LX-SSD: Enhancing the Lifespan of NAND Flash-based Memory via Recycling Invalid Pages

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Outline

- **Backgrounds and Motivations**
- **Design of Recyclable SSD**
- **Performance Evaluation**
- **Conclusion**

Backgrounds

- **NAND flash**

NAND Flash-based SSDs have unique merits outpacing traditional HDDs

High speed | Energy efficient | Random access | resistance to physical shock

high-density scaling technology

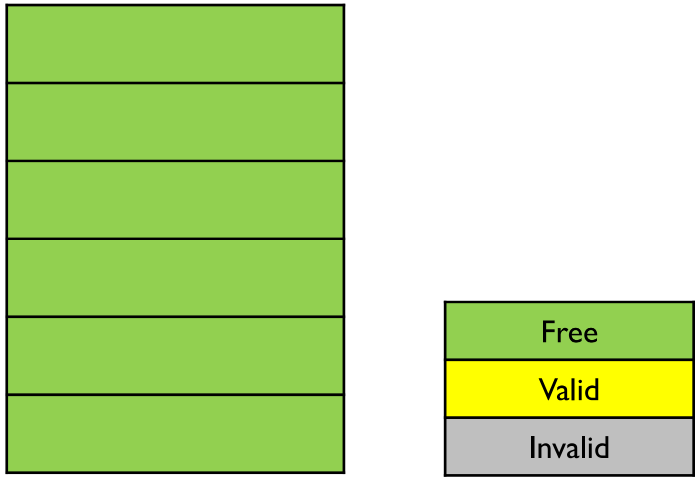
	SLC	MLC	TLC
Bits per cell	1	2	3
P/E Cycles	10,000	3,000	1,000

Backgrounds

- **PE cycle**

The PE cycle of a block is composed of a series of events:

N programmings One erase



Backgrounds

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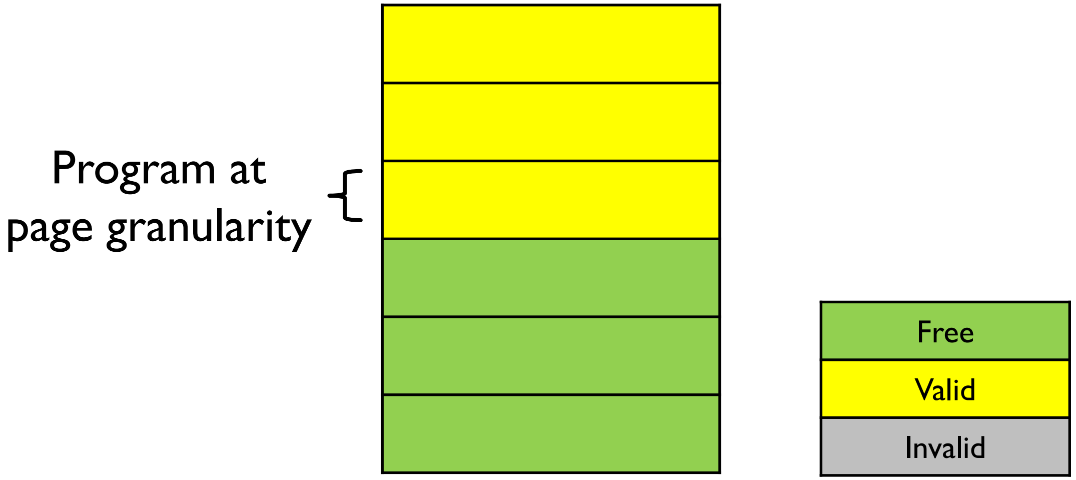

Backgrounds

PE cycle

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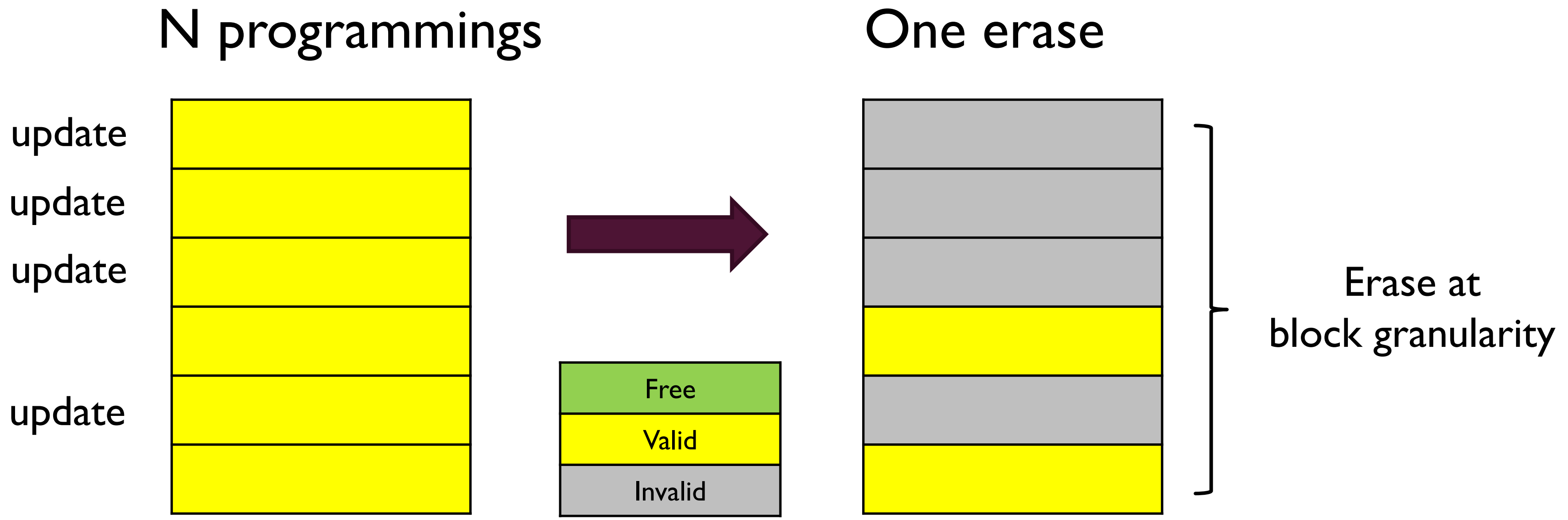


Block recycle

making the entire block reusable again, but at the cost of :

(1) migrating valid pages (2) need erase operation

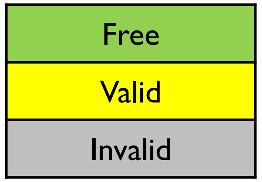
Backgrounds

- **Block recycle**

all invalid pages in the block are considered to be useless

CAN NOT BE ACCESSED

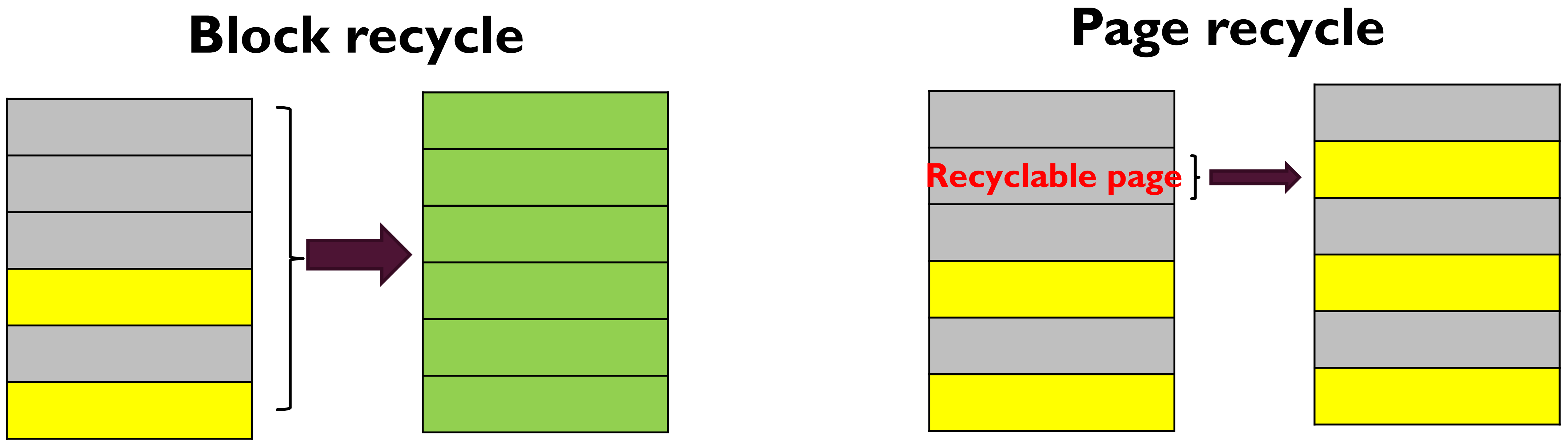
BE CONSIDERED TO BE AS TRASH



Are them truly useless?

Backgrounds

- **Page recycle** recycle ⟷ reusable



- **Recyclable page:** an invalid page shares the identical content with an incoming write request

Backgrounds

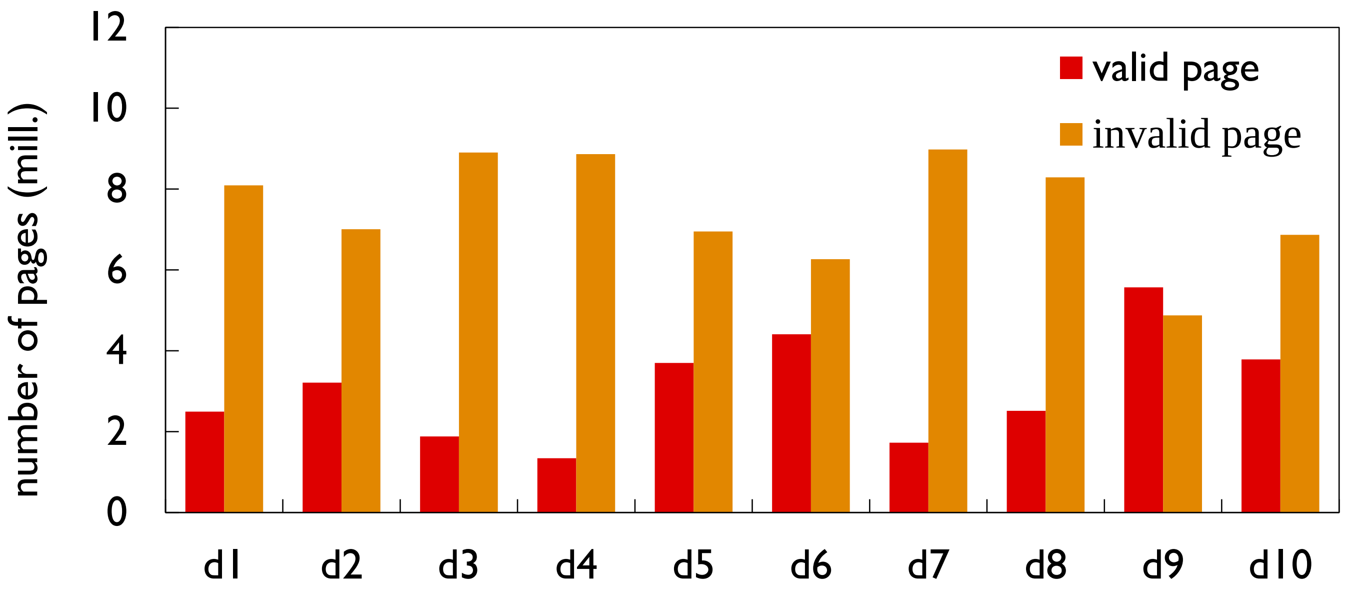
- **Page recycle**
  - recycle the invalid pages
  - act as a supplement to block recycle
  - extend the PE cycle from N-programs-per-erase to N^{+}-programs-per-erase

Motivations

- **Invalid pages are common**

  A NAND flash page alternates between three states: ***free***, ***valid***, and ***invalid***

  free pages only occupy limited space, typically 5%-15%



the number of invalid pages is **1-4 times** the number of valid pages

Motivations

- **Invalid pages could be useful**

three workloads, including ***home***, ***mail***, and ***web***, from FIU, are introduced to observe the appearance of useful data in invalid pages

Workload	Request (mill.)	Size (GB)	Writes (%)	Unique addr (mill.)
homes	9.3	3.7	93.8	2.4
mail	16.3	4.8	75.3	1.2
web	5.9	2.1	82.5	0.8

- **Recyclable page**

  - 24.1 GB, 42.2 GB, and 15.5 GB invalid pages are observed in *home*, *mail,* and *web* respectively
  - 2.8 GB, 7.4 GB, and 2.5 GB recyclable pages
  - 11.5%-17.6% of invalid pages are recyclable

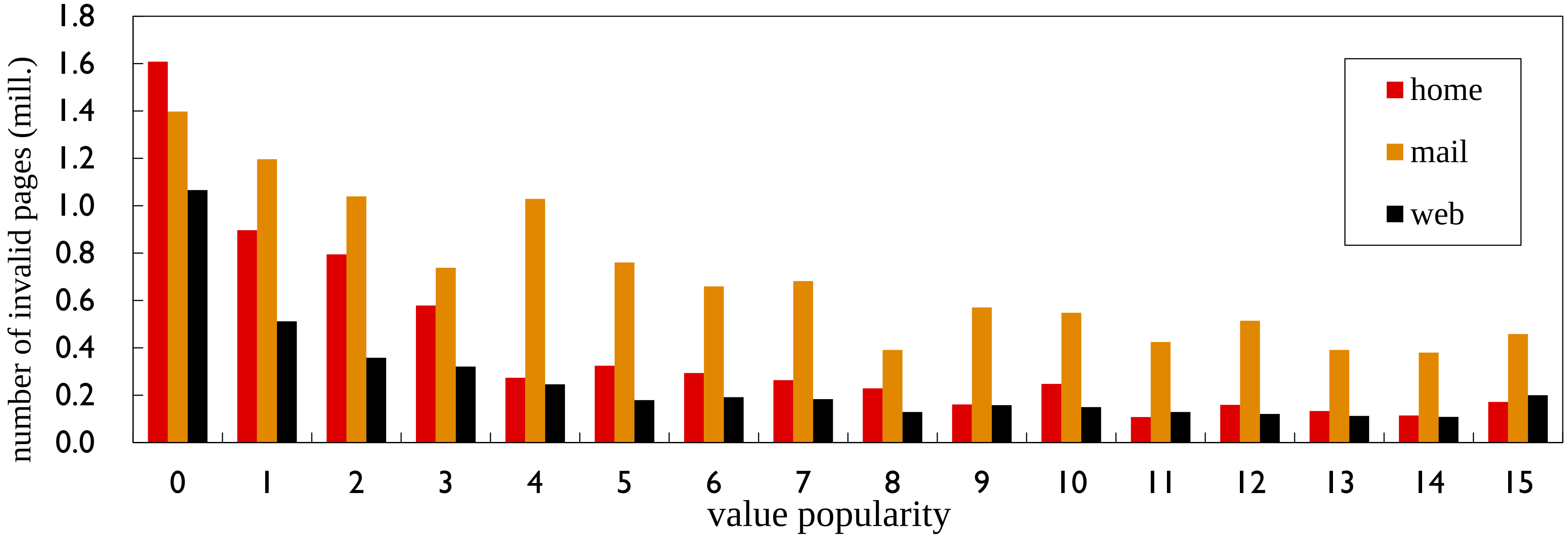
Motivations

- ***Locality Characterization***

We characterize two types of value locality to effectively assist us in dividing the invalid pages into highly recyclable and less recyclable:

- value popularity

  a characterization on frequency representing how many times an invalid page has been accessed



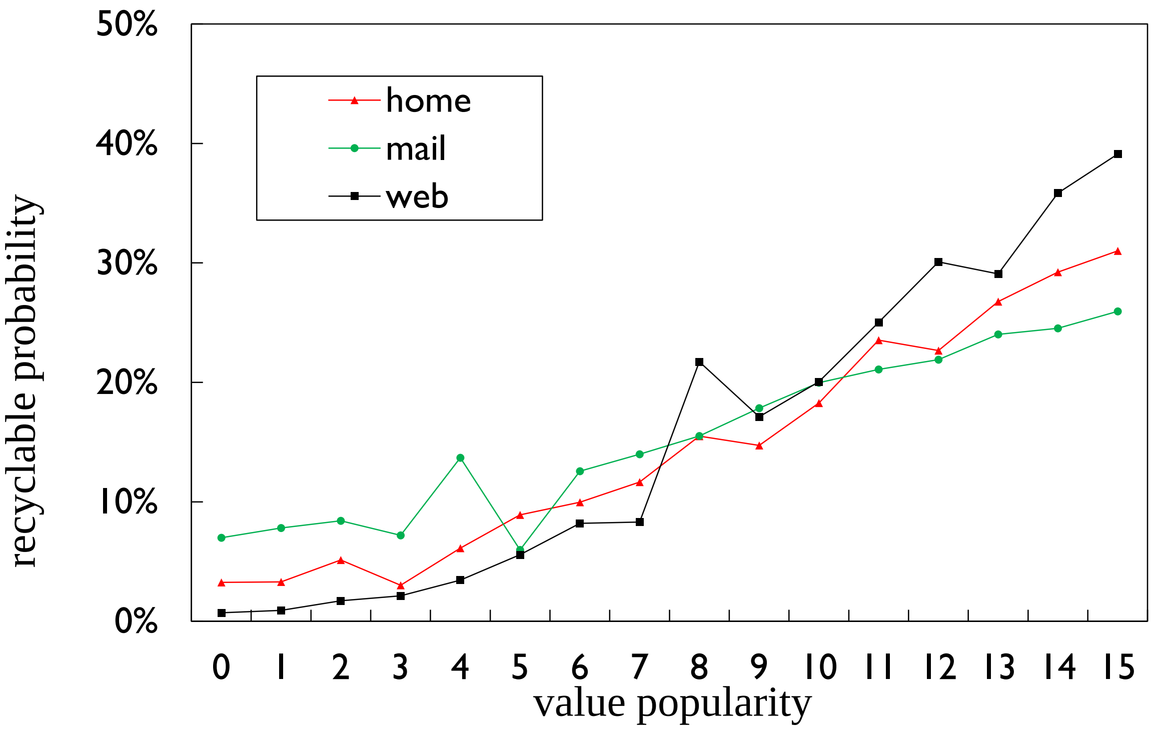
Motivations

- ***Locality Characterization***

We characterize two types of value locality to effectively assist us in dividing the invalid pages into highly recyclable and less recyclable:

  - value popularity

recyclable probability is closely related to the value popularity

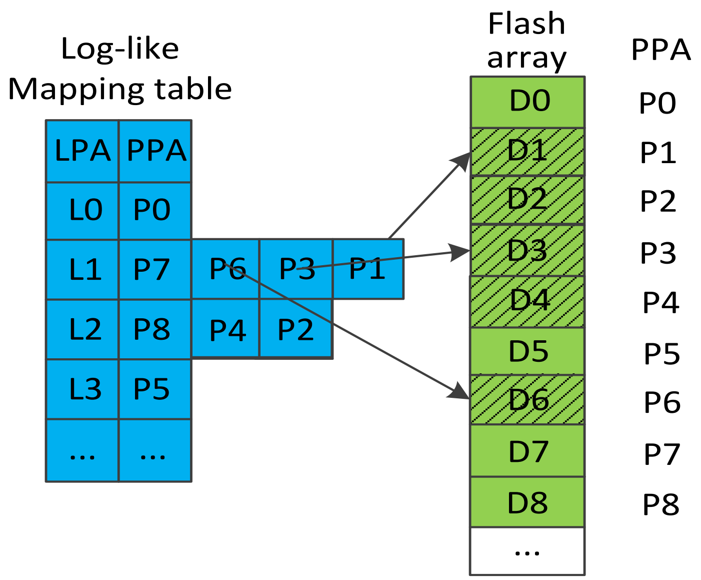


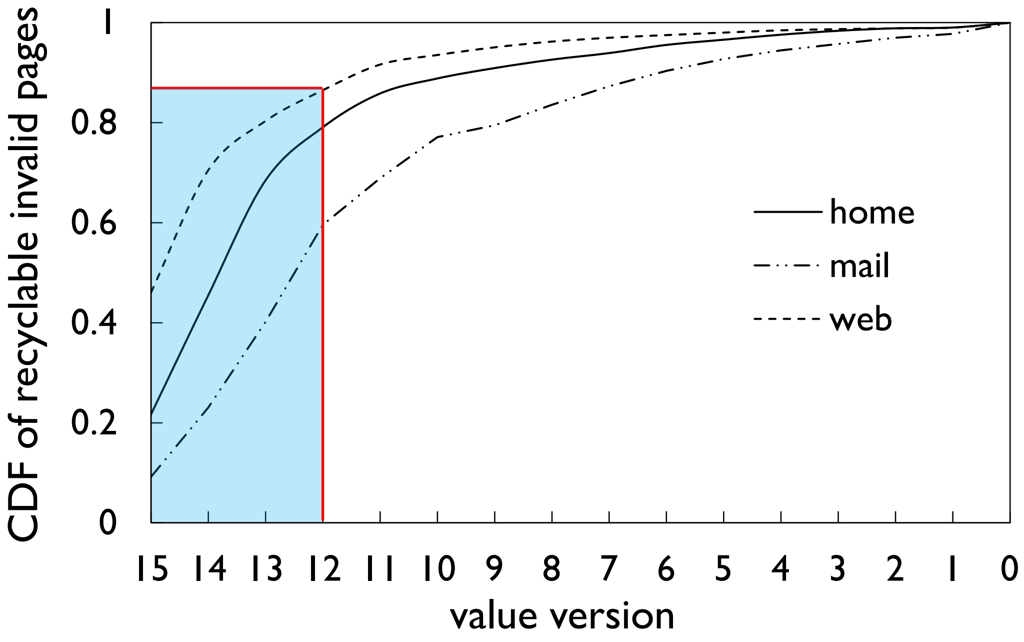
Motivations

- ***Locality Characterization***
  - Value version

a characterization on date representing how long an invalid page has been generated

value version also affects the recycle probability





Challenges

- **Limited RAM capacity**

  Designing a content-aware FTL needs extra metadata which puts additional pressures on the limited RAM

- **Without semantic hints**

  more difficult to identify recyclable invalid pages, and requires more complicated design

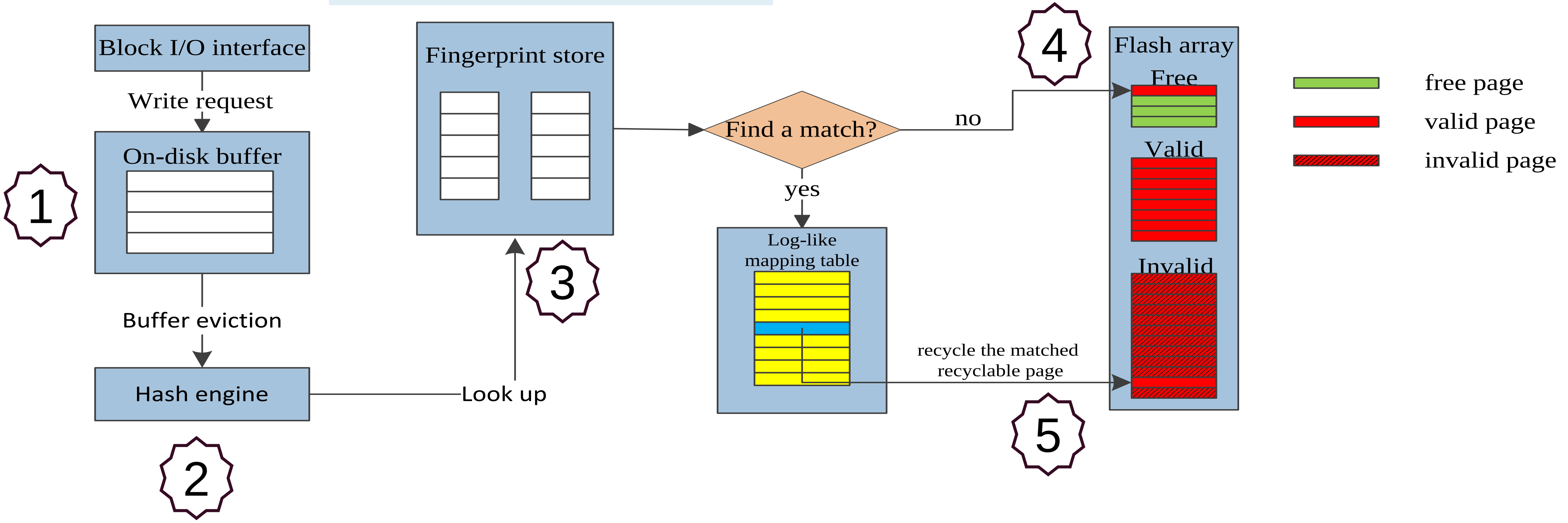
- **Minimize the overhead**

  Recyclable SSD still need to retain high data access performance even when there is little locality among invalid pages.

Design of Recyclable SSD

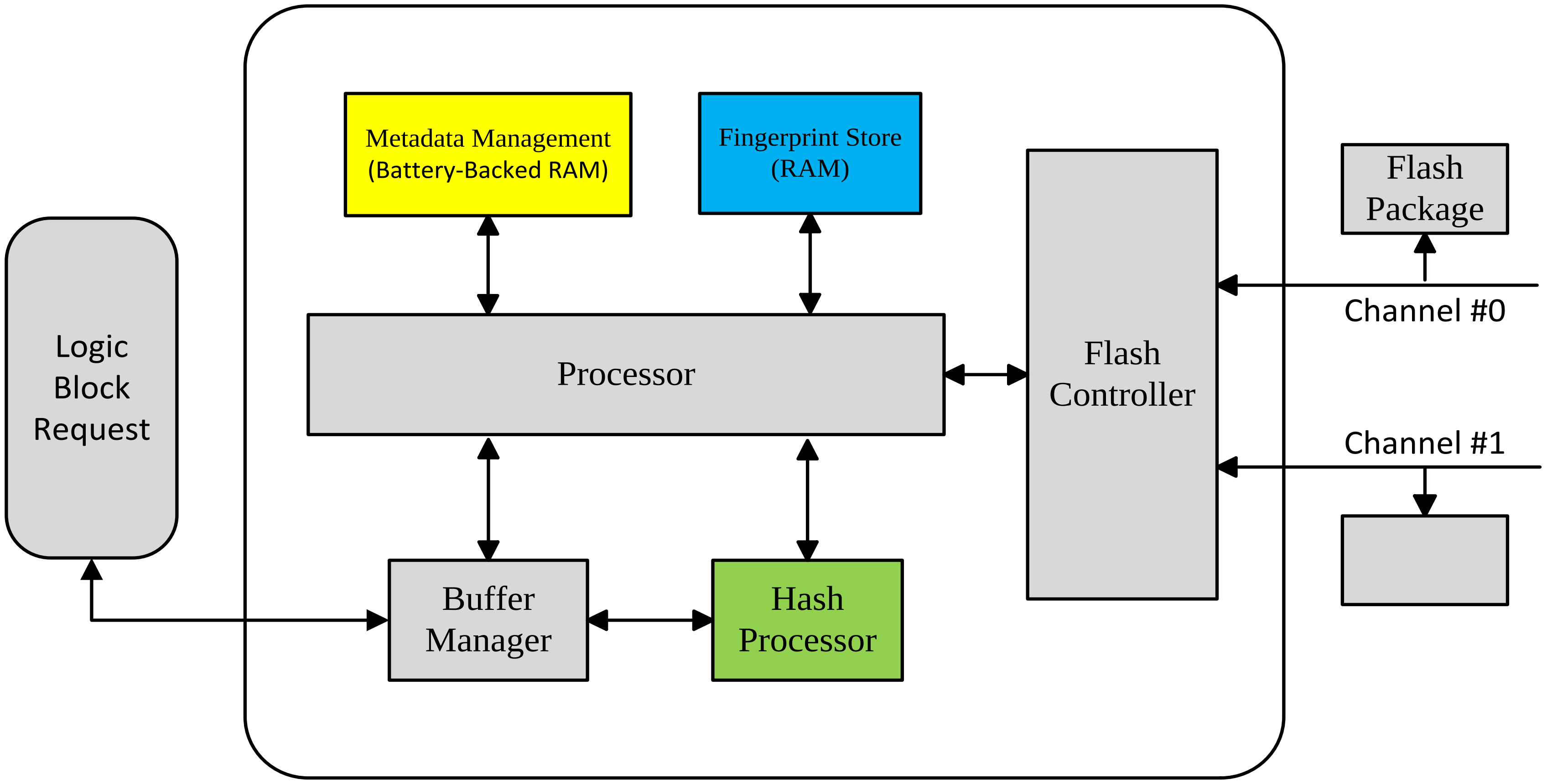
Architecture Overview

maintains the fingerprints of highly recyclable invalid pages



Design of Recyclable SSD

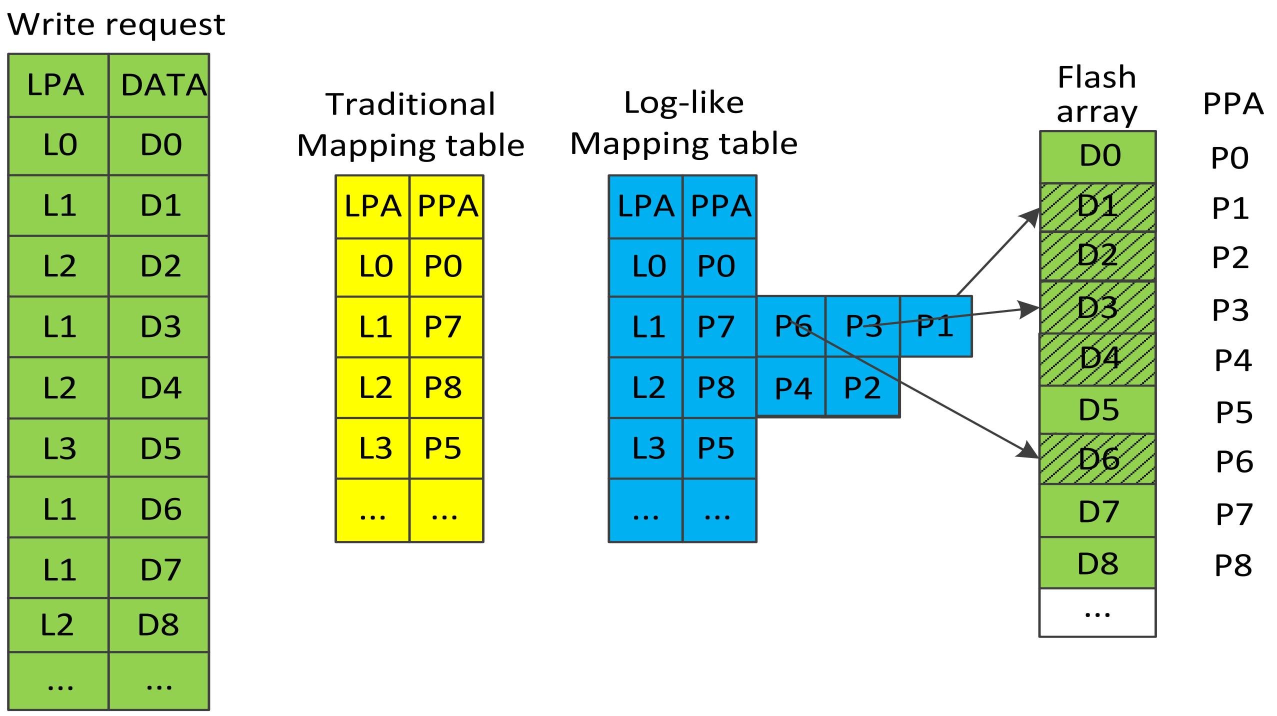
- **Extra components**



Design of Recyclable SSD

- **Metadata management**
  - Log-like mapping table (LMT)

The LMT uses a linked list to store all the physical page addresses that have ever been mapped to the same logical page address.

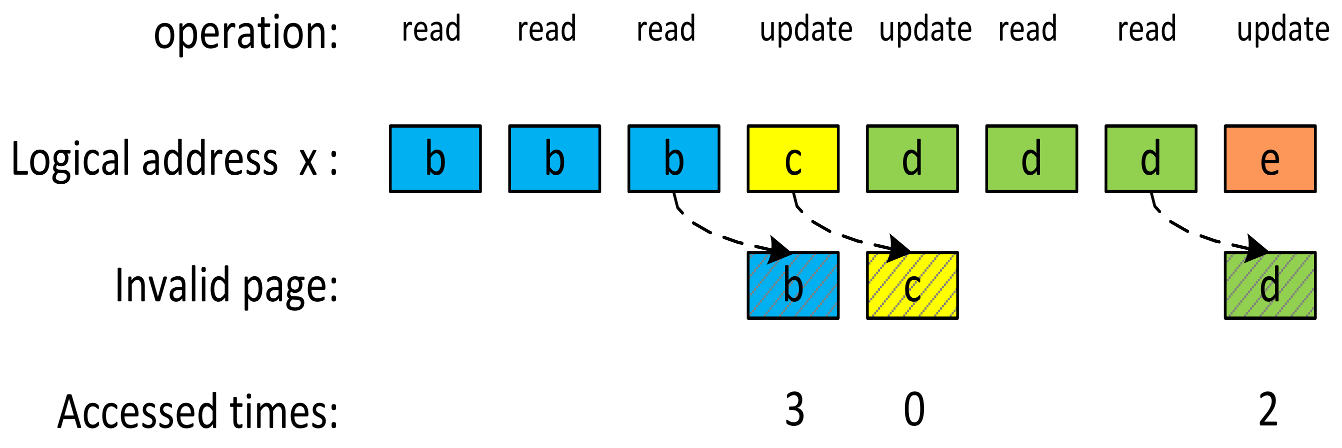


identify the value version

Design of Recyclable SSD

- **Metadata management**
  - Accessing table

record the number of times each physical page has been accessed



identify the value popularity

Design of Recyclable SSD

- **Fingerprint Store management**
  - Recyclable probability calculation

$$pop_{inv}(p) = (1+\alpha)^{ace_{inv}(p)}$$

α is a growth factor

in the range of 0.1 to 0.15

$$ReProb_{ini}(p) = \frac{pop_{inv}(p) - 1}{(1+\alpha)^{15} - 1}$$

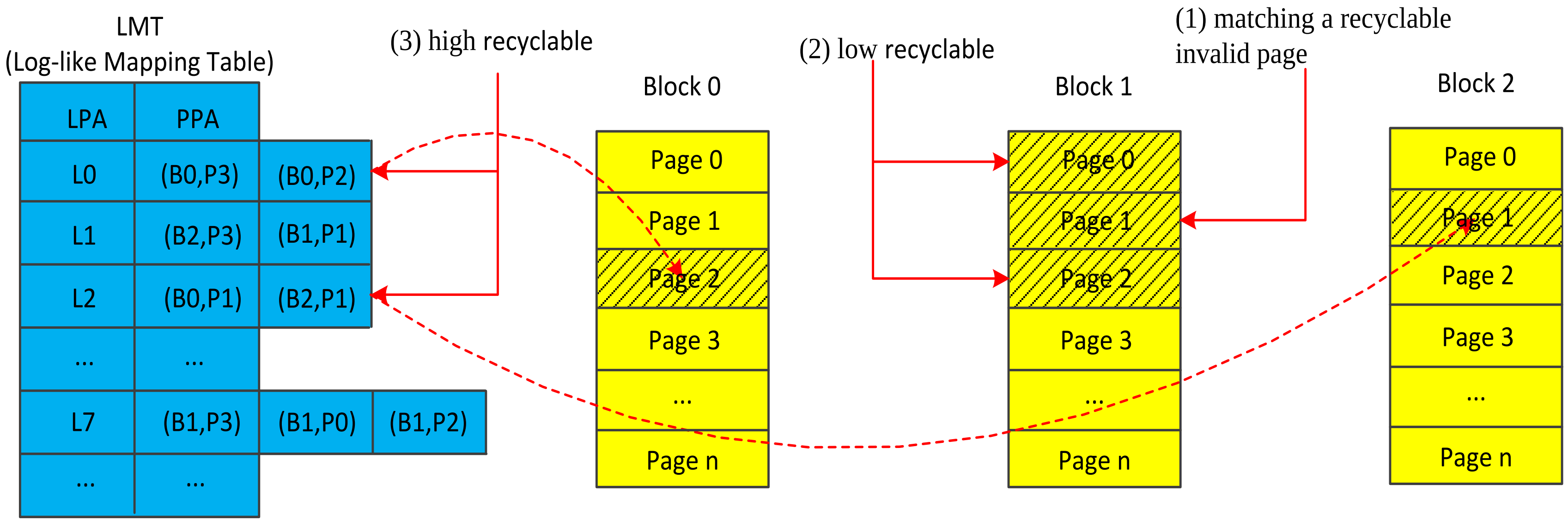
β is a decay factor

in the range 0.15 to 0.2

$$ReProb_{fin}(p) = ReProb_{fin}(p) * (1-\beta)^{(15-ver_{inv}(p))}$$

Design of Recyclable SSD

- **Fingerprint Store management**
  - Fast loading



we use LMT to quickly locate those invalid pages which have spatial locality

Design of Recyclable SSD

- **Garbage collection**

Re**C**yclable-aware GC

$$BlkStats(b) = \sum_{i=1}^{n} PageStats(i) * \left(1 - ReProb_{fin}(i)\right)$$

Evaluation

- **Metrics**

  Write reduction

  Number of block erasures

  Average response time

- **Setup**

  We set simulated SSD with the default configurations from the SSD extension

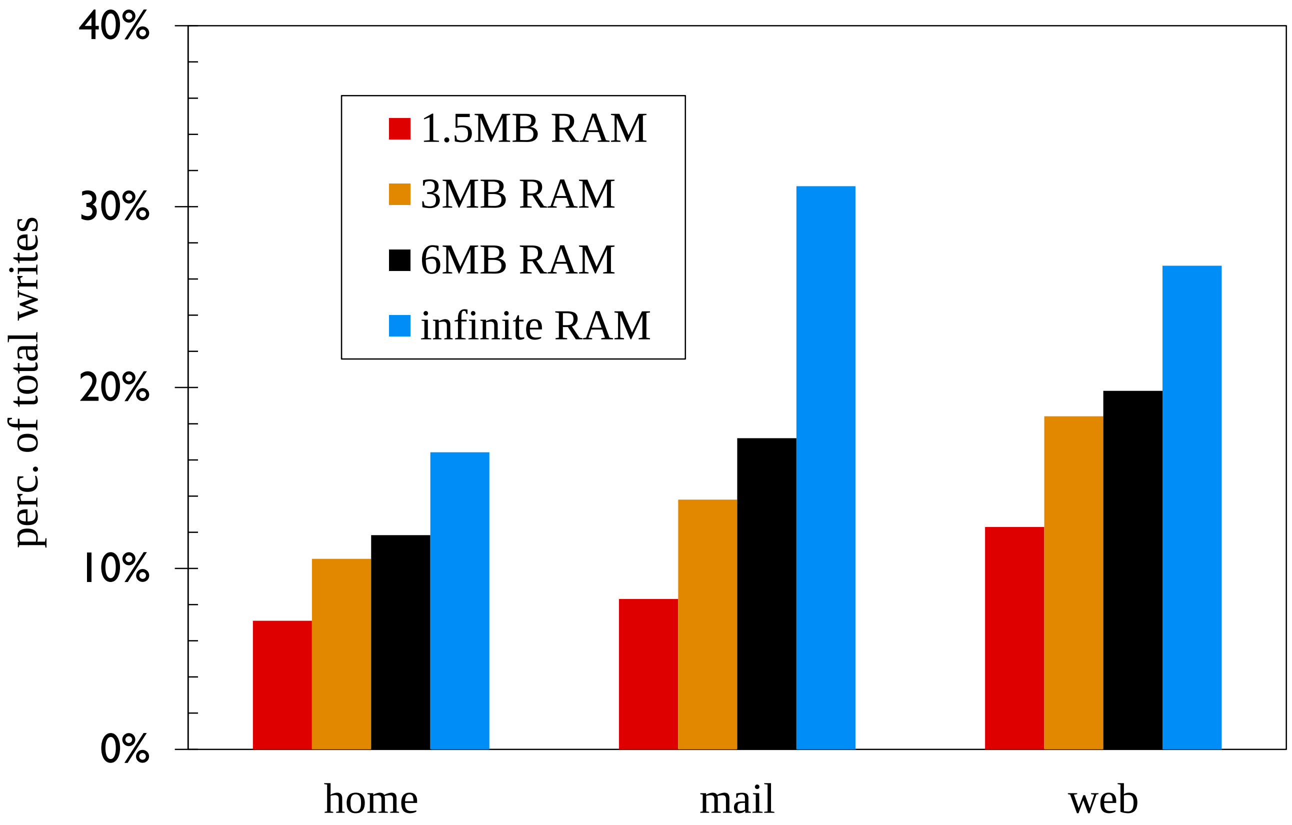
- **Datasets**

  home, *mail*, and *web*, from FIU

Evaluation

- **Write reduction**

With a moderate 3MB RAM size, the Recyclable SSD can achieve 10.5%-18.4% write reduction in three workloads

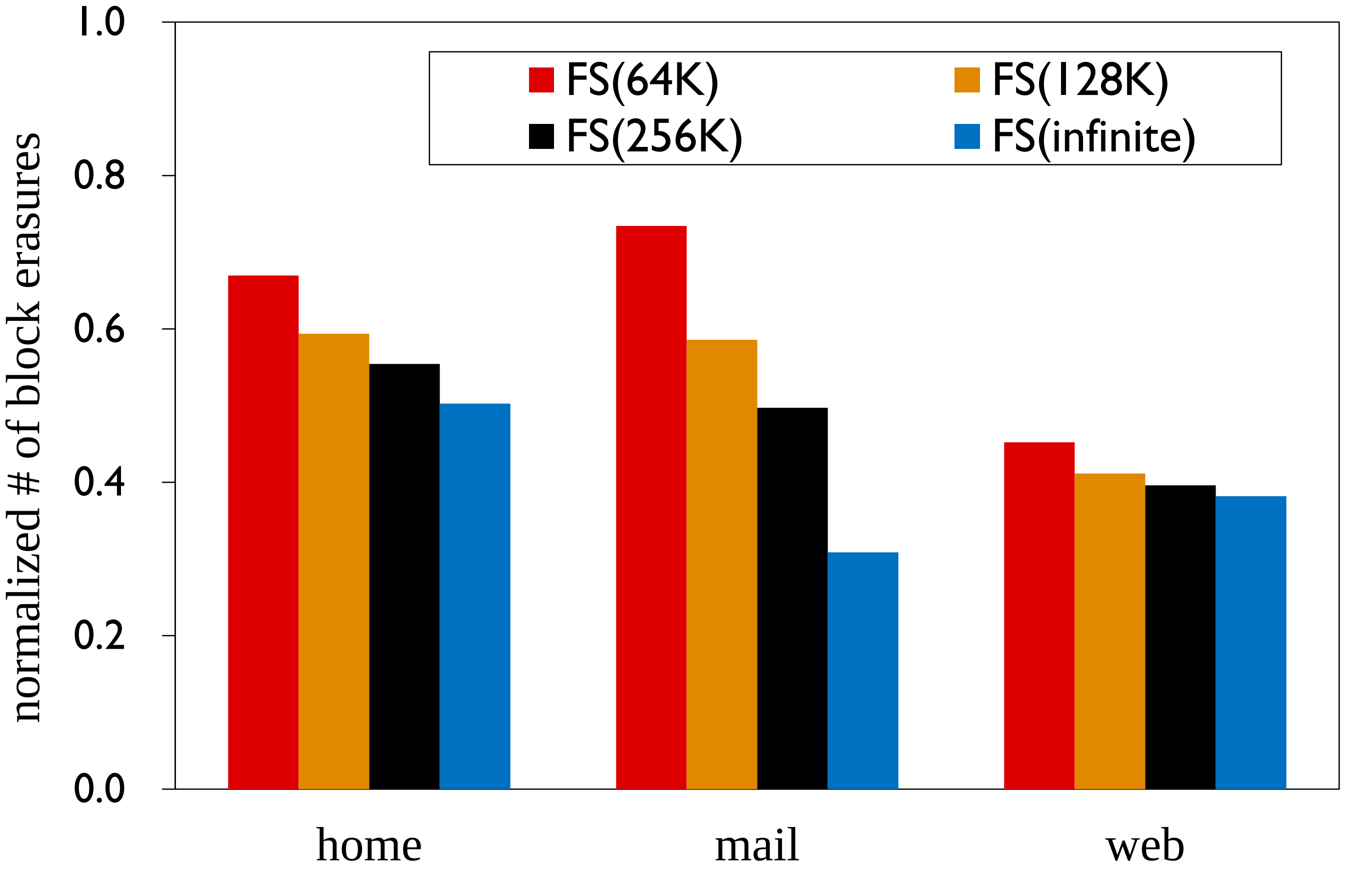


RAM sizes of 1.5MB, 2MB, and 6MB maintaining 64K, 128K, and 256K entries

Evaluation

Number of block erasures

the *web* has exhibited the best results: the normalized number of block erasures under FS of 64K, 128K, and 256K are 45.2%, 41.1%, and 39.6% respectively

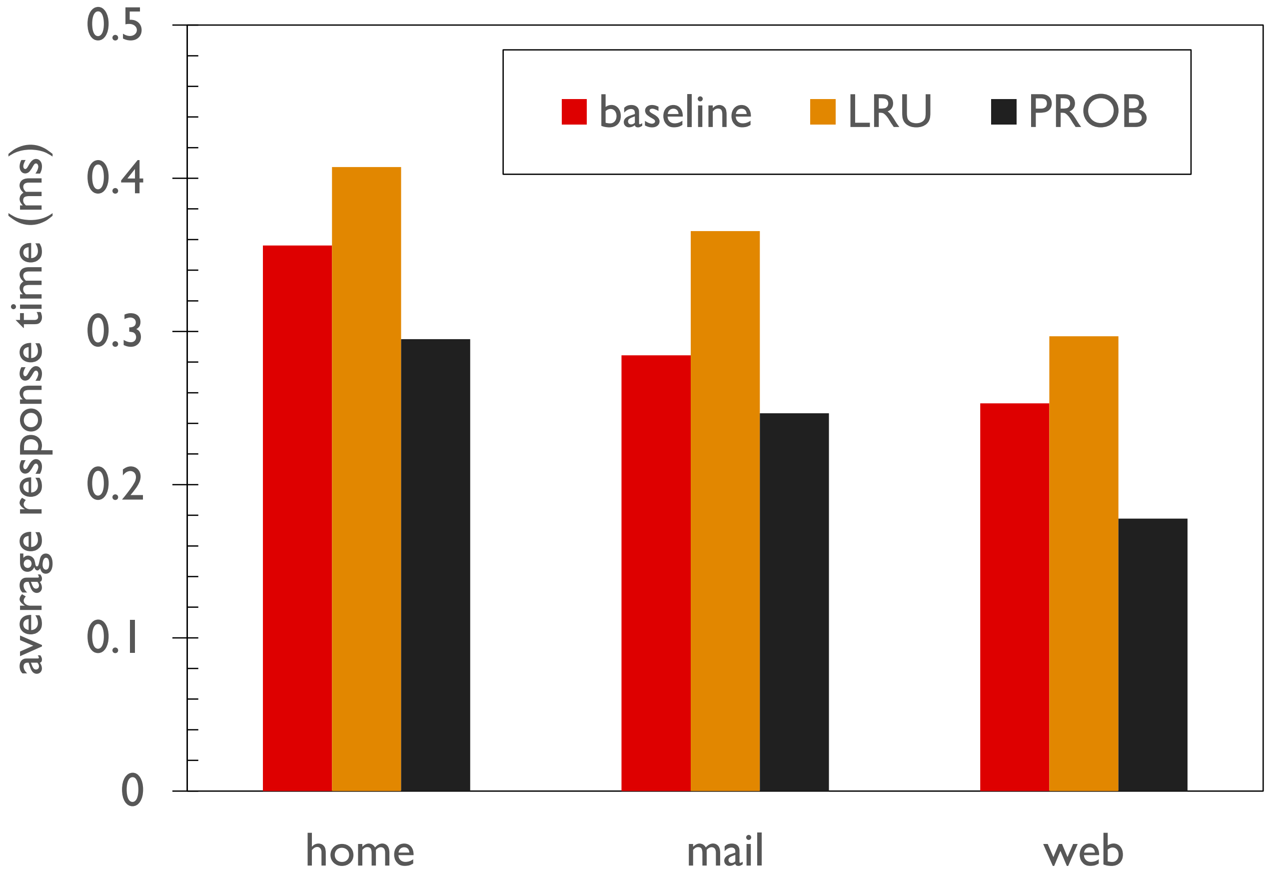


Evaluation

Average response time

the average response time of the Recyclable SSD also benefit a lot from write and block erasure reductions

The *web* workload, which has the most value locality, shows a 29.7% improvements in response times



LRU
manages the FS as a queue with LRU eviction policy
PROB
maintains the FS as an ordered queue sorted by the recycle probability

Conclusion

- **Our study is the first attempt to address the benefit from recycling invalid pages without reprogramming or cleaning**
  - Recyclable SSD can extend SSD lifetime while slightly improving performance
  - The characterized localities ensuring that the implementation of the Recyclable SSD is feasible
  - the number of block erasures can be decreased resulting in significant lifetime extension

- **Most related works for extending SSD lifetime are orthogonal to the design of the Recyclable SSD and can be augmented with recycling invalid pages.**

Thank you!

Questions?

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