

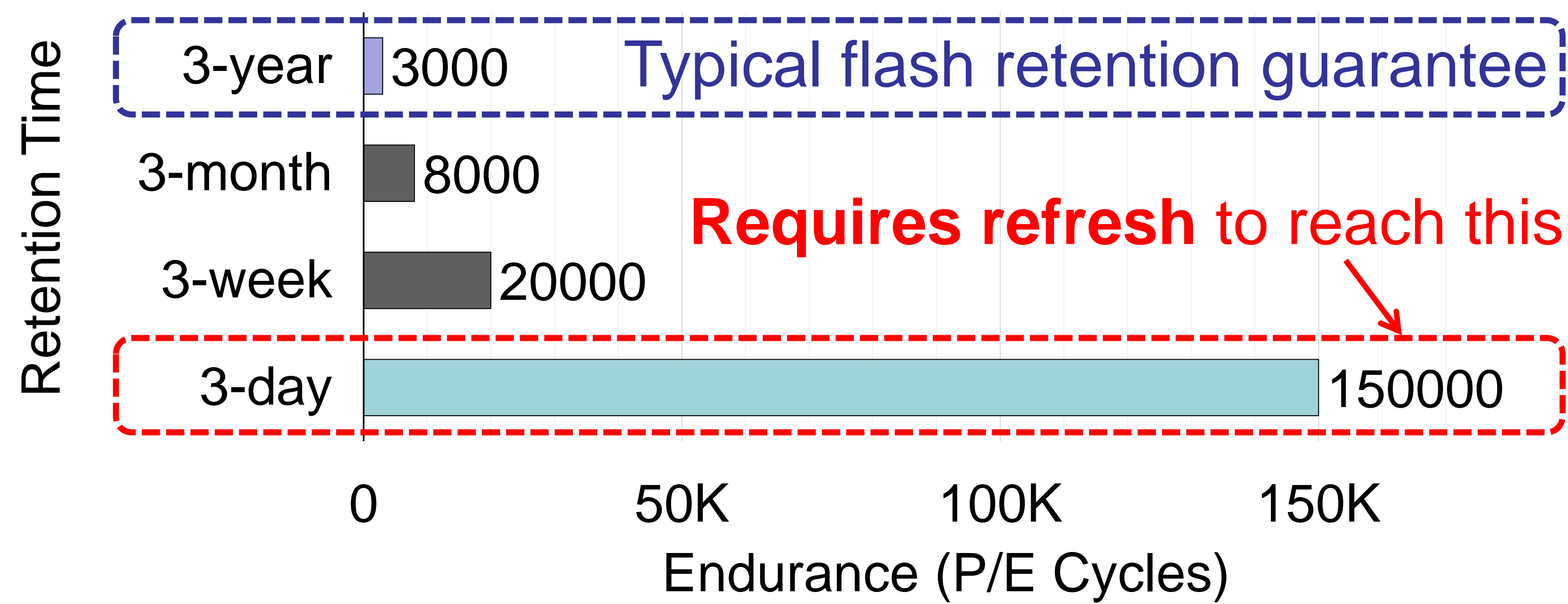
WARM: Improving NAND Flash Memory Lifetime with Write-hotness Aware Retention Management

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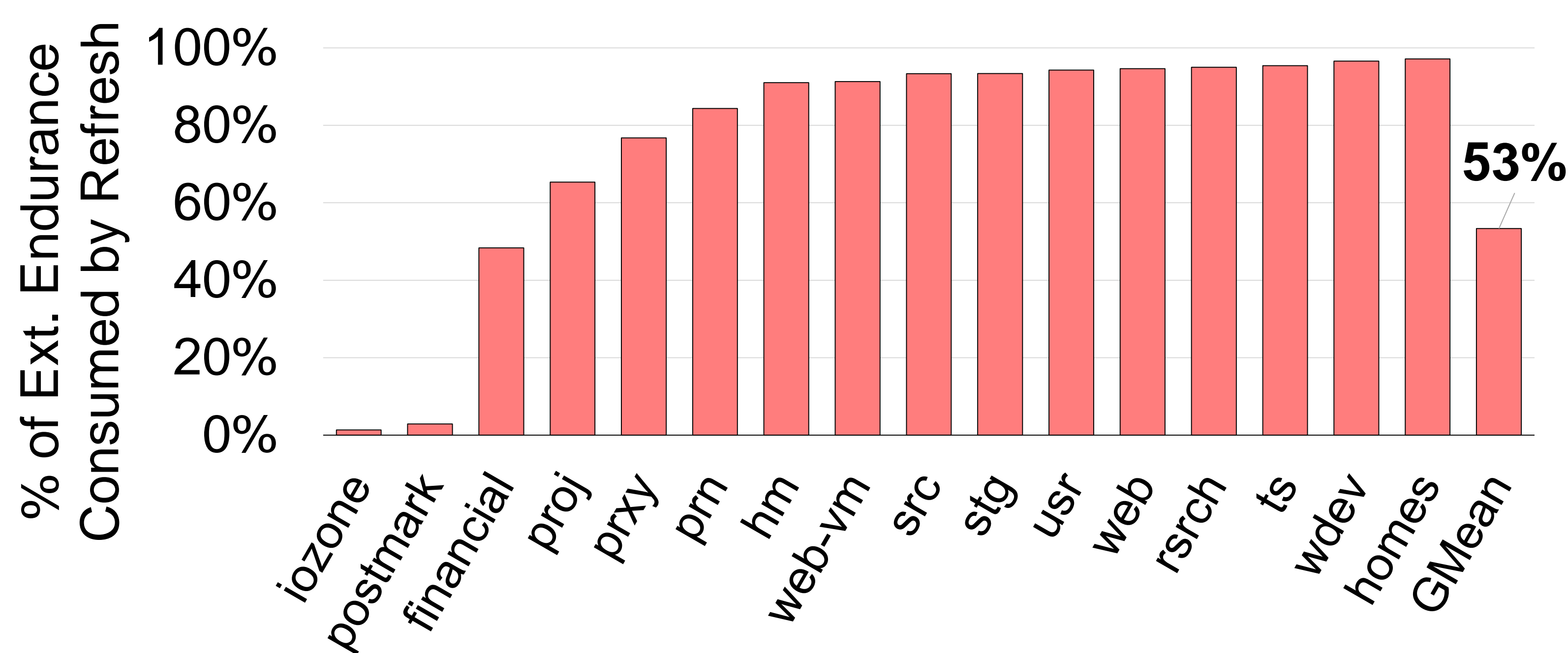
Motivation

Background: Relaxing *internal retention time* of flash memory improves lifetime



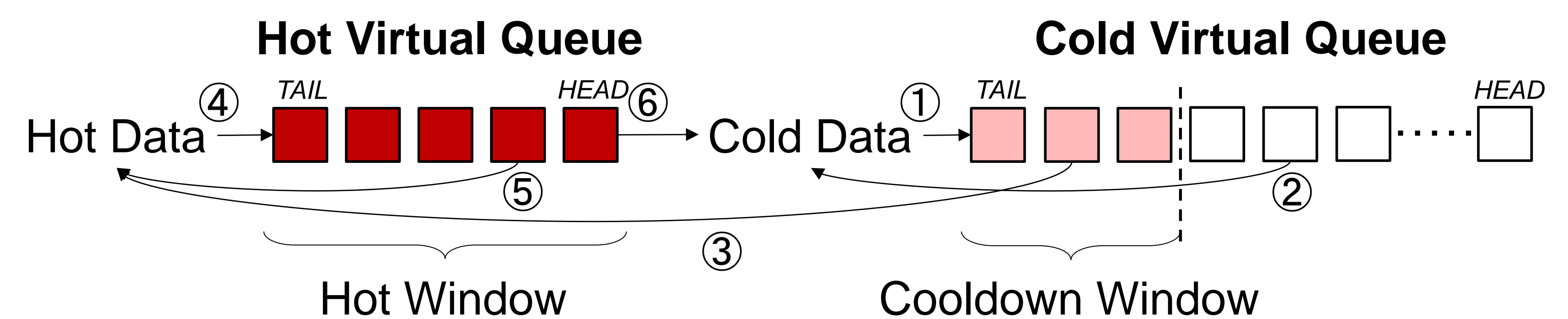
Problem: Refreshes typically required to guarantee data integrity, but consume additional writes →

potential lifetime improvements restricted

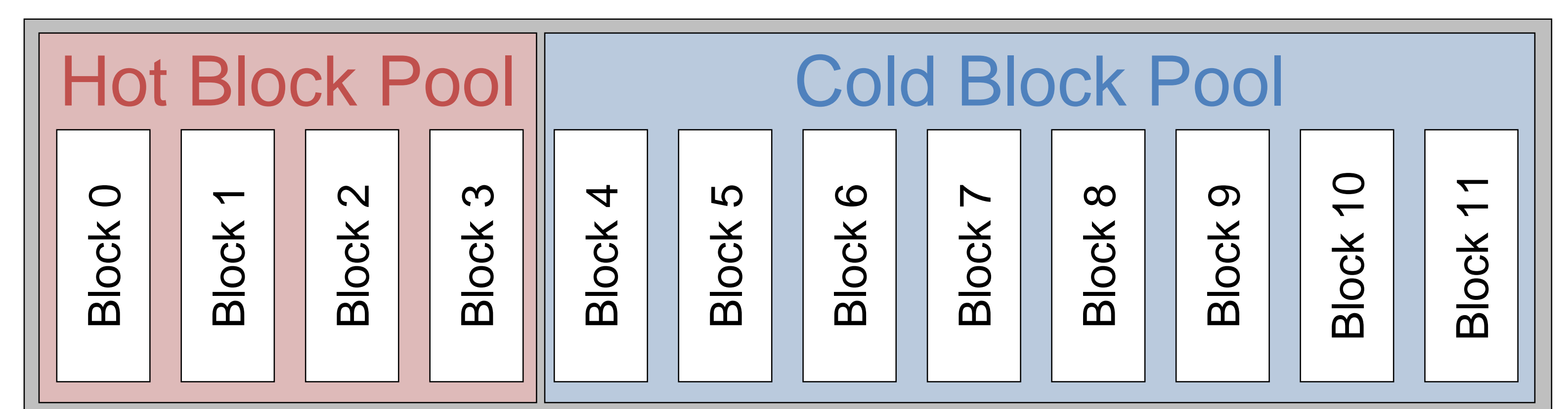


WARM: Write-hotness Aware Retention Mgmt.

- Physically partition pages into two groups using **write frequency**: *write-hot* and *write-cold*
 - Virtual queues for dynamic page reclassification
 - Cooldown window to minimize ping-ponging



- Apply different policies (garbage collection, wear-leveling, refresh) to each group



Write-hot Data

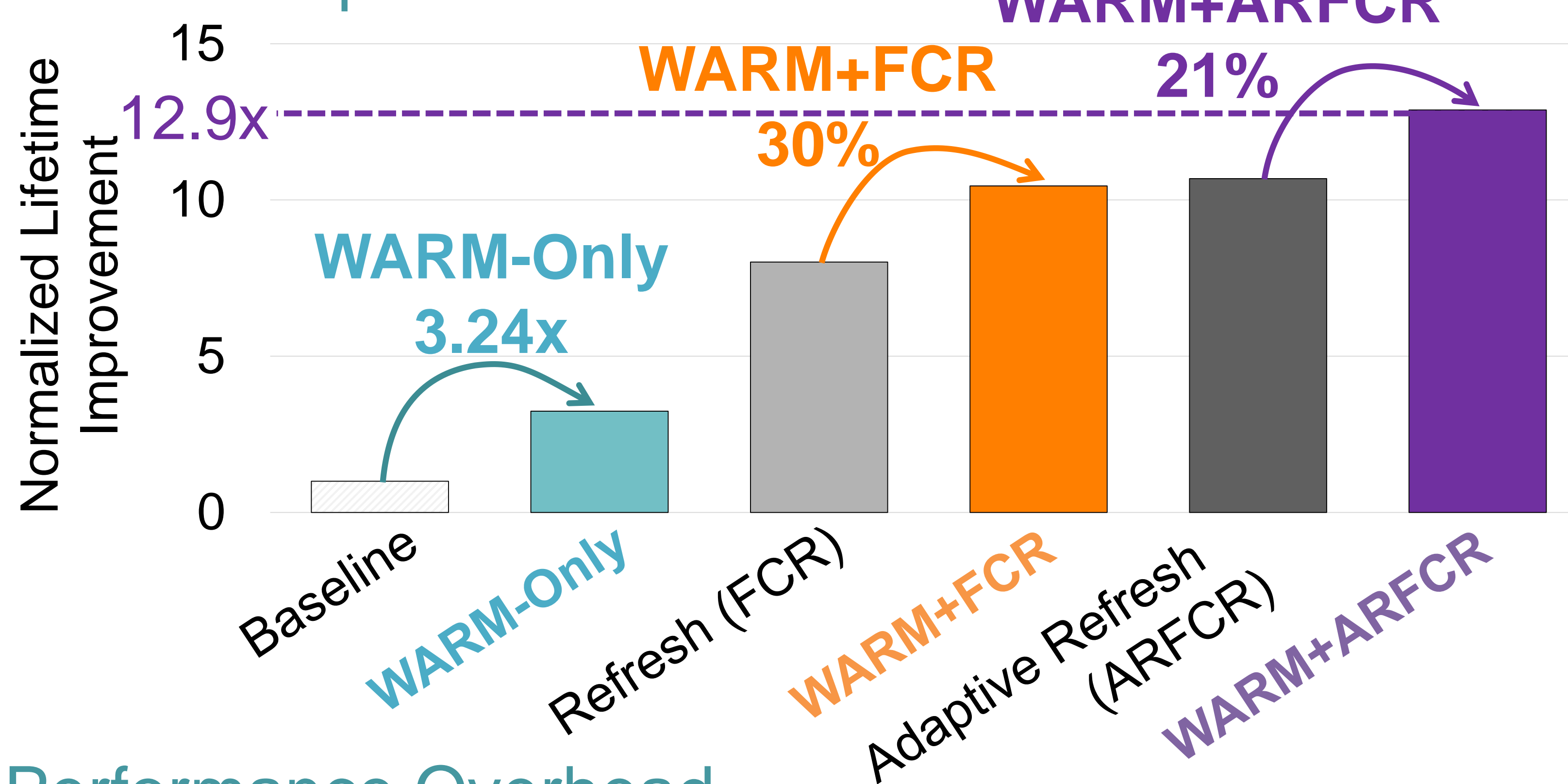
- Naturally relaxed retention time – **no refresh needed**
- Program and garbage collect in block order
- Naturally wear-leveled

Write-cold Data

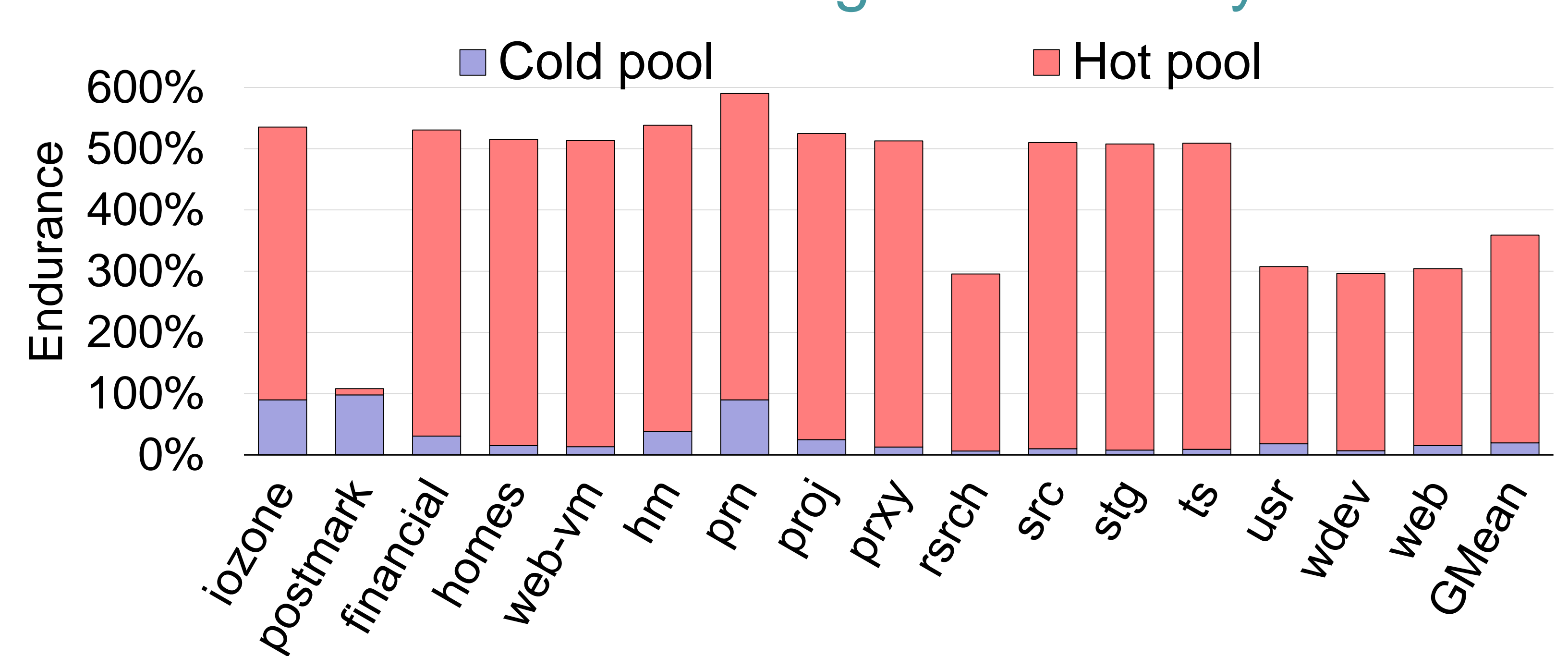
- Low write frequency → slower wear-out
- Conventional garbage collection and wear-leveling

WARM Results

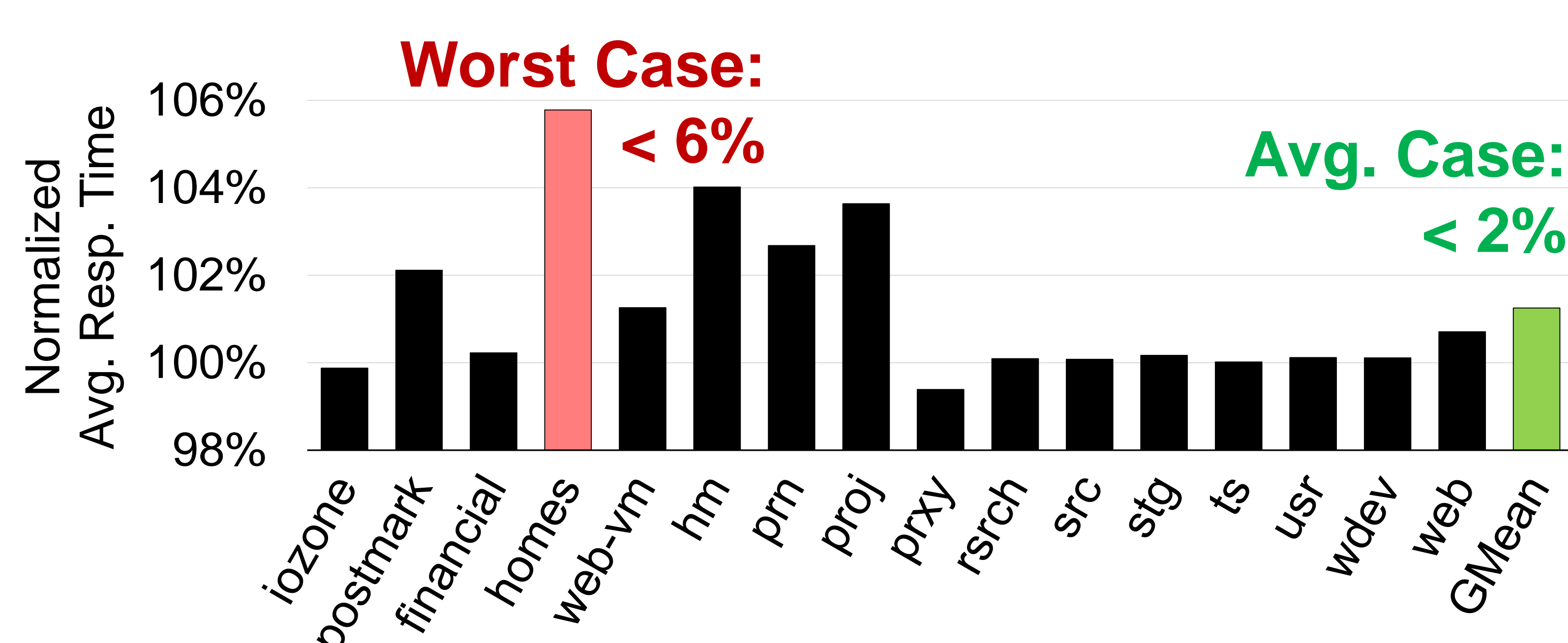
Lifetime Improvements



Increase in Endurance Using WARM-Only



Performance Overhead



Reduction in Refresh Operations w/ WARM

