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Intra-page Cache Update in SLC Mode with Partial Programming in High Density SSDs

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OUTLINE

- **Background and motivation**
- Design
- Evaluation and analysis
- Conclusion

Background(1/2)

- NAND Flash memory based Solid State Drives (SSDs) have been widely applied in multiple storage devices.

USB flash disk


PC

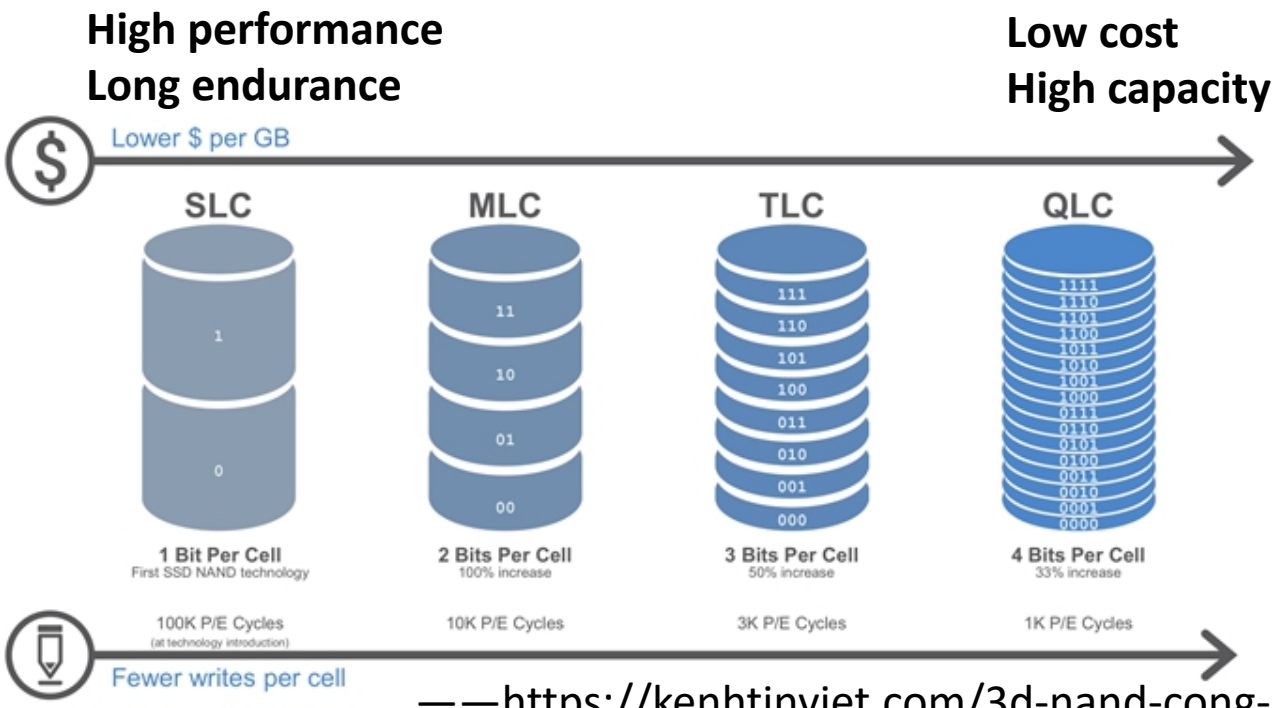
SSD


Data center

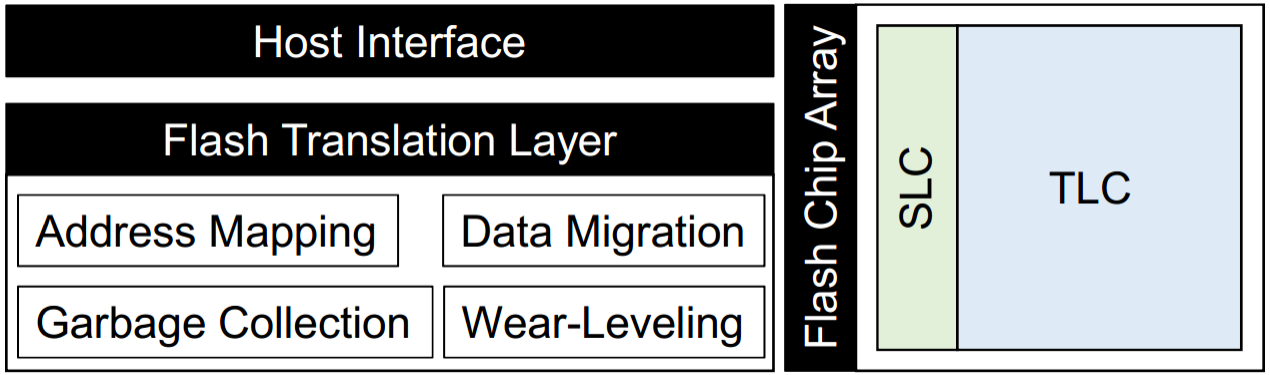
- High access performance, low power consumption, random access, et al.

Background(2/2)

- High density SSDs reduce the price cost, becoming the main-stream storage device.
  - Performance and lifetime reduce
- SLC(Single-level cell)-mode applied in high density SSDs。
  - better performance and endurance, as the cache



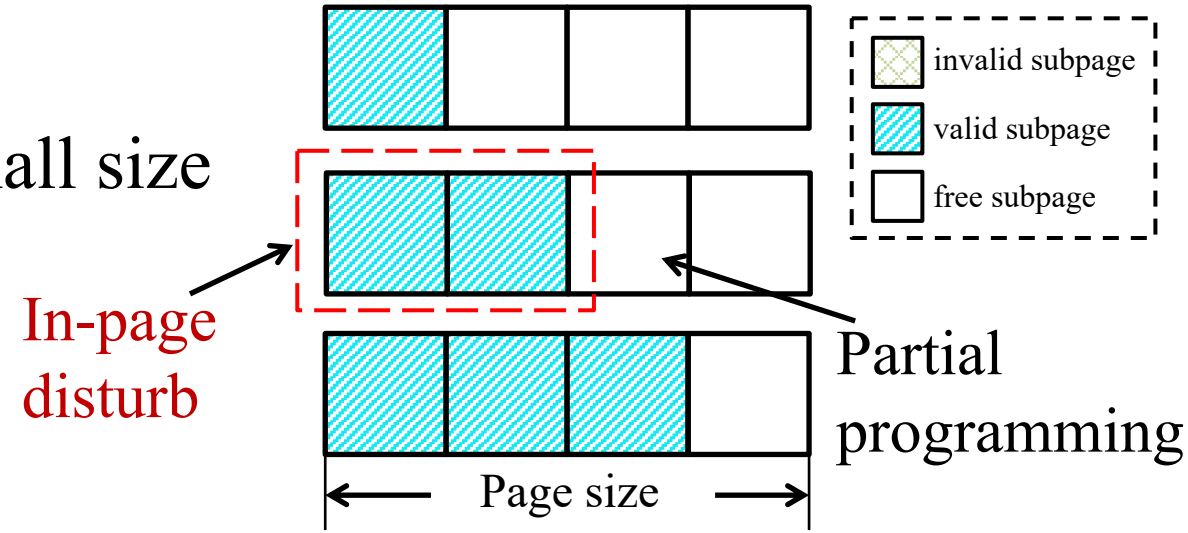
——https://kenhtinviet.com/3d-nand-cong-nghe-giup-ssd-vua-co-dung-luong-lon-v/



——Zhang et al. ICCD 2019

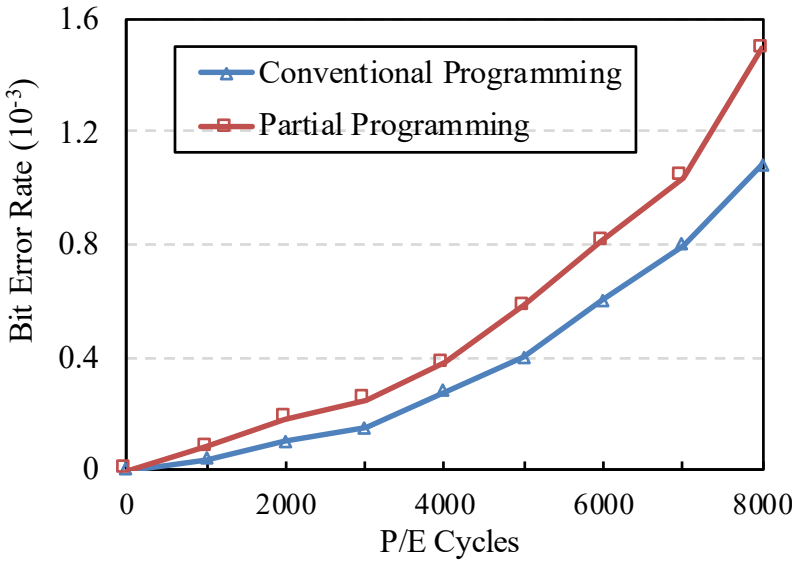
Motivation(1/2)

- A large number of requests with small size cause space fragmentation in SSD
  - Write granularity: page



- Partial programming
  - Multiple programming with different offset in the same page
  - Space utilization increases
  - Program disturbance

Eliminate the error caused by in-page program disturbance



Error rate comparison of traditional page-level programming and partial programming

——Zhang et al. Fast 2016

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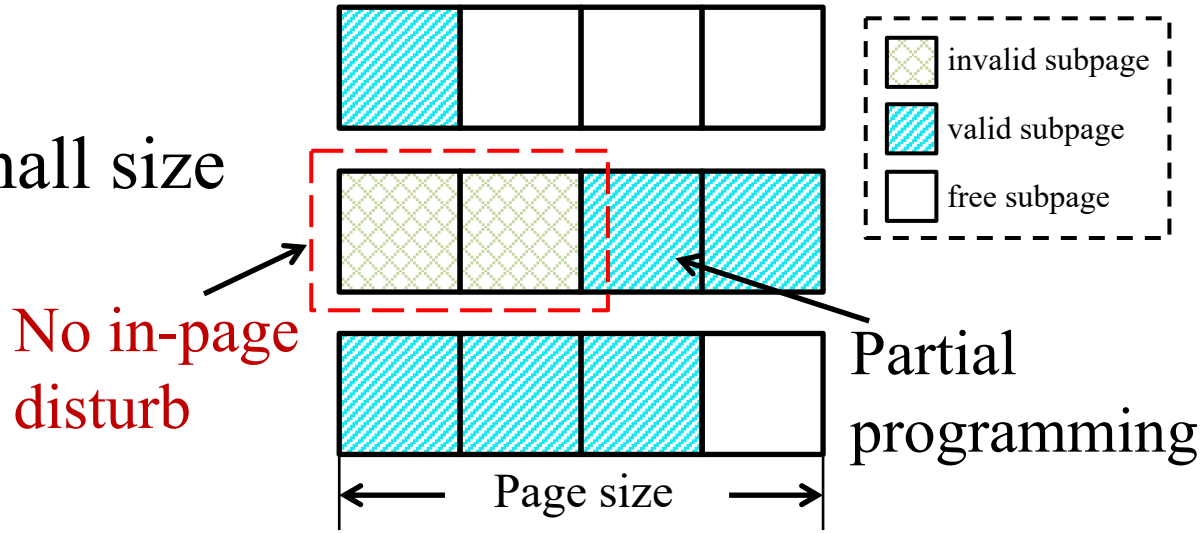
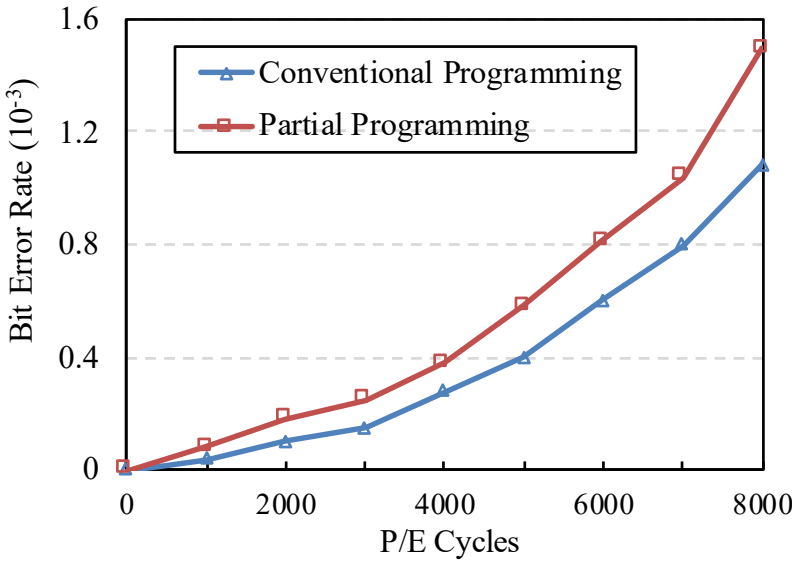


- Partial programming
  - Multiple programming with different offset in the same page
  - Space utilization increases
  - Program disturbance

Towards update requests utilizing partial programming in the same page



Error rate comparison of traditional page-level programming and partial programming

——Zhang et al. Fast 2016

Motivation(2/2)

- The requests with 4K account for the majority
  - It is possible to use partial programming for update requests on the same page!

Trace	Update Ratio	SZ∈(0, 4K]	SZ∈(4K, 8K]	SZ>8K
ts0	78.3%	**69.8%**	17.9%	12.3%
wdev0	76.5%	**73.2%**	6.8%	20.1%
lun1	49.8%	**85.2%**	7.3%	7.5%
usr0	54.4%	**66.3%**	12.1%	21.6%
lun2	7.4%	**92.6%**	2.5%	4.9%
ads	7.6%	**74.5%**	14.1%	11.4%

- Update ratio has different degrees
  - Hold hot write (frequent accessed) data in SLC cache

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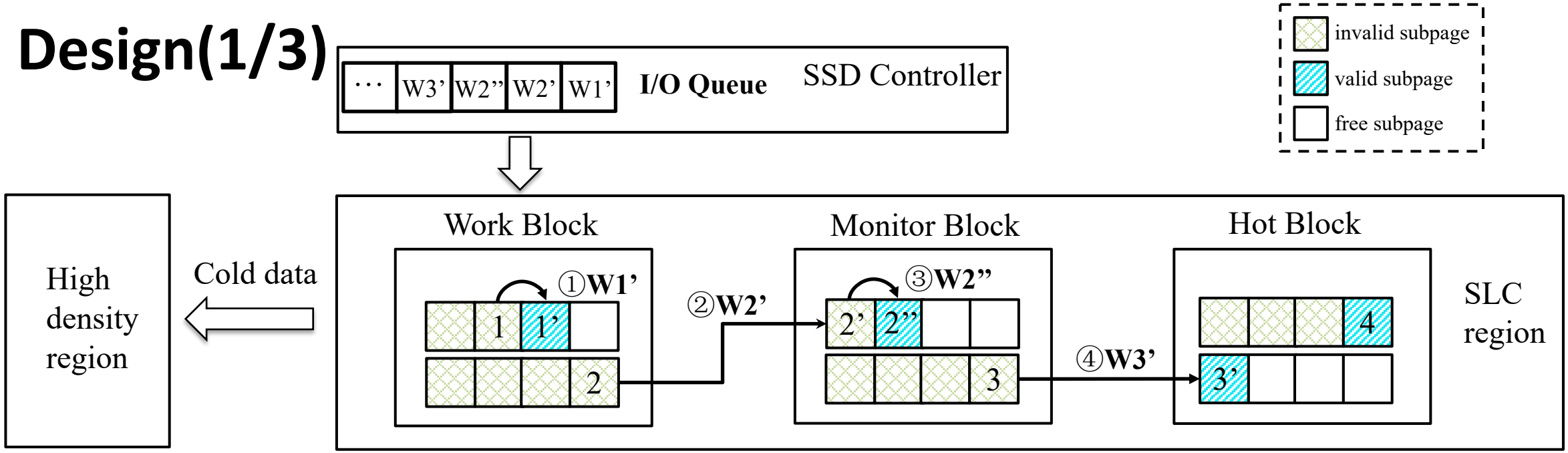
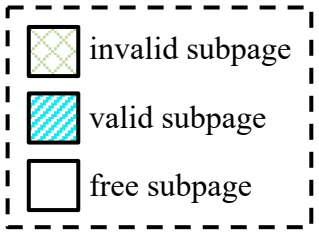
Design(1/3)



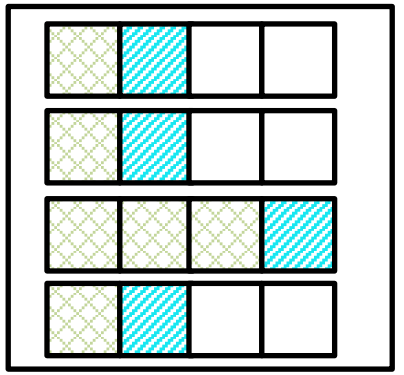
- Updated requests utilizes partial programming in the same page
  - Three-level SLC-mode blocks（Work Block<Monitor Block<Hot Block）
  - Hot write (frequent accessed) data "upgrade"
  - Holding hot write data in SLC cache

Design(2/3)



- Traditional GC policy: Greedy
  - Traverse target Plane, and select the block having the least number of invalid page

GC candidate A

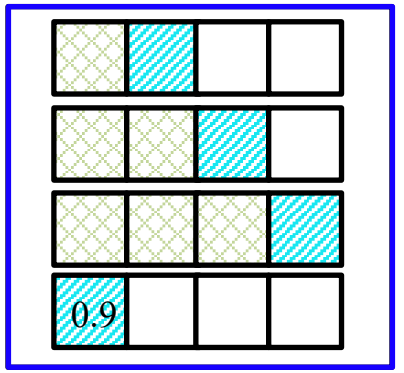


Tradition: **0无效页**

Proposal: **6 invalid subpages**
4 valid subpages

- Proposed GC policy: subpage granularity
  - Traverse target Plane, and select the block having the least value of Invalid Subpage Ratio (ISR)
  - ISR: measure the cold degree of block.

GC candidate B



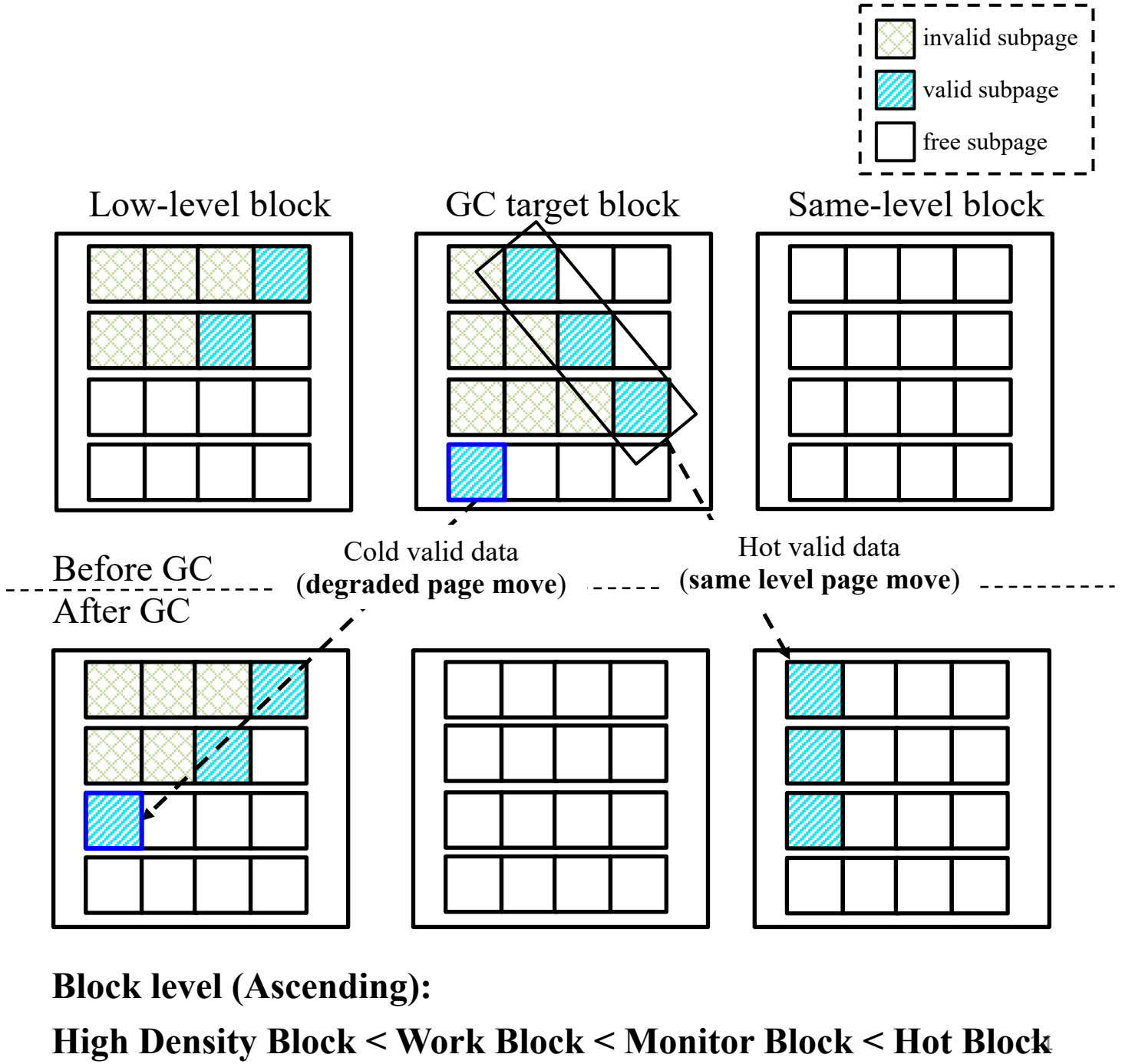
Tradition: **0无效页**

Proposal: **6 invalid subpages**
4 valid subpages
(including 1 cold valid subpage)

Design(3/3)

- Valid data migration
  - DEGRADE cold write data
  - Hold the level of other data

- Free up the SLC region occupied by cold data
  - Hold cold data in high density SSD blocks



Block level (Ascending):

High Density Block < Work Block < Monitor Block < Hot Block

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Experiment setup(1/2)

- SSDSim settings

EXPERIMENTAL SETTINGS OF *SSDsim*

Parameters	Values	Parameters	Values (ms)
Page size	16KB	*SLC read time*	0.025
Page per block	1024	*MLC read time*	0.05
SLC mode ratio	5%	*ECC min decode time*	0.0005
GC threshold	0.05	*ECC max decode time*	0.0968
GC policy	greedy	*SLC write time*	0.3
Wear-leveling	static	*MLC write time*	0.9
FTL scheme	Page	*Erase time*	10

- Benchmark

SPECIFICATIONS ON SELECTED DISK TRACES

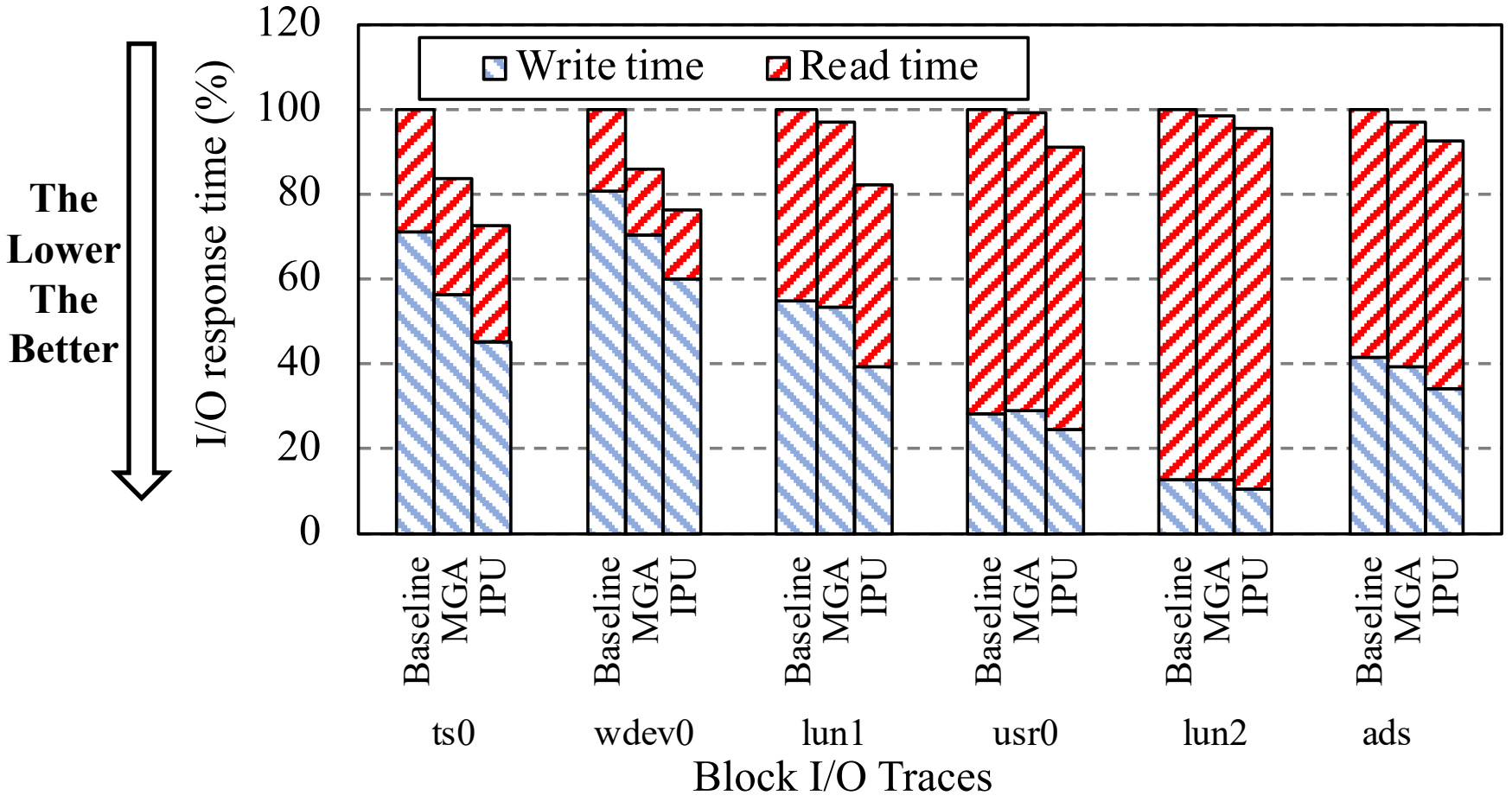
Trace	# of Request	Write ratio	Write size	Hot write
ts0	1,801,734	82.4%	8.0KB	50.5%
wdev0	1,143,261	79.9%	8.2KB	58.2%
lun1	1,073,405	73.1%	7.6KB	10.0%
usr0	2,237,889	59.6%	10.3KB	36.5%
lun2	1,758,887	19.3%	9.7KB	8.5%
ads	1,532,120	9.5%	7.0KB	18.3%

Experiment setup(2/2)

- Comparison methods:
  - ***Baseline***: hybrid SLC/MLC SSD architecture.
  - ***MGA***(Mapping Granularity Adaptive)[1]: utilizes subpage granularity management with partial programming, by employing two-level mapping table to record subpage information in same pages
  - ***IPU***(Intra-page Update): proposed method, which performs update operations with partial programming in the same pages which previously holds the old version of data, and ejects cold write data during GC operations.

[1] Yazhi Feng, Dan Feng, Chenye Yu,Wei Tong, and Jingning Liu. Mapping granularity adaptive ftl based on flash page re-programming. In ***DATE***, 2017.

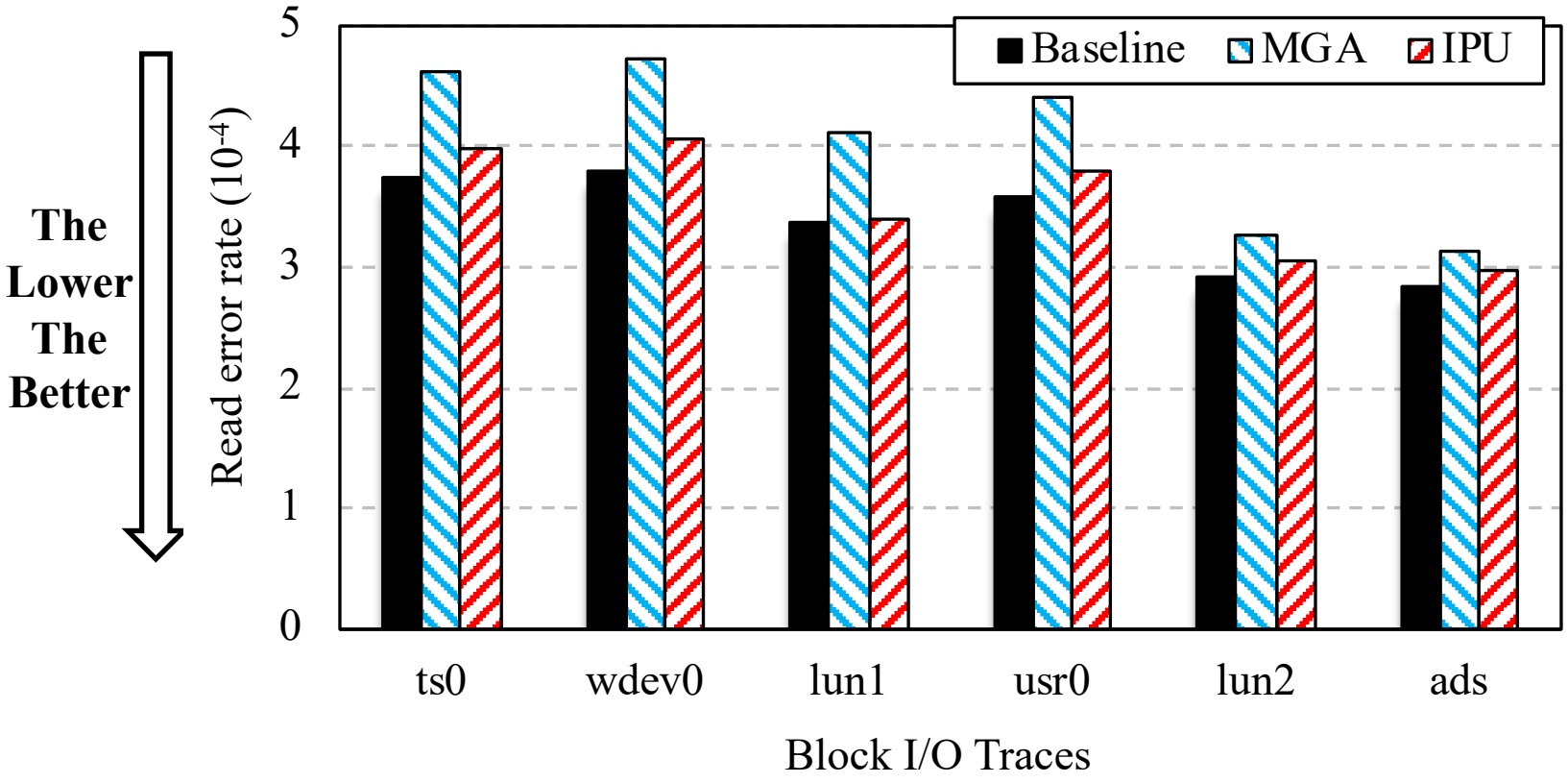
Result(1/3): I/O performance



I/O Benefit:
1. decreasing Read error rate
2. Holding hot data in SLC cache

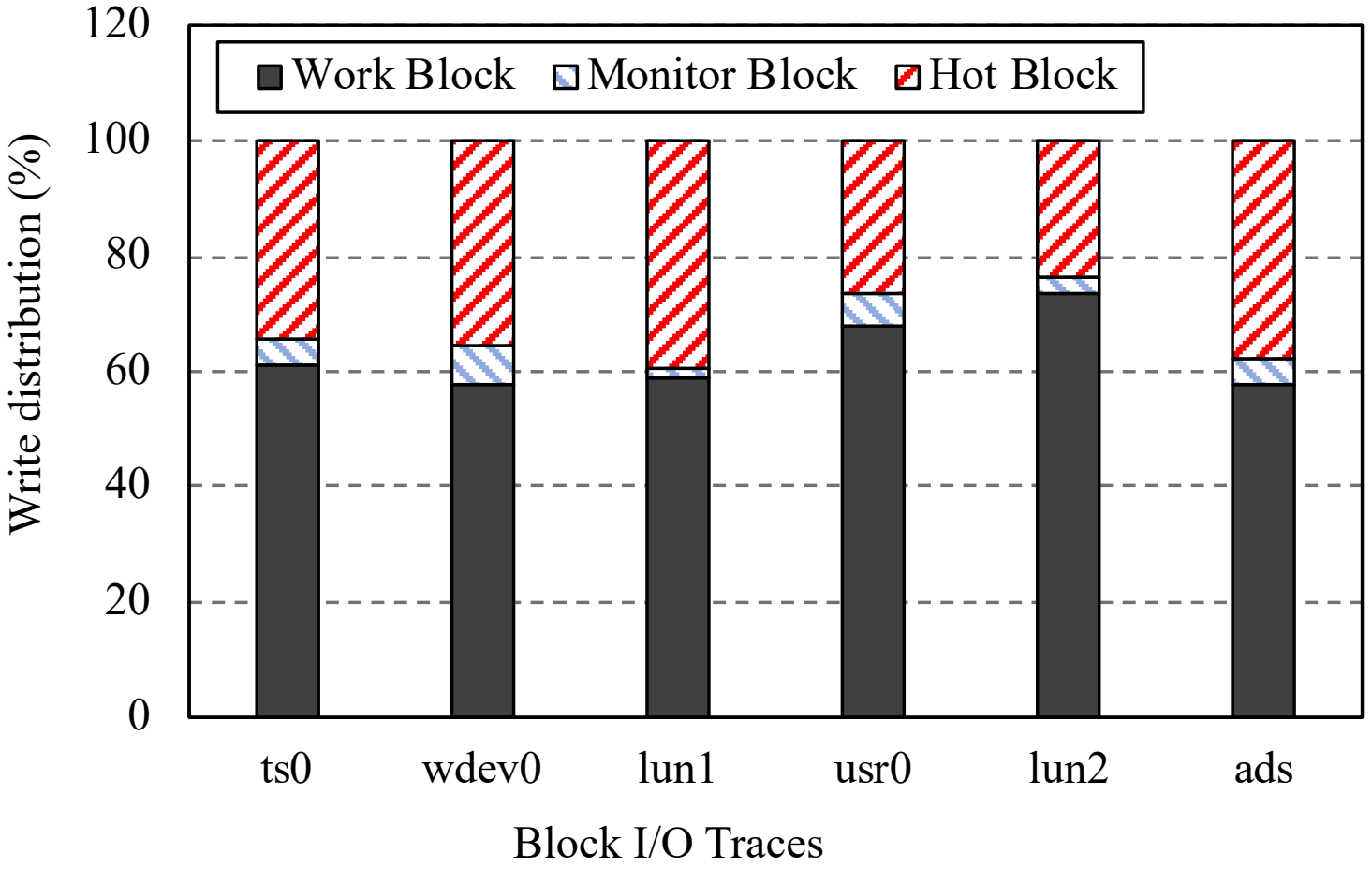
- **Our proposal of IPU can decrease I/O time by 11.9% and 7.3%, compared with Baseline and MGA.**

Result(2/3): Read error rate



- **Our proposal of IPU can decrease read error rate, and thus present less read response time (ECC decode time).**

Result(3/3): Three-level blocks



- **32.9% write are the most frequently updated data on average, and hold in SLC-mode blocks to utilize the I/O benefits.**

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Conclusion

- Intra-page update (IPU) utilizes partial programming towards update requests in the same page.
  - Mitigate program disturbance caused by partial programming.
- We further propose three-level SLC-mode blocks and degraded GC policy for SLC mode blocks.
  - Hold hot write data in SLC mode cache (block).
- Preliminary evaluation prove that, proposed method can reduce the I/O latency and read error rate, compared with the related work.

Thank you very much!
Q&A

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