Improving Cache Performance by Exploiting Read-Write Disparity

Samira Khan, Alaa R. Alameldeen, Chris Wilkerson, Onur Mutlu, and Daniel A. Jiménez

Summary

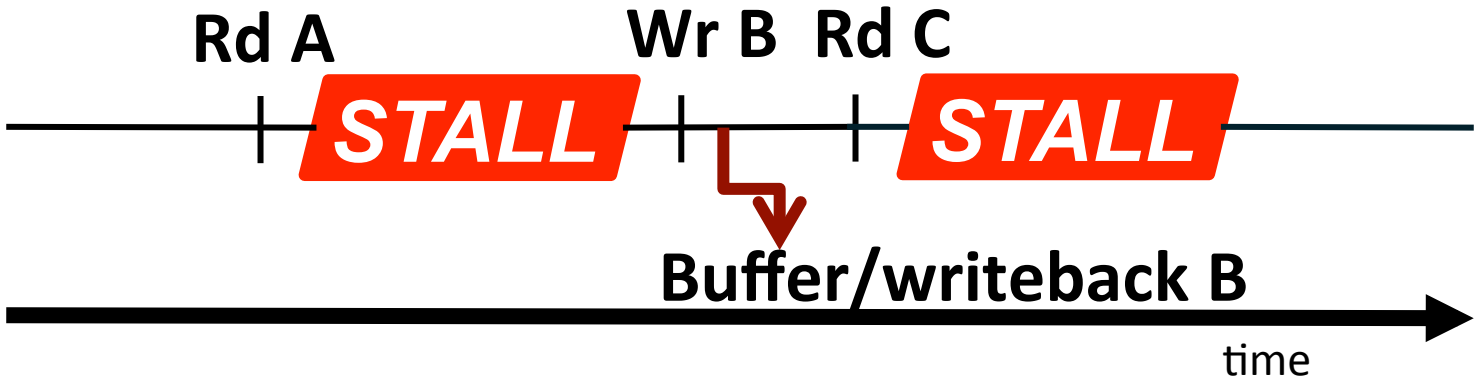
- Read misses are more critical than write misses
  - Read misses can stall processor, writes are not on the critical path
- **Problem:** Cache management does not exploit read-write disparity
- **Goal:** Design a cache that favors reads over writes to improve performance
  - Lines that are **only written to** are **less critical**
  - **Prioritize** lines that service **read requests**
- **Key observation:** Applications differ in their read reuse behavior in clean and dirty lines
- **Idea:** Read-Write Partitioning
  - Dynamically partition the cache between clean and dirty lines
  - Protect the partition that has more read hits
- **Improves performance over three recent mechanisms**

Outline

- **Motivation**
- **Reuse Behavior of Dirty Lines**
- **Read-Write Partitioning**
- **Results**
- **Conclusion**

Motivation

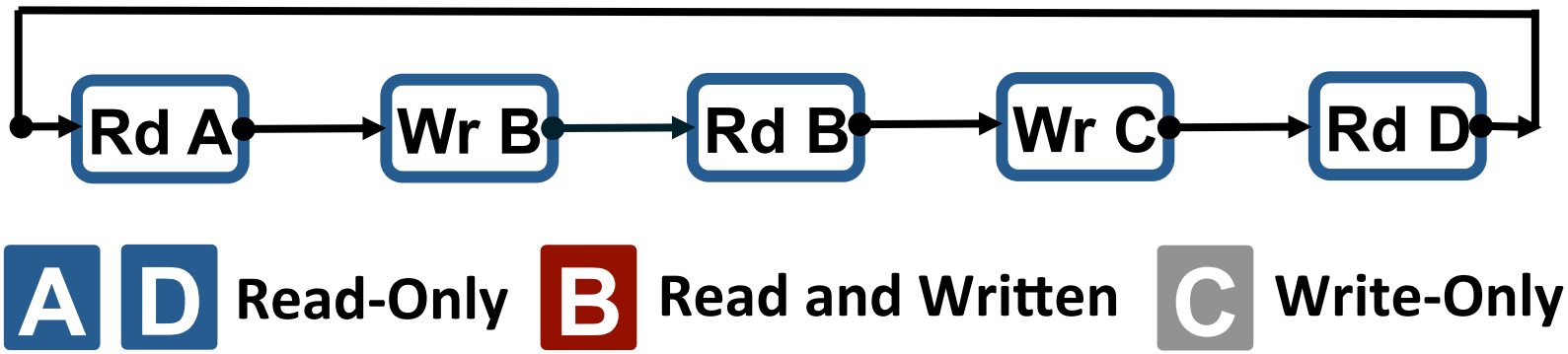
- Read and write misses are not equally critical
- Read misses are more critical than write misses
  - Read misses can stall the processor
  - Writes are not on the critical path



Cache management does not exploit the disparity between read-write requests

Key Idea

- Favor reads over writes in cache
- Differentiate between **read** vs. **only written to** lines
- Cache should protect lines that serve read requests
  - Lines that are **only written to** are **less critical**
- Improve performance by maximizing **read hits**
- An Example



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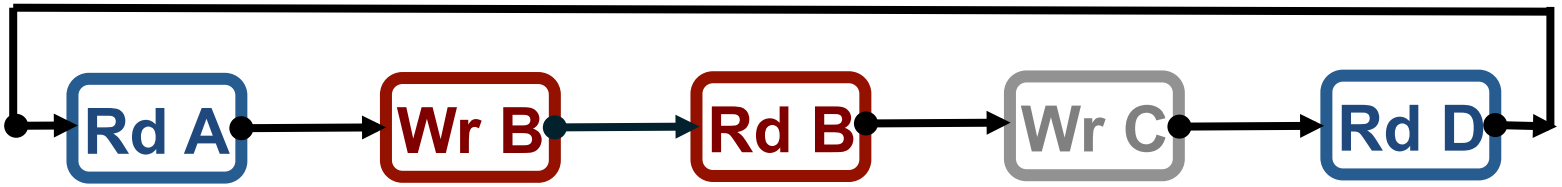
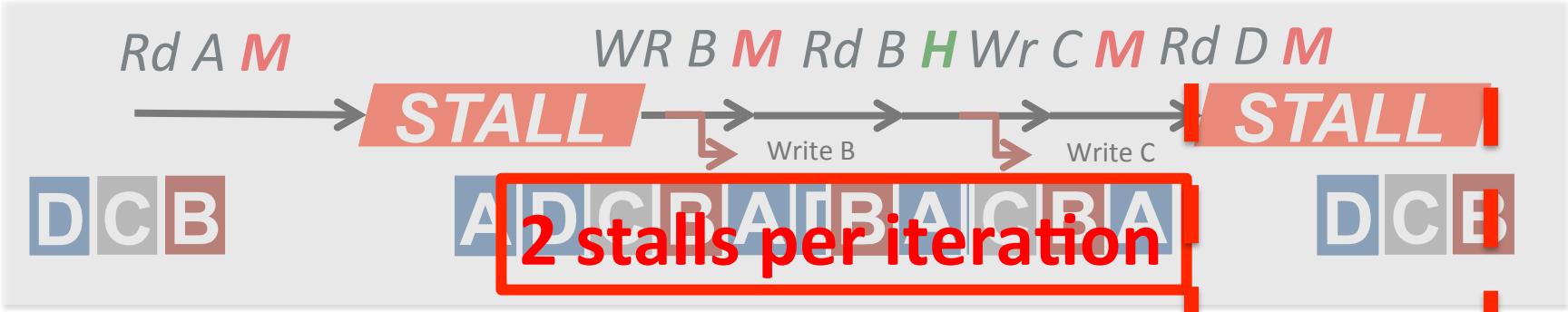
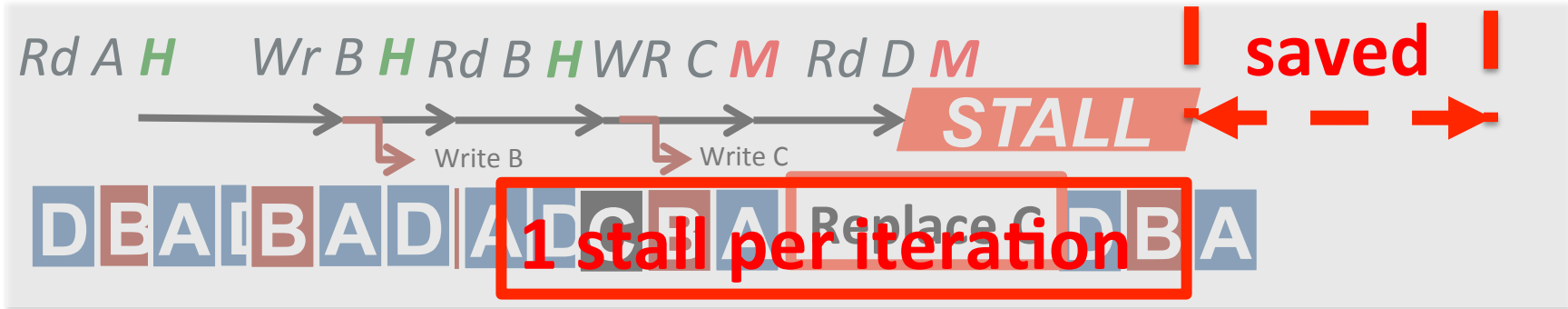




LRU Replacement Policy



Read-Biased Replacement Policy

cycles saved

Dirty lines treated differently to reduce performance

Evicting lines treated equally to improve performance

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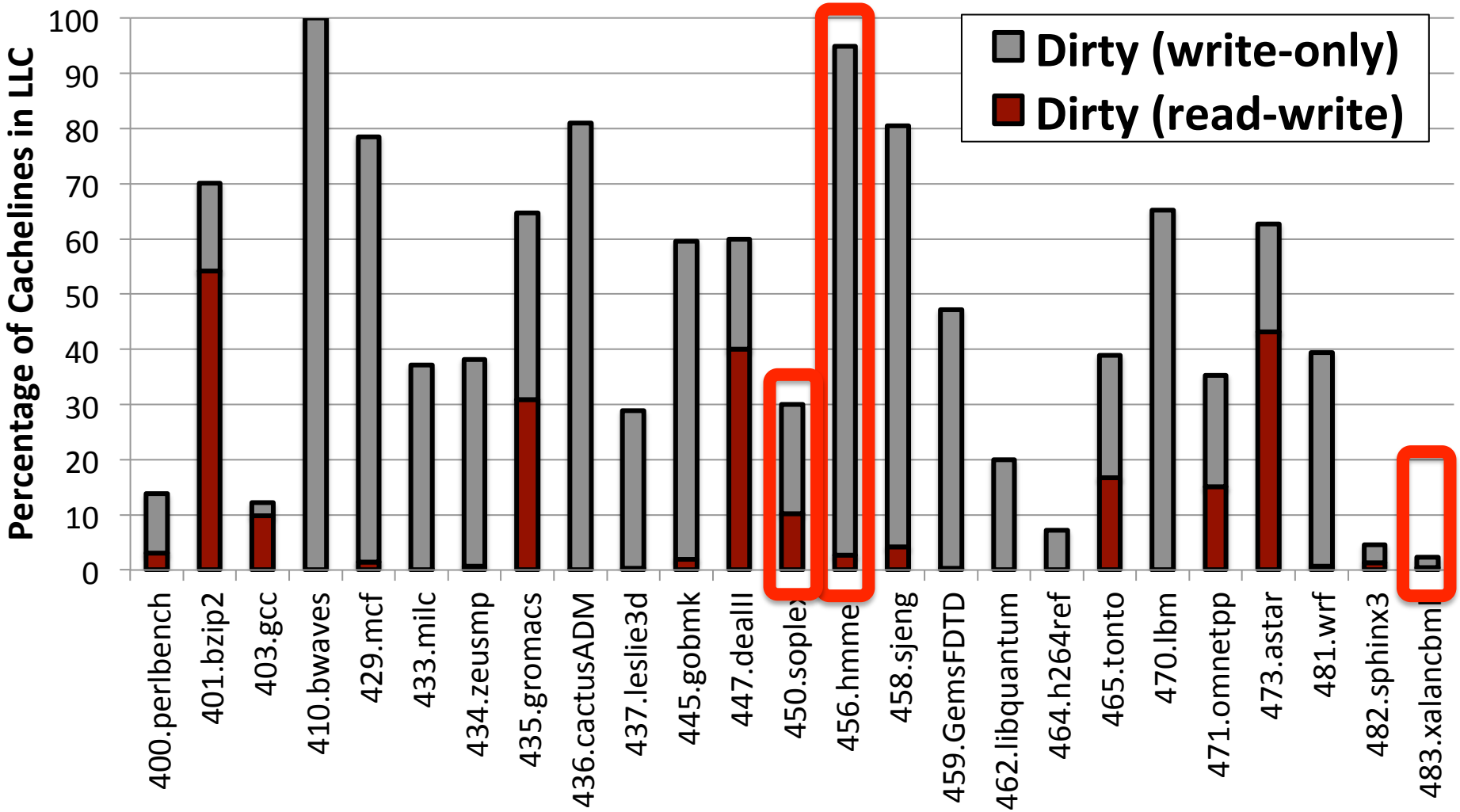
Reuse Behavior of Dirty Lines

- Not all dirty lines are the same
- Write-only Lines
  - Do not receive read requests, can be evicted
- Read-Write Lines
  - Receive read requests, should be kept in the cache

Evicting write-only lines provides more space for read lines and can improve performance

Reuse Behavior of Dirty Lines



Applications have different reuse behavior

On average, 37% lines are read or written only, 9.4% lines are both read and written

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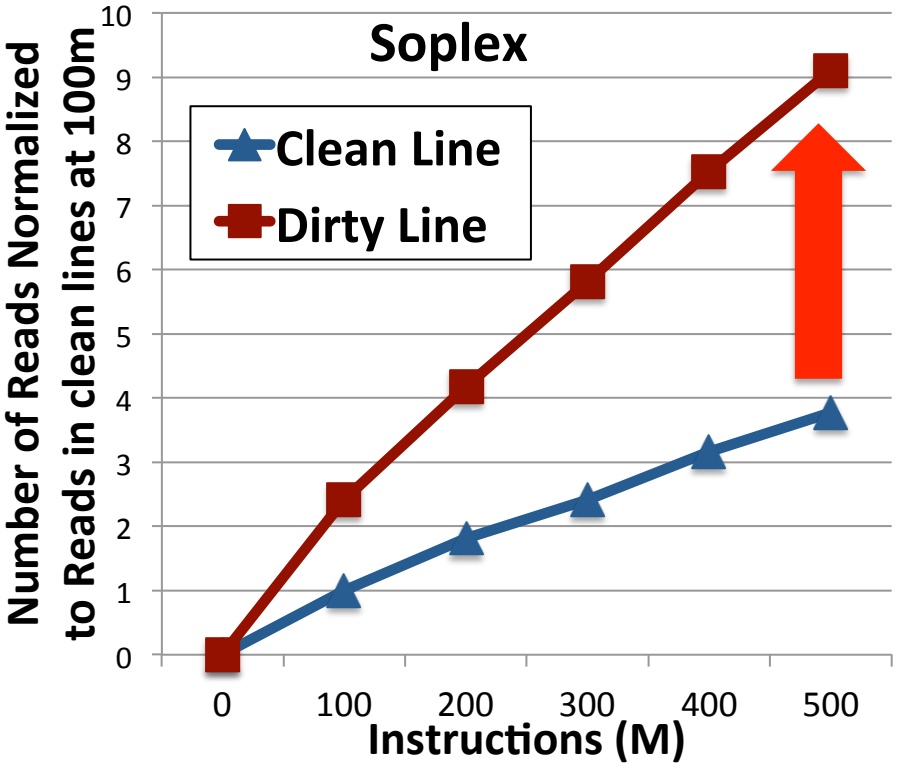
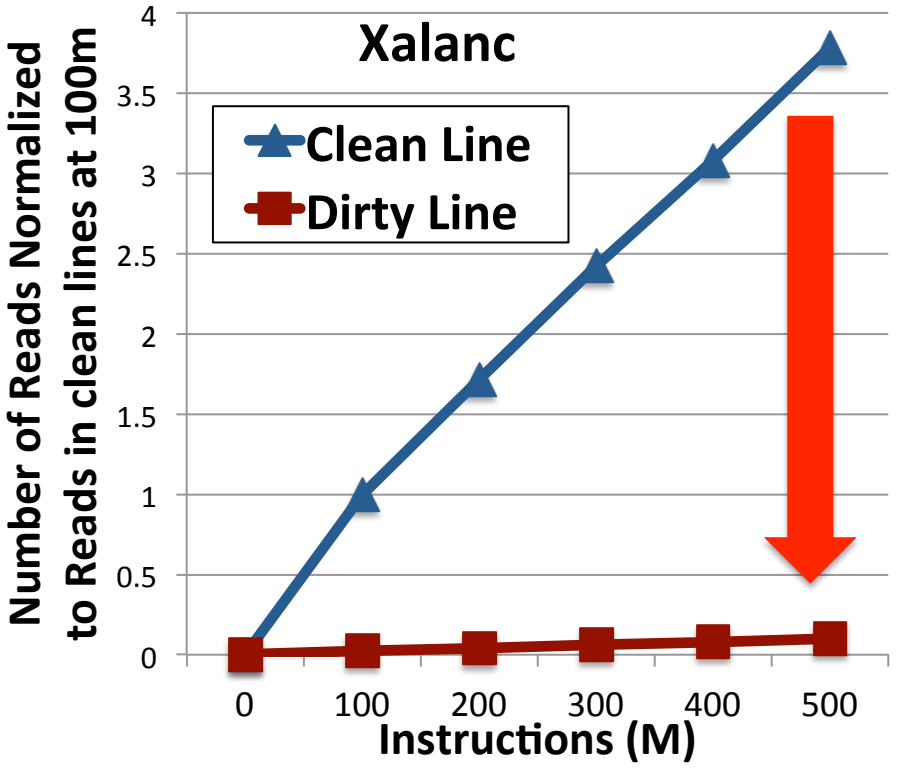
Read-Write Partitioning

- **Goal:** Exploit different read reuse behavior in dirty lines to maximize number of read hits
- **Observation:**
  - Some applications have more reads to clean lines
  - Other applications have more reads to dirty lines
- **Read-Write Partitioning:**
  - Dynamically partitions the cache in clean and dirty lines
  - Evict lines from the partition that has less read reuse

Improves performance by protecting lines with more read reuse

Read-Write Partitioning

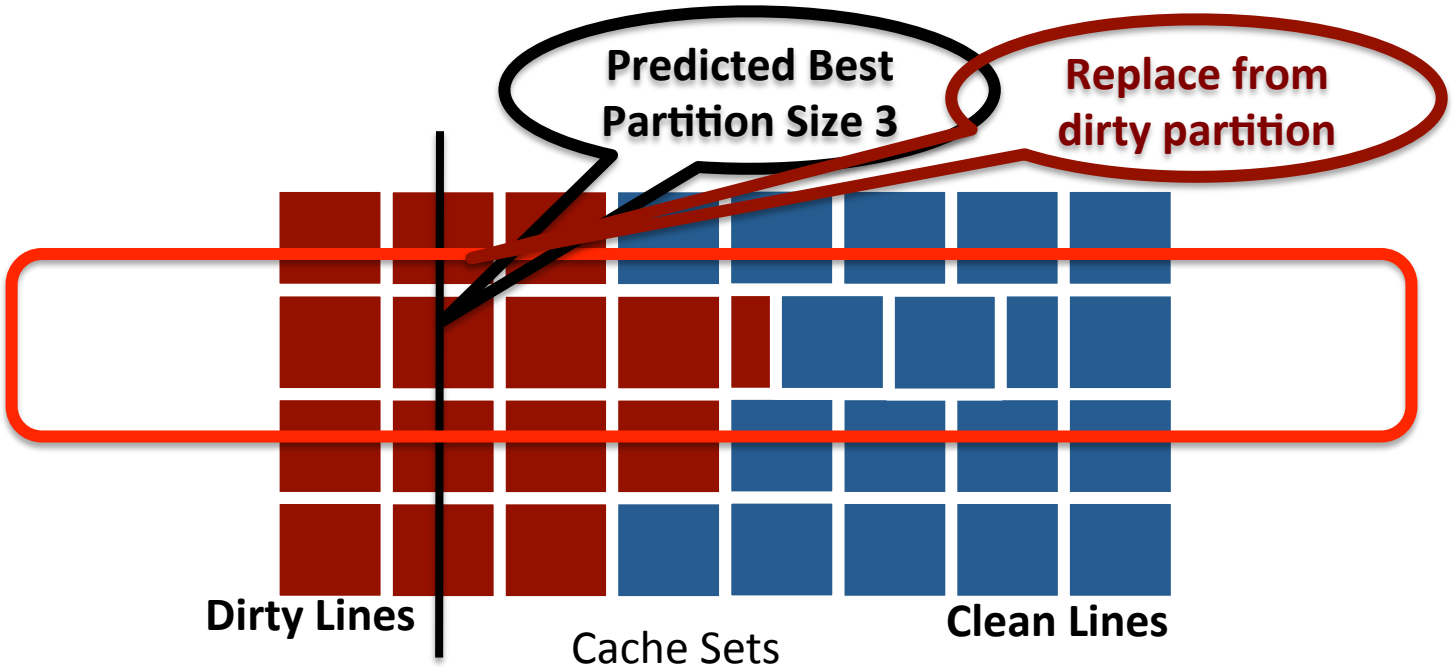




Applications have significantly different read reuse behavior in clean and dirty lines

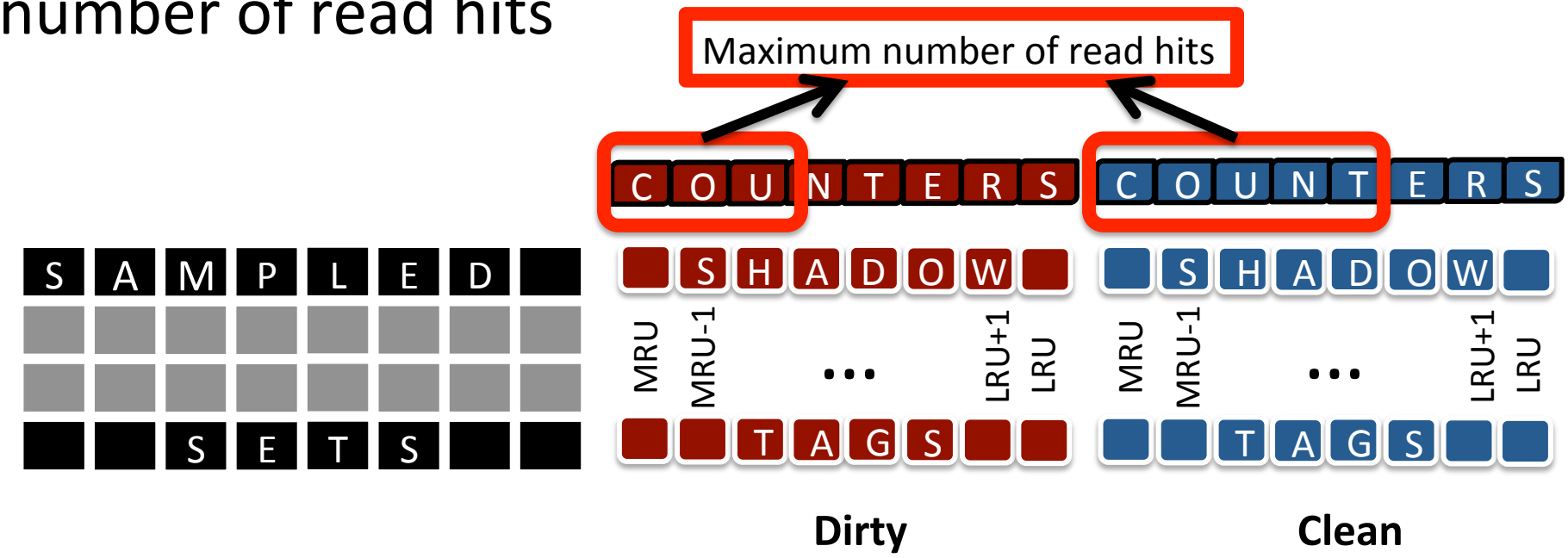
Read-Write Partitioning

- Utilize disparity in read reuse in clean and dirty lines
- Partition the cache into clean and dirty lines
- Predict the partition size that maximizes read hits
- Maintain the partition through replacement
  - DIP [Qureshi *et al.* 2007] selects victim within the partition



Predicting Partition Size

- Predicts partition size using sampled shadow tags
  - Based on utility-based partitioning [Qureshi *et al. 2006*]
- Counts the number of read hits in clean and dirty lines
- Picks the partition (x, associativity – x) that maximizes number of read hits



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Methodology

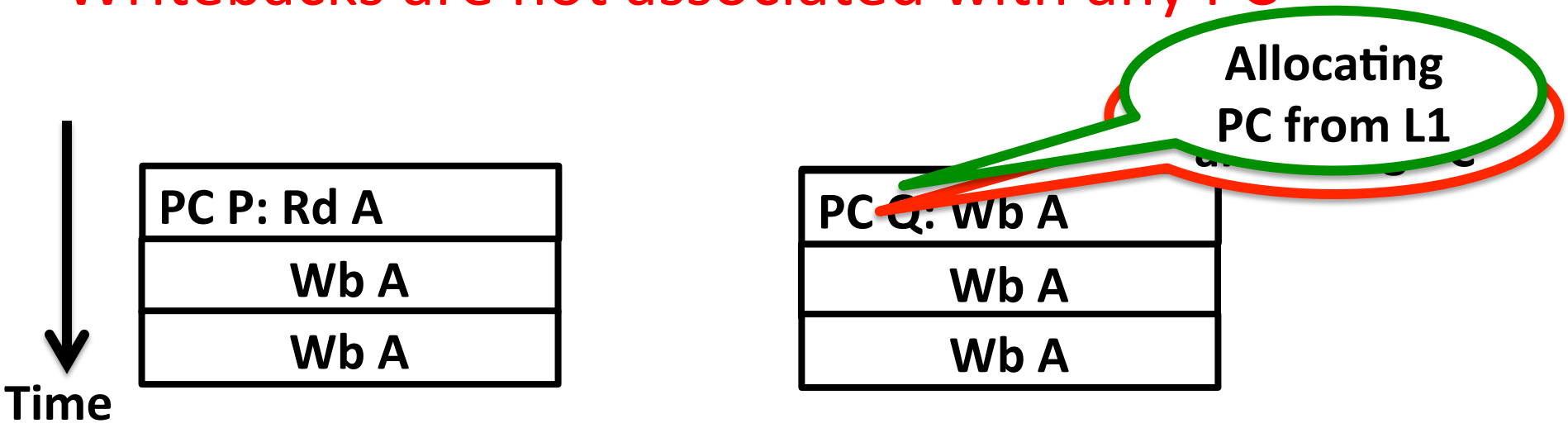
- CMP$im x86 cycle-accurate simulator [Jaleel *et al.* 2008]
- 4MB 16-way set-associative LLC
- 32KB I+D L1, 256KB L2
- 200-cycle DRAM access time
- 550m representative instructions
- Benchmarks:
  - 10 memory-intensive SPEC benchmarks
  - 35 multi-programmed applications

Comparison Points

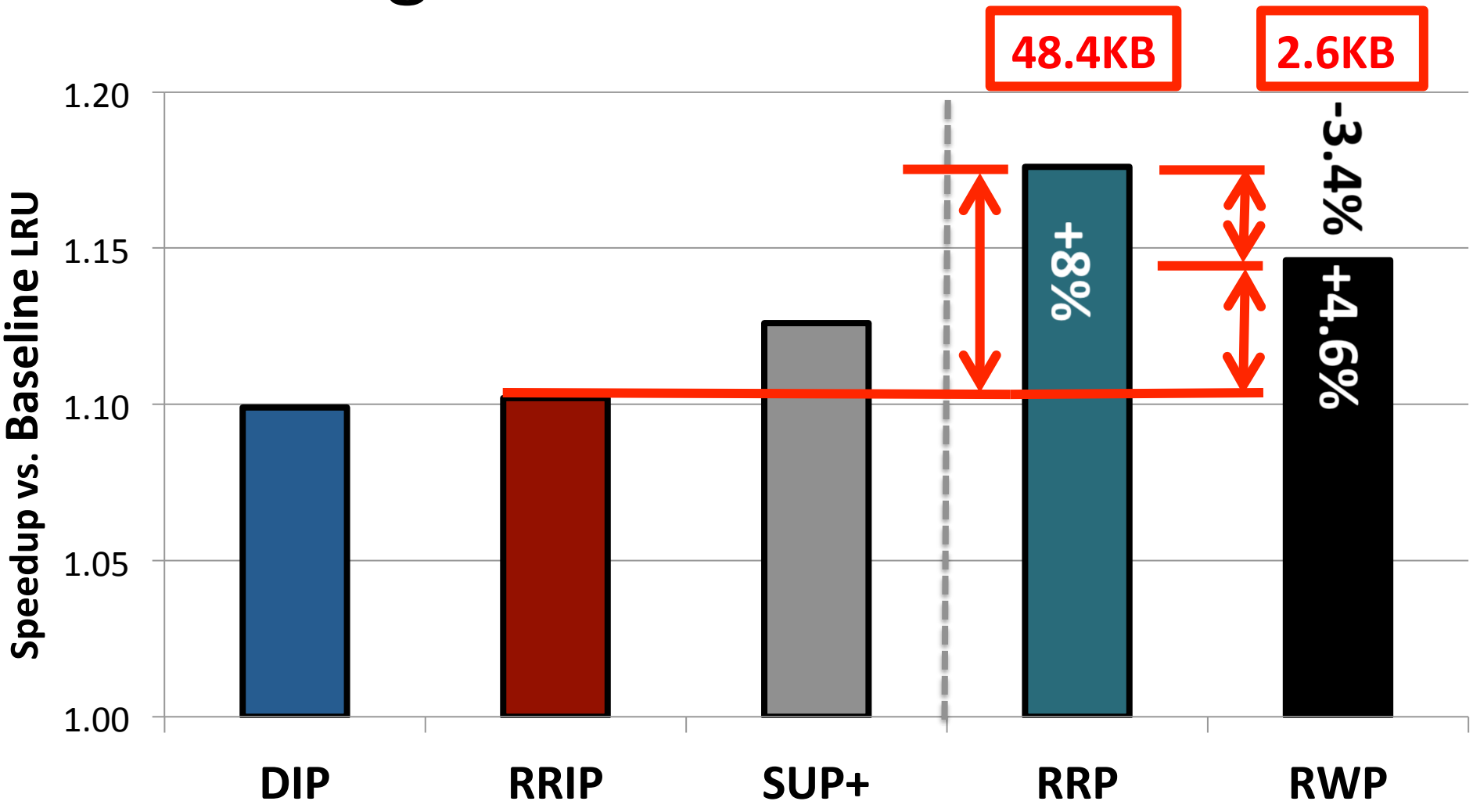
- DIP, RRIP: Insertion Policy [Qureshi *et al.* 2007, Jaleel *et al.* 2010]
  - Avoid thrashing and cache pollution
    - Dynamically insert lines at different stack positions
  - Low overhead
  - Do not differentiate between read-write accesses
- SUP+: Single-Use Reference Predictor [Piquet *et al.* 2007]
  - Avoids cache pollution
    - Bypasses lines that do not receive re-references
  - High accuracy
  - Does not differentiate between read-write accesses
    - Does not bypass write-only lines
  - High storage overhead, needs PC in LLC

Comparison Points: Read Reference Predictor (RRP)

- A new predictor inspired by prior works [Tyson *et al.* 1995, Piquet *et al.* 2007]
- Identifies read and write-only lines by allocating PC
  - Bypasses write-only lines
- Writebacks are not associated with any PC



Single Core Performance

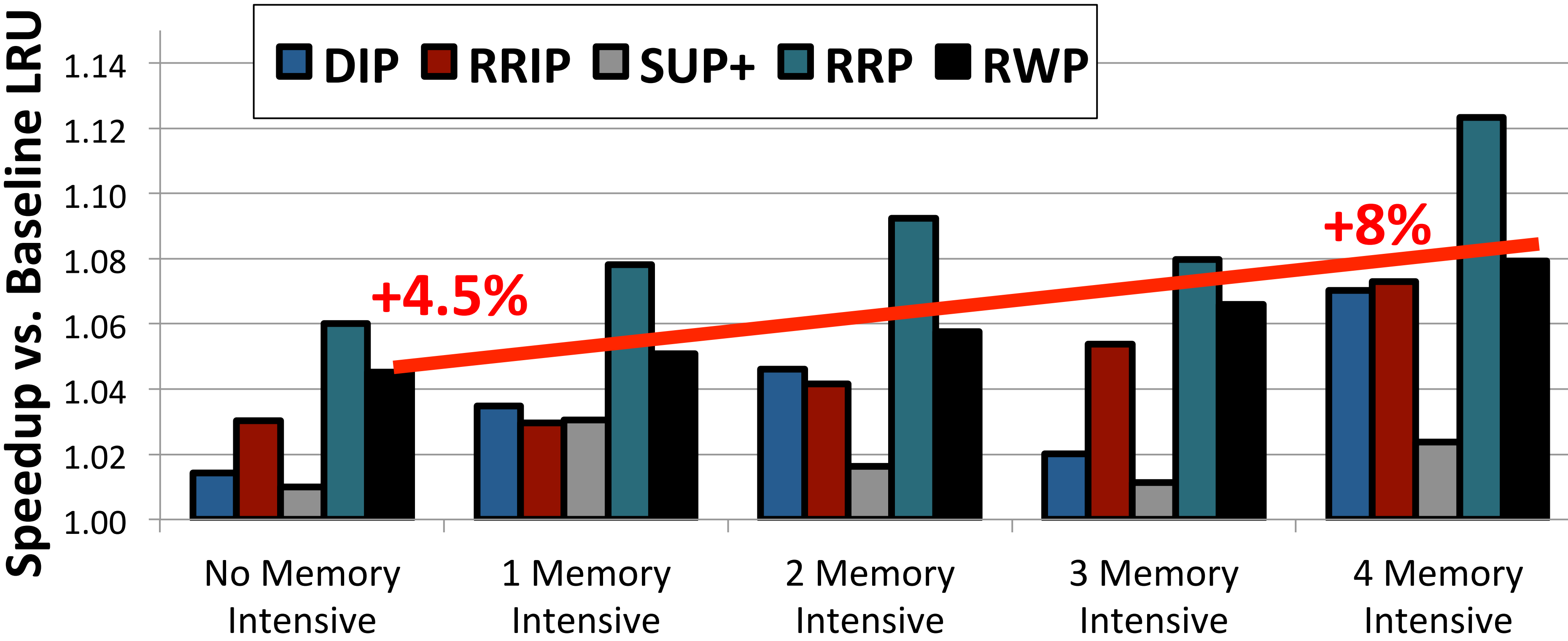


Different performance and storage overheads

RWP performs within 3.4% of RRP, but requires 18X less storage overhead

RWP improves performance over recent mechanisms

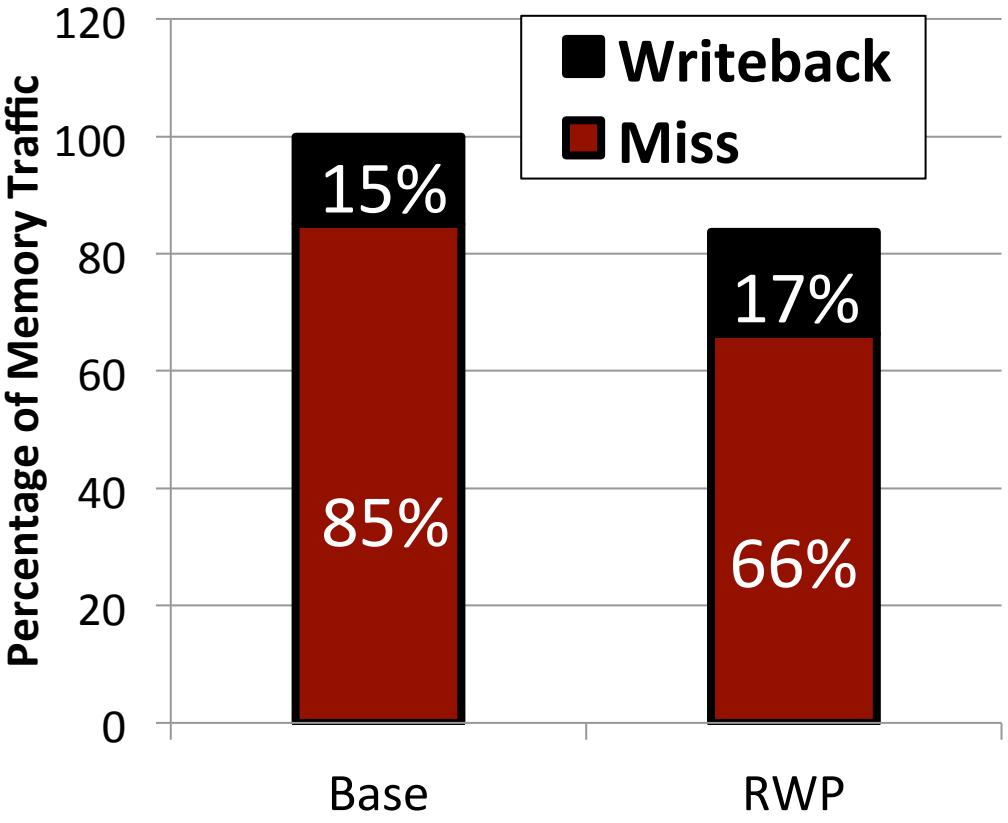
4 Core Performance



Differentiating read vs. write-only lines improves performance over recent mechanisms

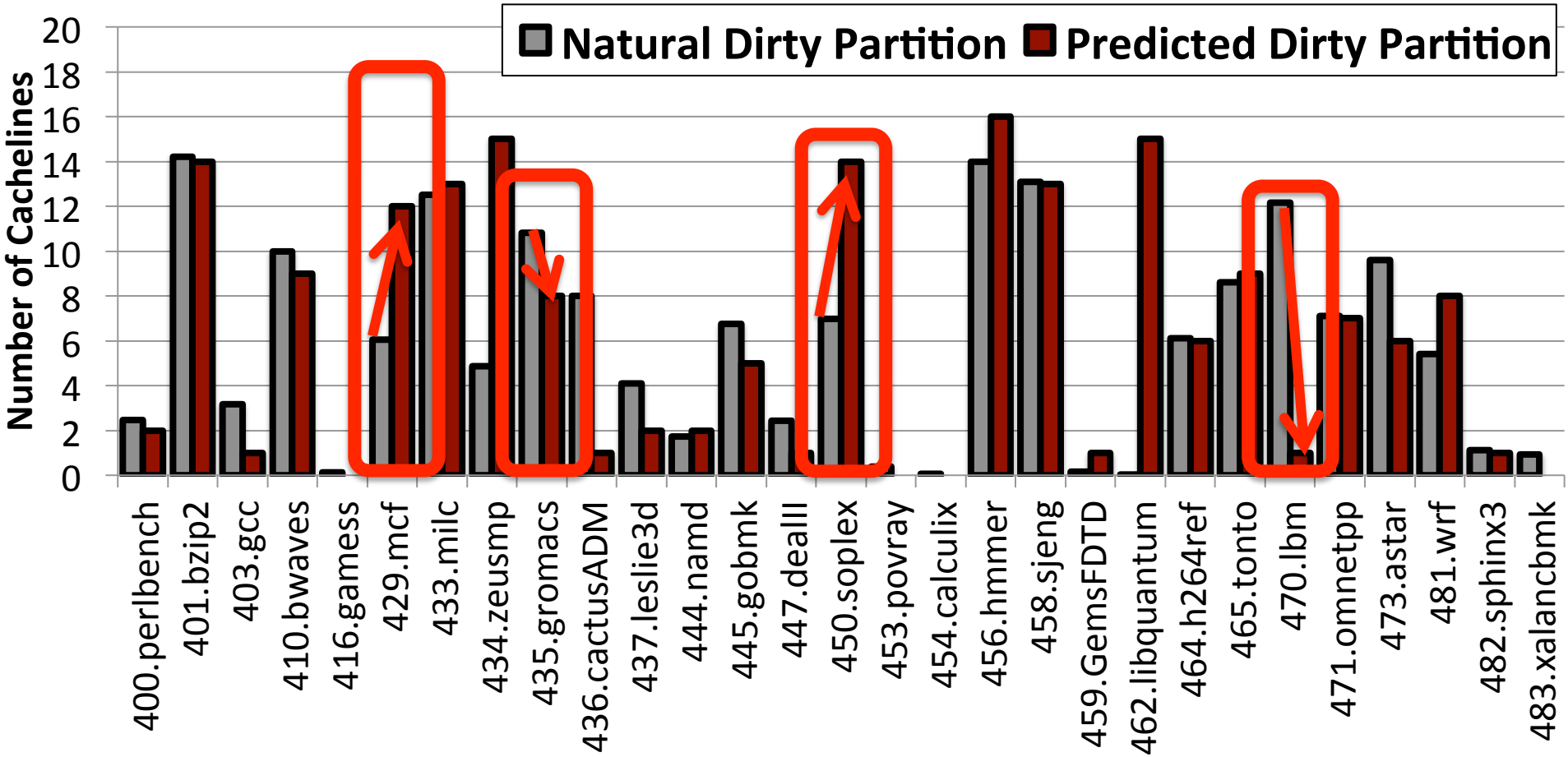
More benefit when more applications are memory intensive

Average Memory Traffic



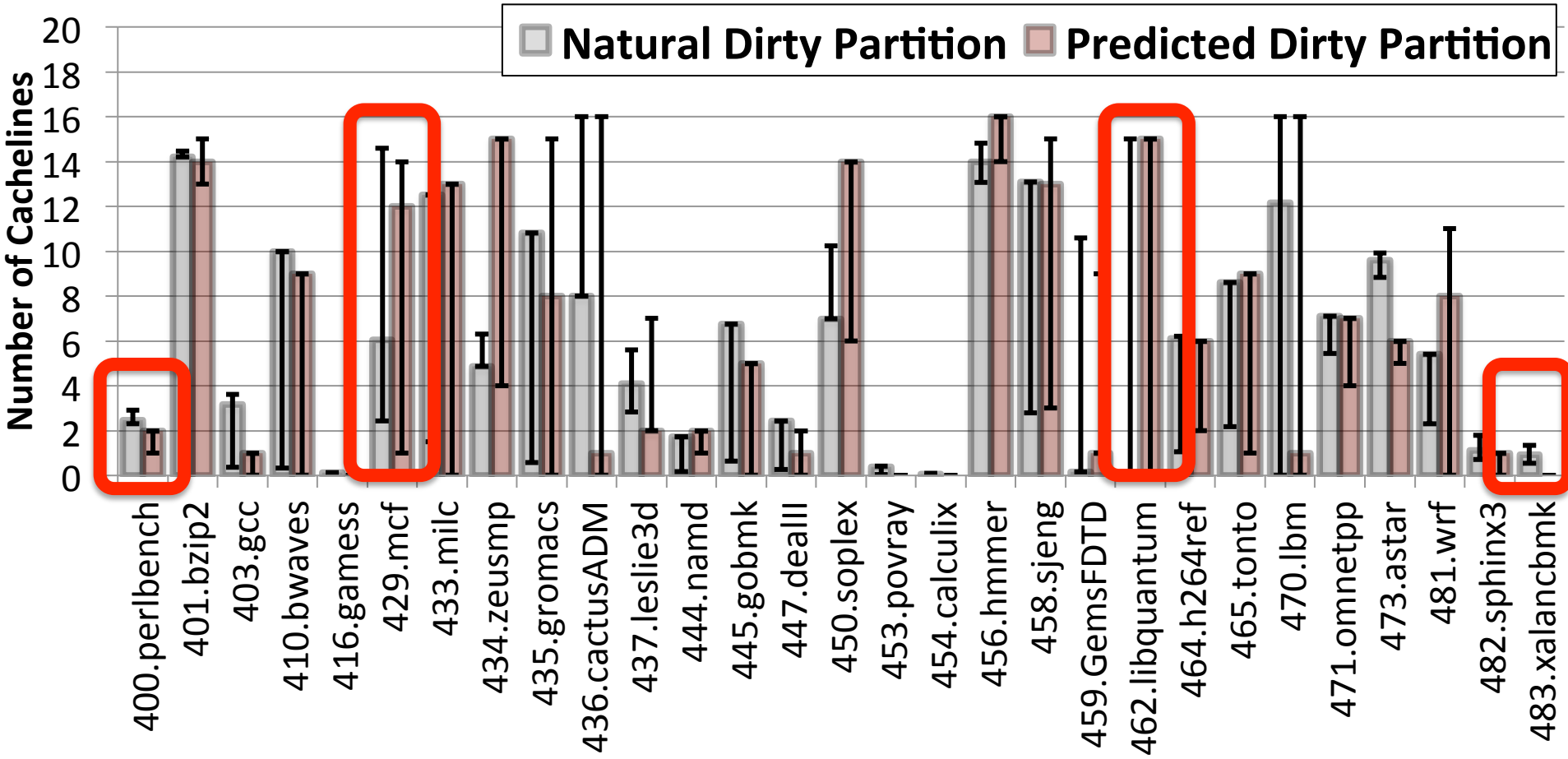
Increases writeback traffic by 2.5%,
but reduces overall memory traffic by 16%

Dirty Partition Sizes



Partition size varies significantly for some benchmarks

Dirty Partition Sizes



Partition size varies significantly during the runtime for some benchmarks

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Thank you

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