Dynamic Read Retry Method

——Achieving Near-Zero Read Retry for 3D NAND Flash Memory

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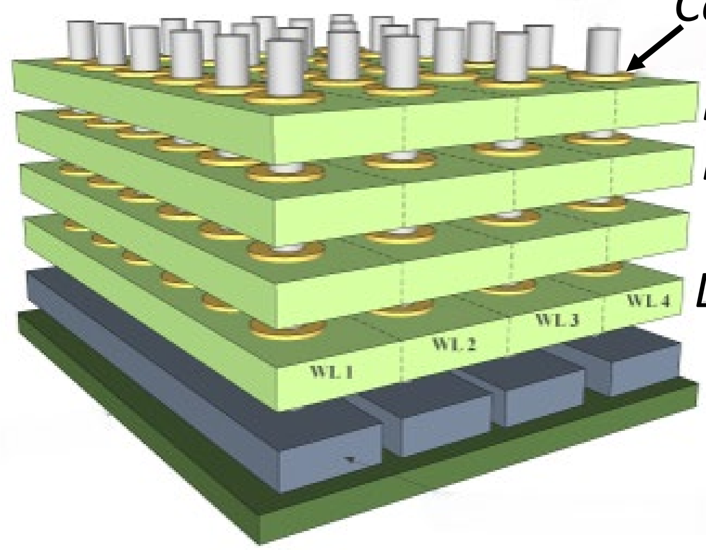
FMS the Future of Memory and Storage

3D NAND Flash Memory

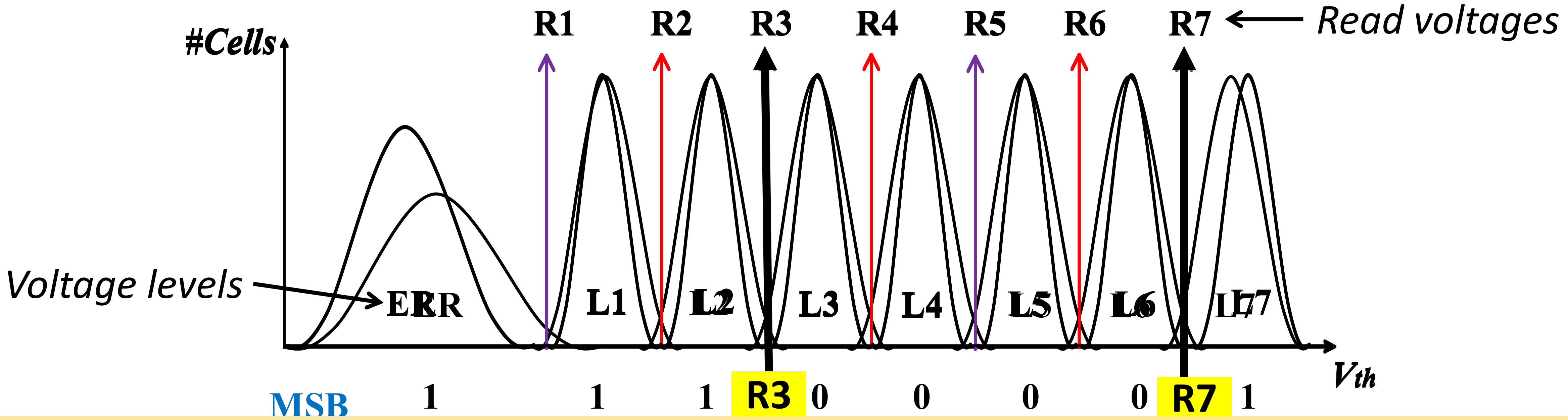
- **Everywhere today: from mobile to data centers**
  - By 2025, 3D NAND will consume over 95% of all NAND flash memory.
- **3D NAND Structure: high-density, large-capacity**
  - Stacked layers increase
  - Multiple bits per cell technique, such as TLC (triple-level-cell)

3D NAND Structure



Page Reading of TLC flash

- During page reading, a set of read voltages is added.
- Voltage levels are overlapped when flash ages or are subject to retention time and disturbance.



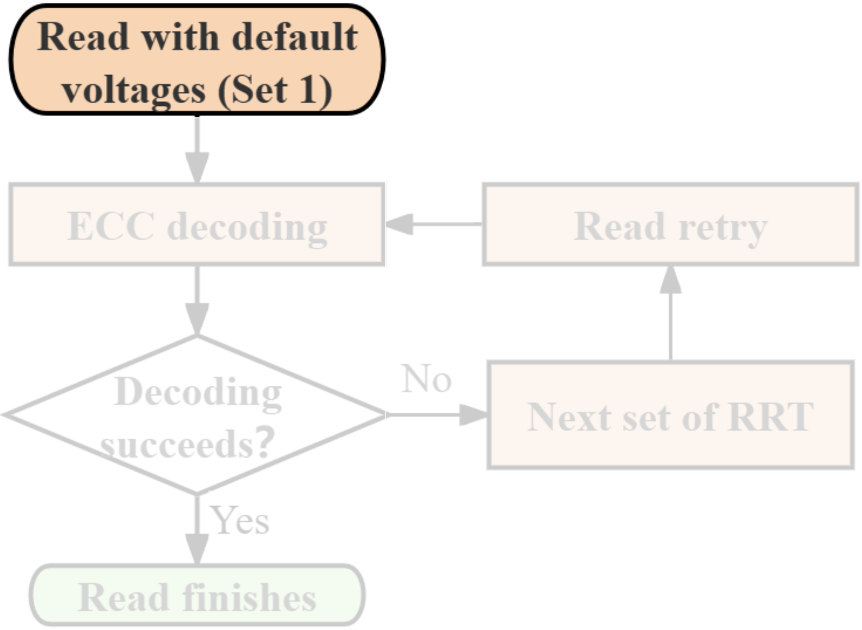
Read Retry Issue:

overlapped voltage levels require read retries for error correction.

Traditional Read Retry

- **Read Retry Table (RRT)**
  - Providing **several sets of retry offsets**
  - Each ***Set*** represents a normalized value of the read voltage.

CASE	R1	R2	R3	R4	R5	R6	R7
Set 1	0	0	0	0	0	0	0
Set 2	-3	6	8	10	9	4	8
Set 3	-16	-6	-5	-6	-6	1	8
Set 4	5	13	12	16	14	14	14
Set 5	-22	-11	-8	-9	-8	-2	-2
Set 6	6	2	4	0	3	-4	-8
Set 7	-12	-12	-11	-19	-16	-12	-10
Set 8	10	1	3	3	5	8	12

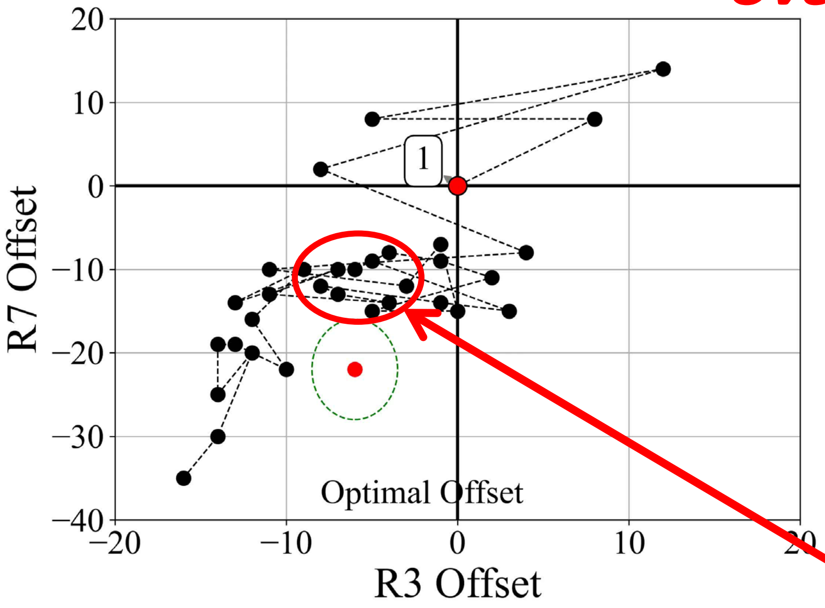


- Each read retry requires a **new page read** operation.

More read retries cause poor read performance.

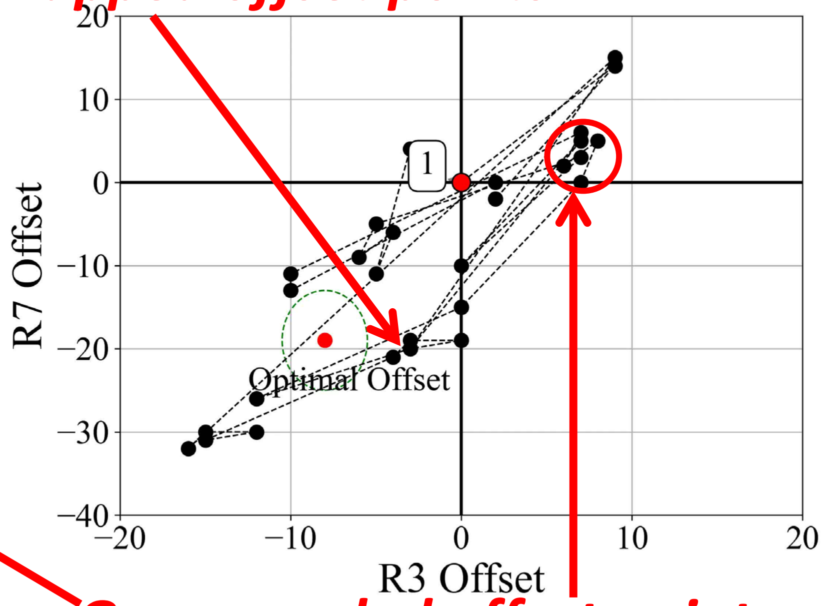
Traditional Read Retry under Latest Flash Chips

Flash A



Flash B

Overlapped offset points



Flash C

Overcrowded offset points

Unreasonable retry order

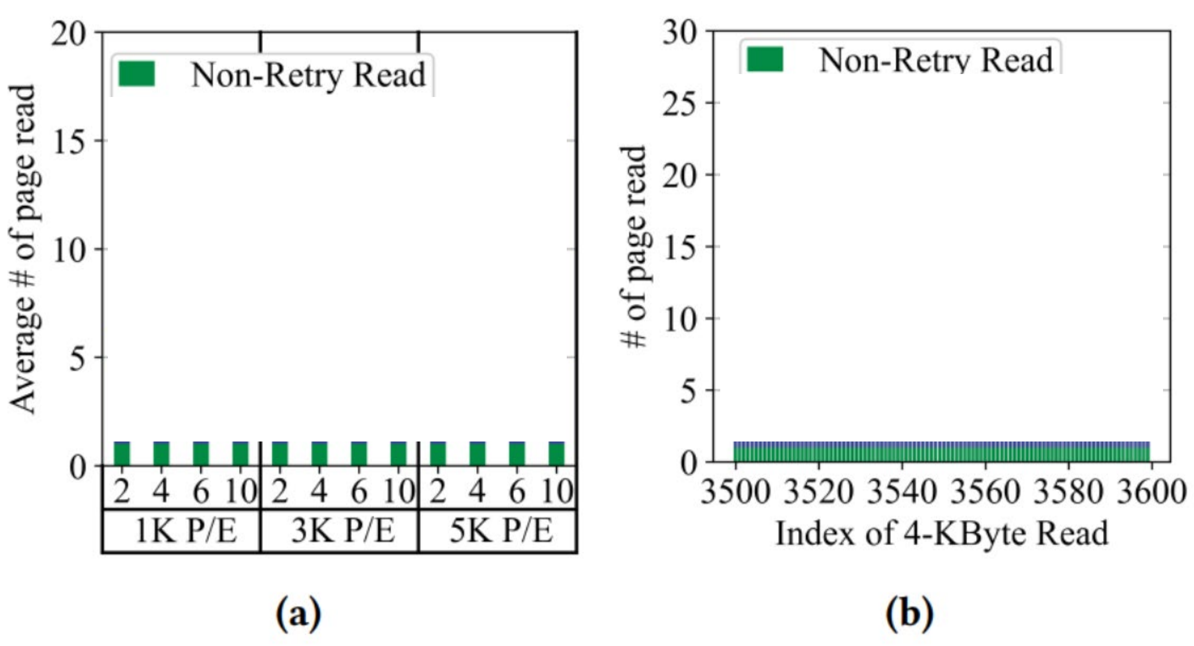
Black points: *retry offset point of the R3-R7 pair*

Red point: *optimal offset point of a codeword*

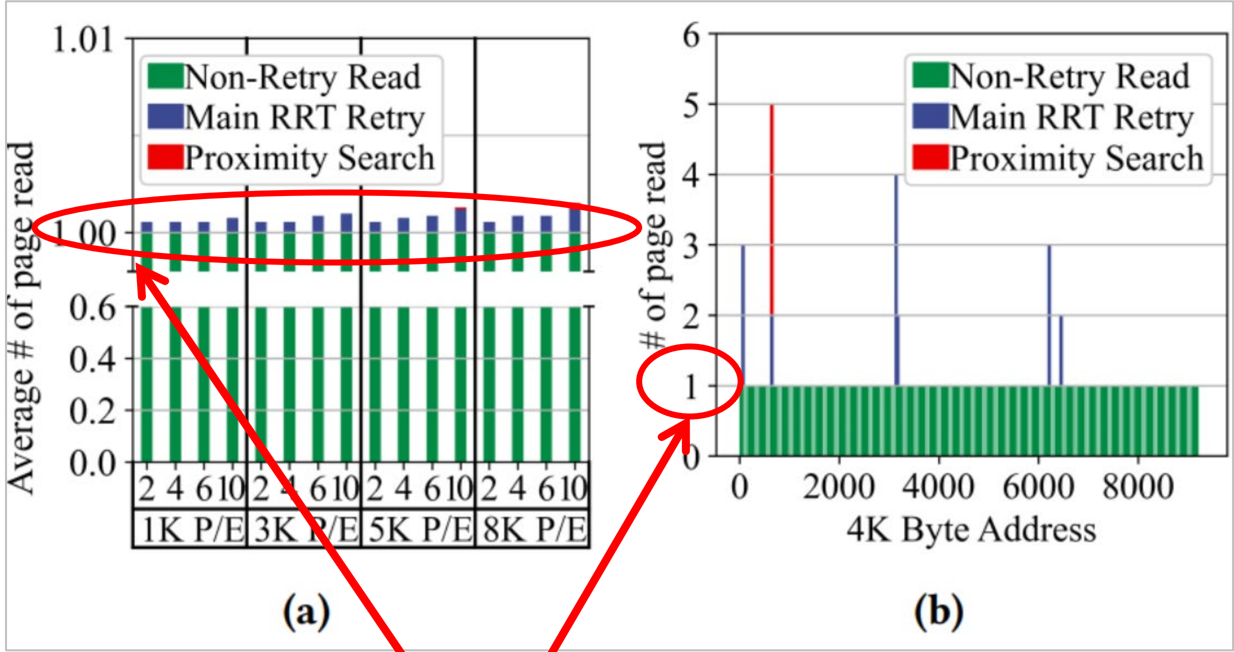
Green dotted circle: *reliable read retry area*

TRRM vs DRRM: The Number of Read Retry

TRRM (traditional read retry method)



DRRM (our proposal)



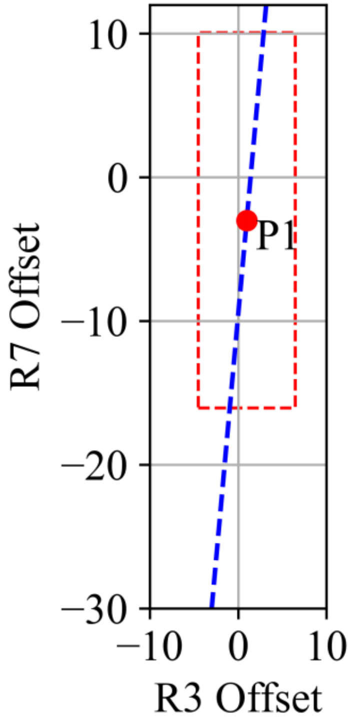
- ***Dozens of read retries***, **greatly reduce the read performance*!!***
- **Rigid, sequential retry method**

- **Near-*zero* read retry**
- **Dynamic read retry method**

DRRM Technique #1: A Tailored RRT

How to decide the offset distance?

- **50%** valid window overlap between two neighboring offset points



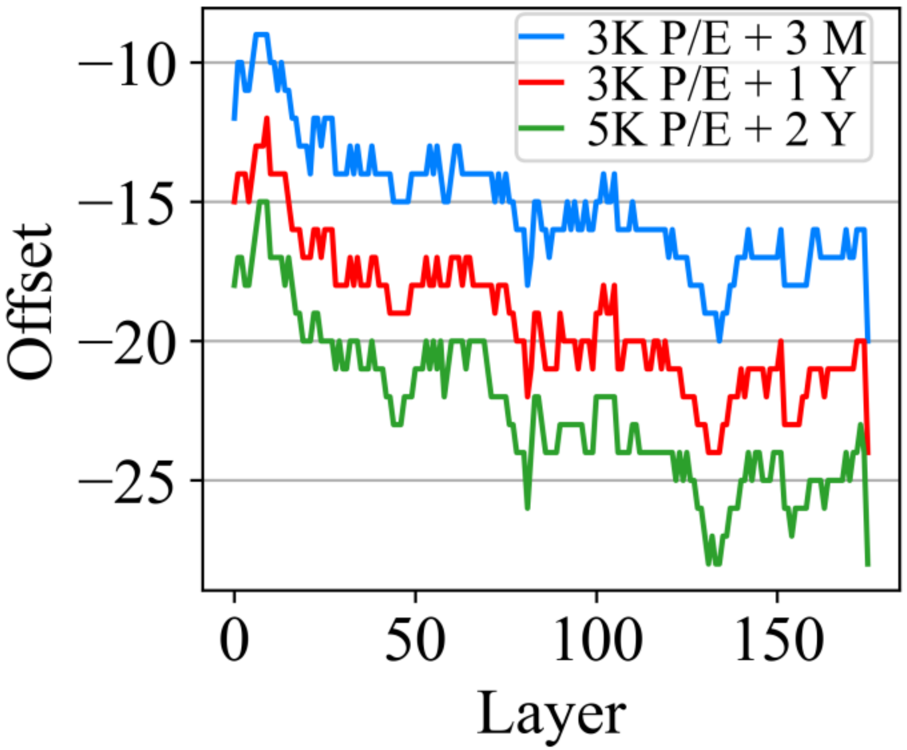
(a) Step 1

A Tailored RRT

CASE	LSB		CSB			MSB	
	R1	R5	R2	R4	R6	R3	R7
Set 1	1	0	1	-2	-2	0	-3
Set 2	4	-5	2	-5	-10	-1	-13
Set 3	6	-9	2	-7	-15	-2	-20
Set 4	9	-13	2	-8	-19	-2	-25
Set 5	11	-17	2	-10	-23	-3	-29
Set 6	14	-21	2	-12	-27	-4	-33
Set 7	16	-25	2	-13	-31	-4	-37
Set 8	19	-29	3	-15	-35	-5	-41

DRRM Technique #2: An OVD Table

How to eliminate layer variations of a 3D block?



- Read offset varies among layers of a 3D block, making a set of read offsets can only cover a few layers.
- Optimal read offset variations are relatively consistent.

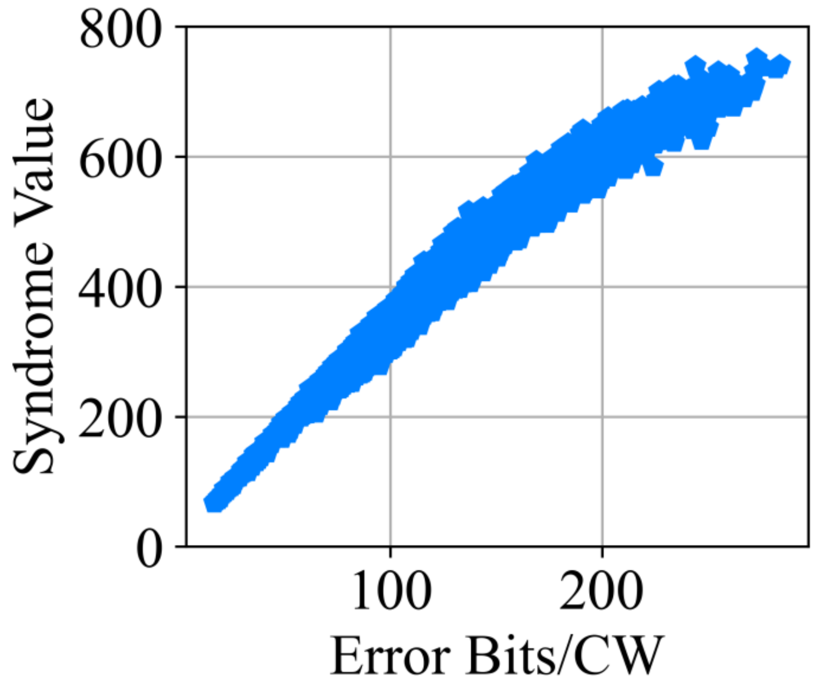
$$Retry(Ri) = MRRT(Ri) + OVD(Ri)$$

Optimal Voltage Difference (OVD) table

- Recording the ***deviation*** of each layer's optimal read offset
- Making a set of read offsets covers all layers of the same block

Technique #3: A Proximity-Search

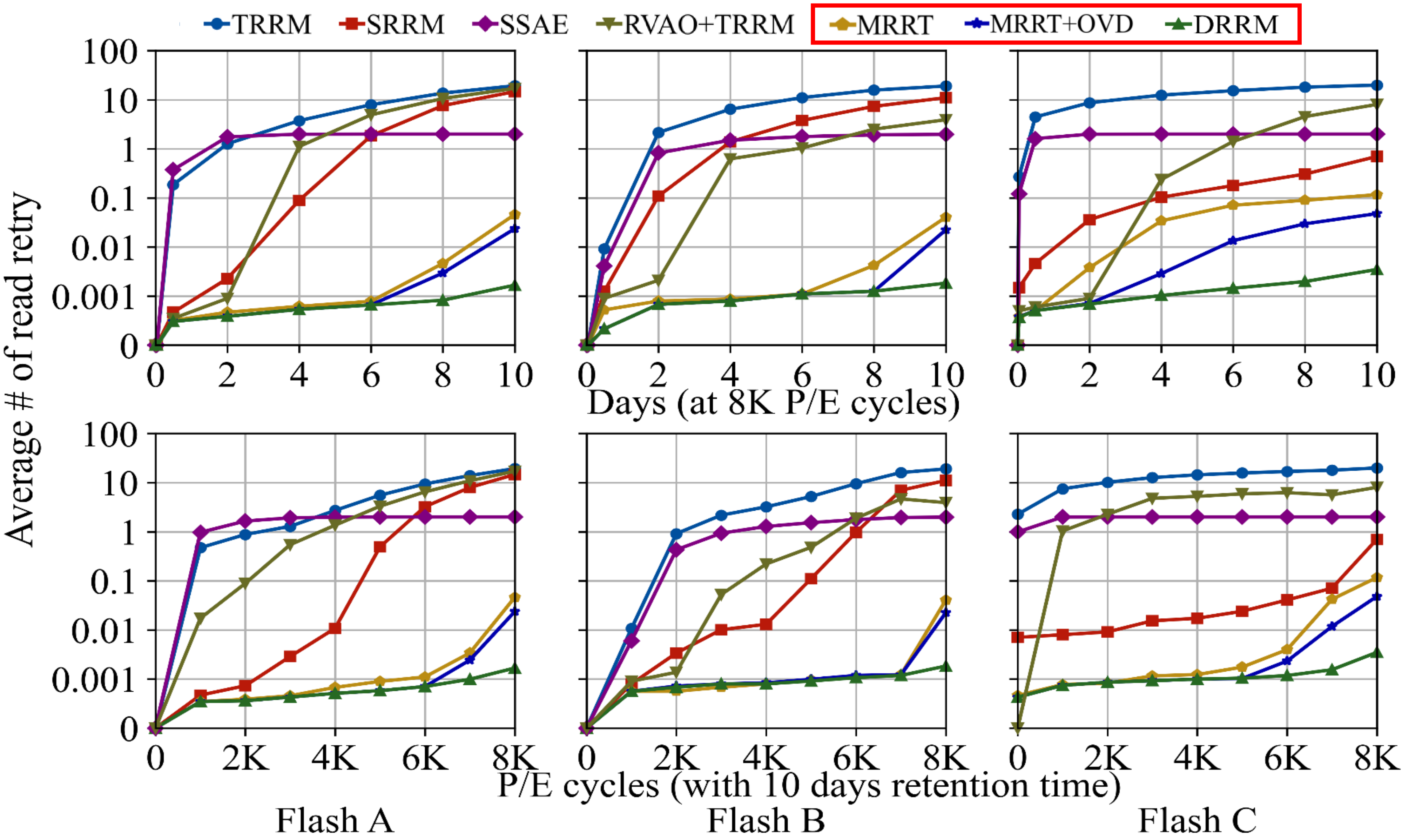
How to apply the read retry table?



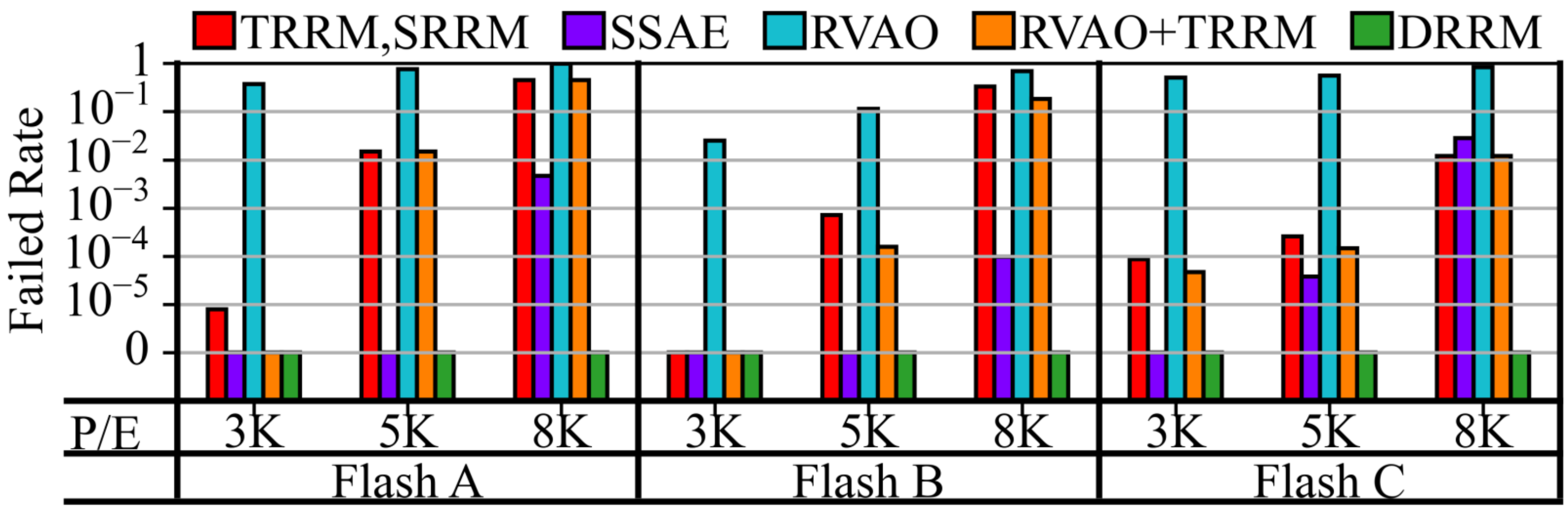
- **Syndrome value** of LDPC (Low-Density Parity-Check code) is nearly **linear** with bit errors.
- **Proximity-Search** covers corner cases by using the syndrome value.

$$Retry(Ri) = MRRT(Ri) + OVD(Ri) + PSO(Ri)$$

Performance Evaluation: Synthetic Workloads



Reliability Analysis



The failure rate of read retry based on LDPC hard decoding, observed after retention of **10 days at 85℃**

- Compared methods show poor reliability, certain retry techniques reach the failure rate over **40%**.
- DRRM ensures a ***zero failure rate*** for ***up to 8K P/E cycles***.

Thanks
Q&A

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Achieving Near-Zero Read Retry for 3D NAND Flash Memory

- **Min Ye, Qiao Li, Yina Lv**, Jie Zhang, Tianyu Ren,
- Daniel Wen, Tei-Wei Kuo, Chun Jason Xue