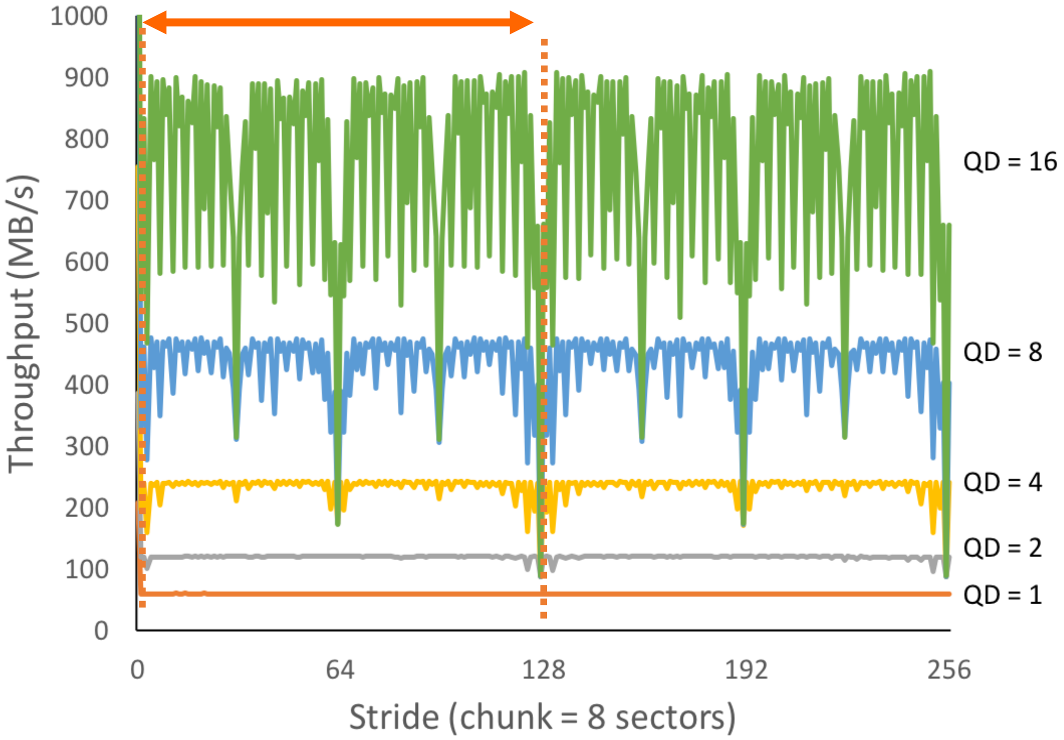
Detecting Interleaving Degree of Optane SSD:

- What we observe:
  - Internal parallelism: Optane SSD (7) << Flash SSD (128)
  - Explains Optane SSD's worse behavior serving workloads with high request scale

Optane SSD



Flash SSD



Rule 4: Control Overall Load

Motivation:

- Optane SSD facing mixed (read and write) workloads?

What is the rule?

- Distinctive from Flash SSD!
- "To achieve optimal latency from Optane SSD, the client must control the overall load of both reads and writes."

Rule 4: Control Overall Load

Experiments: Optane SSD serving mixed workloads

- What we do?
  - Random 4KB requests (reads + writes, QD=64), varying write%

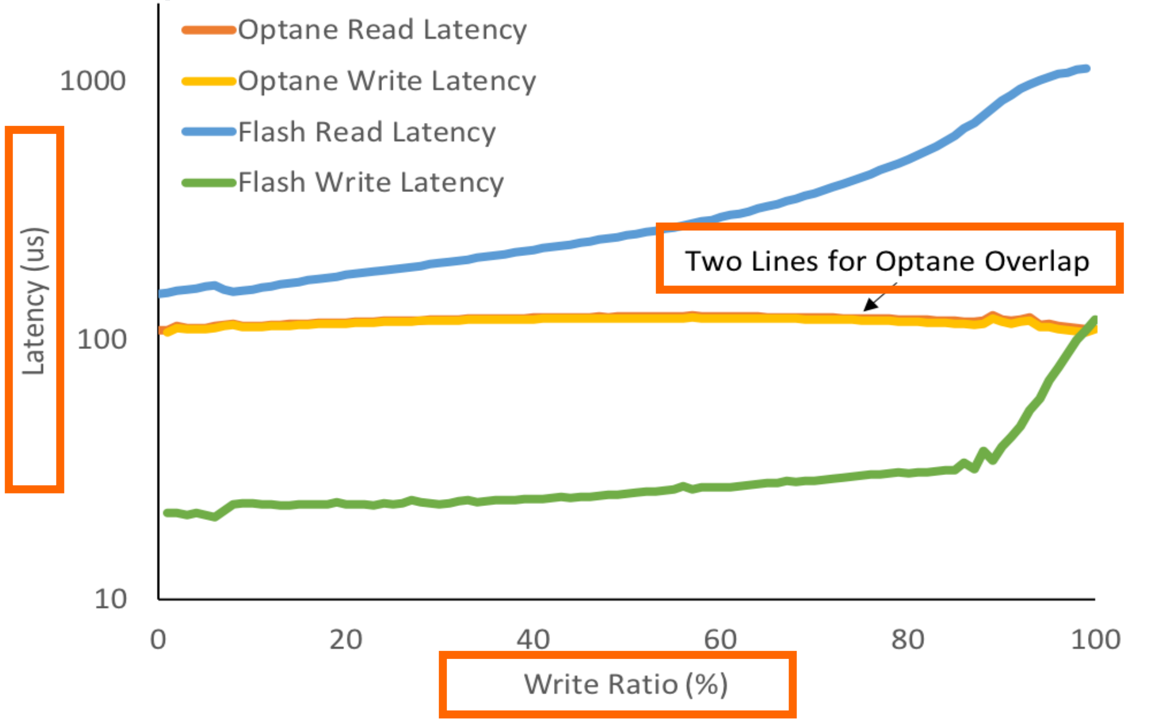
Rule 4: Control Overall Load

Experiments: Optane SSD serving mixed workloads

- What we observe?
  - Optane SSD (throughput yield similar results)

    Reads = Writes;

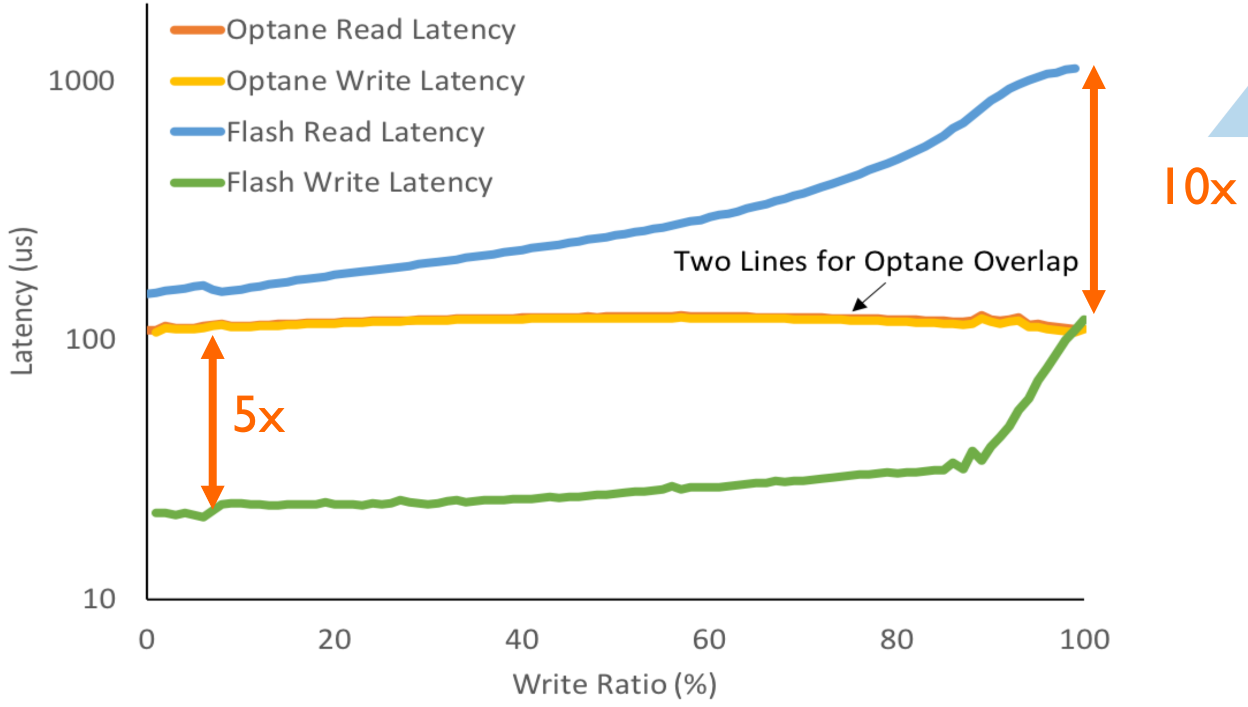
    Latency is related to the overall load, not to write%

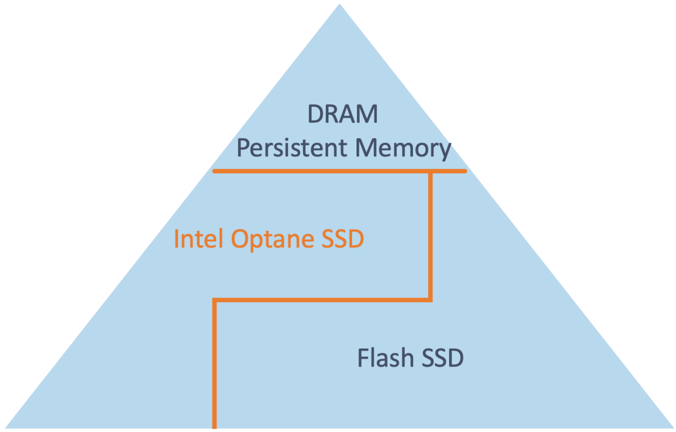


Rule 4: Control Overall Load

Experiments: Optane SSD serving mixed workloads

- What we observe?
  - Optane SSD vs. Flash SSD: distinctive behavior



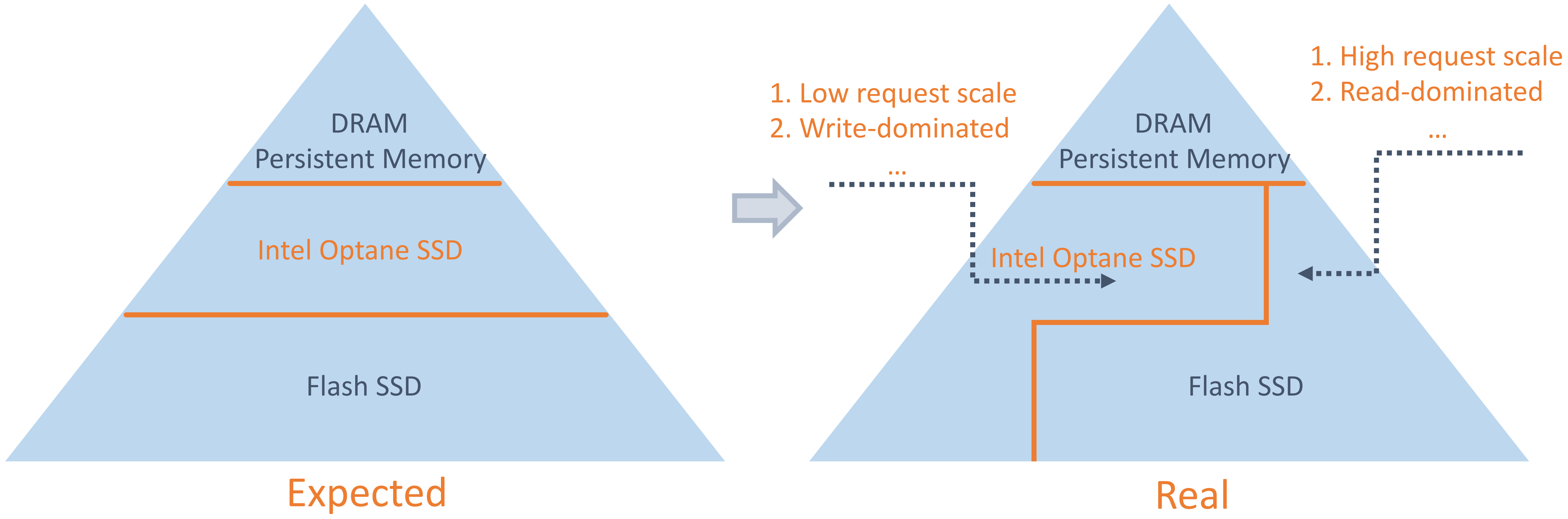


Real

An Unwritten Contract of Intel Optane SSD

Rule 1: Access with Low Request Scale

Rule 4: Control Overall Load



Storage Hierarchy

Other Rules…

Rule 2: Random Access is OK

Motivation:

- Optane SSD: Random vs. Sequential?

What is the rule?

- "Optane SSD is a random access block device, where clients can observe the same performance for random and sequential workloads"

Rule 3, Rule 5, Rule 6

Motivation:

- Byte-addressability of 3D XPoint Memory
  => Efficient tiny accesses to Optane SSD?

What is the rule?

- Rule 3: Avoid Crowded Accesses (4.6x)
  - Clients of Optane SSD should never issue parallel accesses to a single chunk (4KB)
- Rule 5: Avoid Tiny Accesses (5x)
  - To exploit bandwidth of the SSD, the client must not issue requests less than 4KB.
- Rule 6: Issue 4KB Aligned Requests (1.2x)
  - To achieve the best latency, requests issued to Optane SSD should always align to eight sectors.

Rule 7: Forget Garbage Collection

Motivation:

- Optane SSD maintains MAX throughput for sustained writes
- Insights of this?
  Optane: LBA-based mapping vs. Flash : written-order based

What is the rule?

- There is no need to worry about garbage collection in Optane SSD.

An Unwritten Contract of Intel Optane SSD

Immediate performance: (6)

- ➡ Access with Low Request Scale Rule
- ➡ Random Access is OK Rule
- ➡ Avoid Crowded Accesses Rule
- ➡ Control Overall Load Rule
- ➡ Avoid Tiny Accesses Rule
- ➡ Issue 4KB Aligned Requests Rule

(Feedback)
More interesting questions to answer?

Sustainable performance: (1)

- ➡ Forget Garbage Collection Rule

Implications from the Contract

Users design systems for Optane SSD

- Random Access is Okay.
  - Restructuring of external data structures

    Much effort: random -> sequential accesses ; Less necessary

    E.g. Single Machine Graph Processing Systems (Nima Elyasi et al. FAST'19)
  - Applications which behave poorly on Flash thus become potential consumers
- No Crowded Accesses, No Tiny Access, and Alignment rule
  - Pitfalls that fine-grained external data structure must be aware

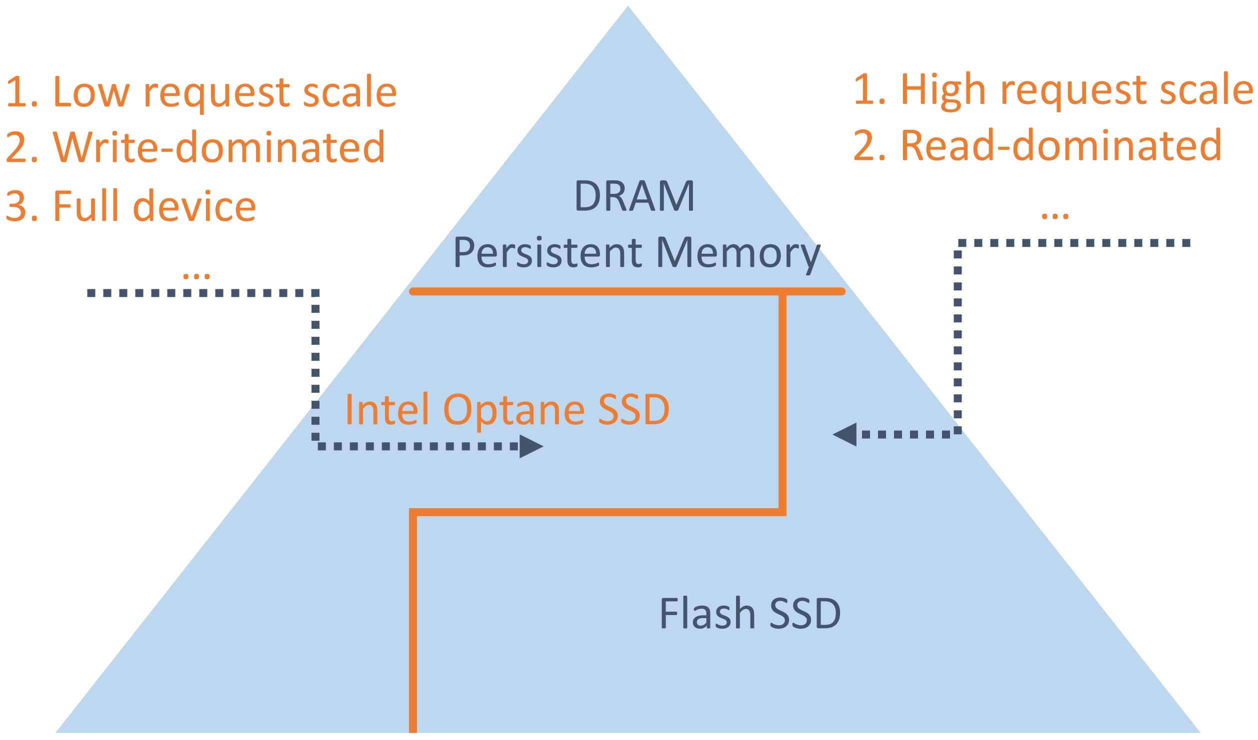
Implications from the Contract

Users who combine Flash and Optane in a hybrid setting

- ➡ Access with Low Request Scale Rule
- ➡ Control Overall Load Rule
- ➡ Forget Garbage Collection Rule

Classic concept of hierarchy need to be reconsidered

- ➡ How to split accesses?



Real

Conclusion

We analyze a NVM-based block device: the Intel Optane SSD

We formalize the rules that Optane SSD users should follow

Implications from this Contract

Interesting thing we can do with the contract?

Acknowledgement

Thanks!

Questions?