Improving Cache Performance by Exploiting Read-Write Disparity

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

Summary

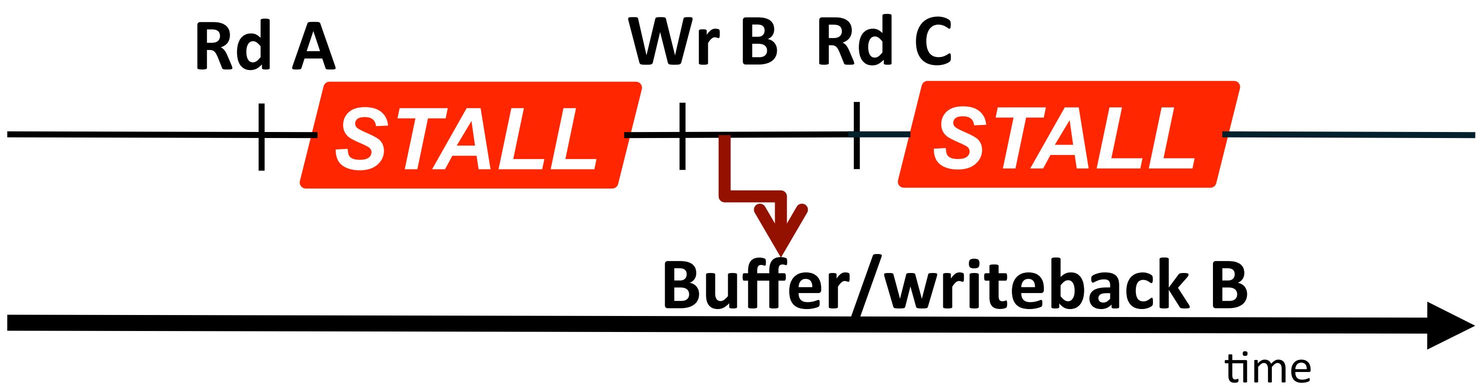
- Read misses are more critical than write misses
  - Read misses can stall processor, writes are not on the critical path
- **Problem:** Cache management does not exploit read-write disparity
- **Goal:** Design a cache that favors reads over writes to improve performance
  - Lines that are **only written 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

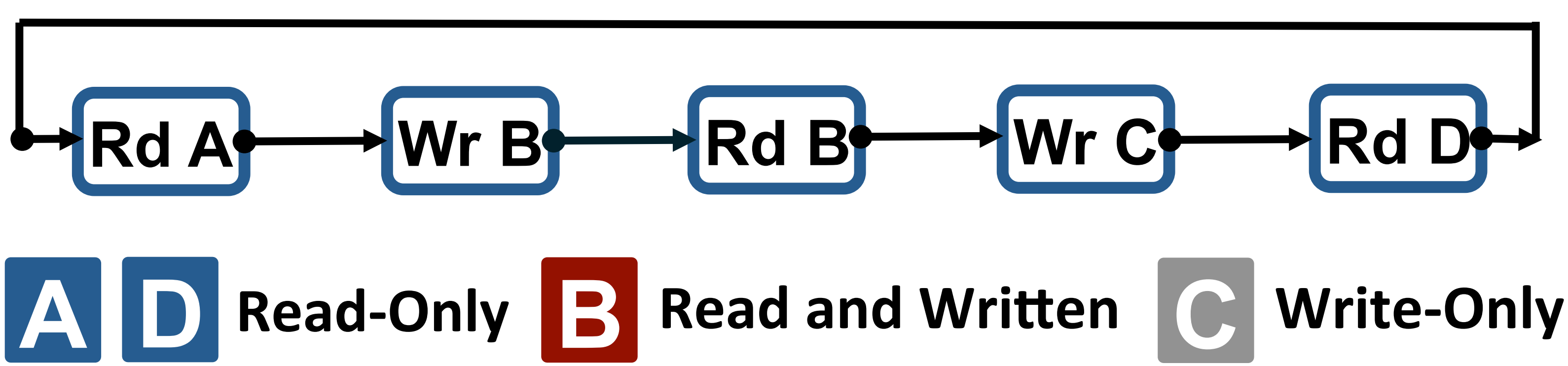
- Read and write misses are not equally critical
- Read misses are more critical than write misses
  - Read misses can stall the processor
  - Writes are not on the critical path



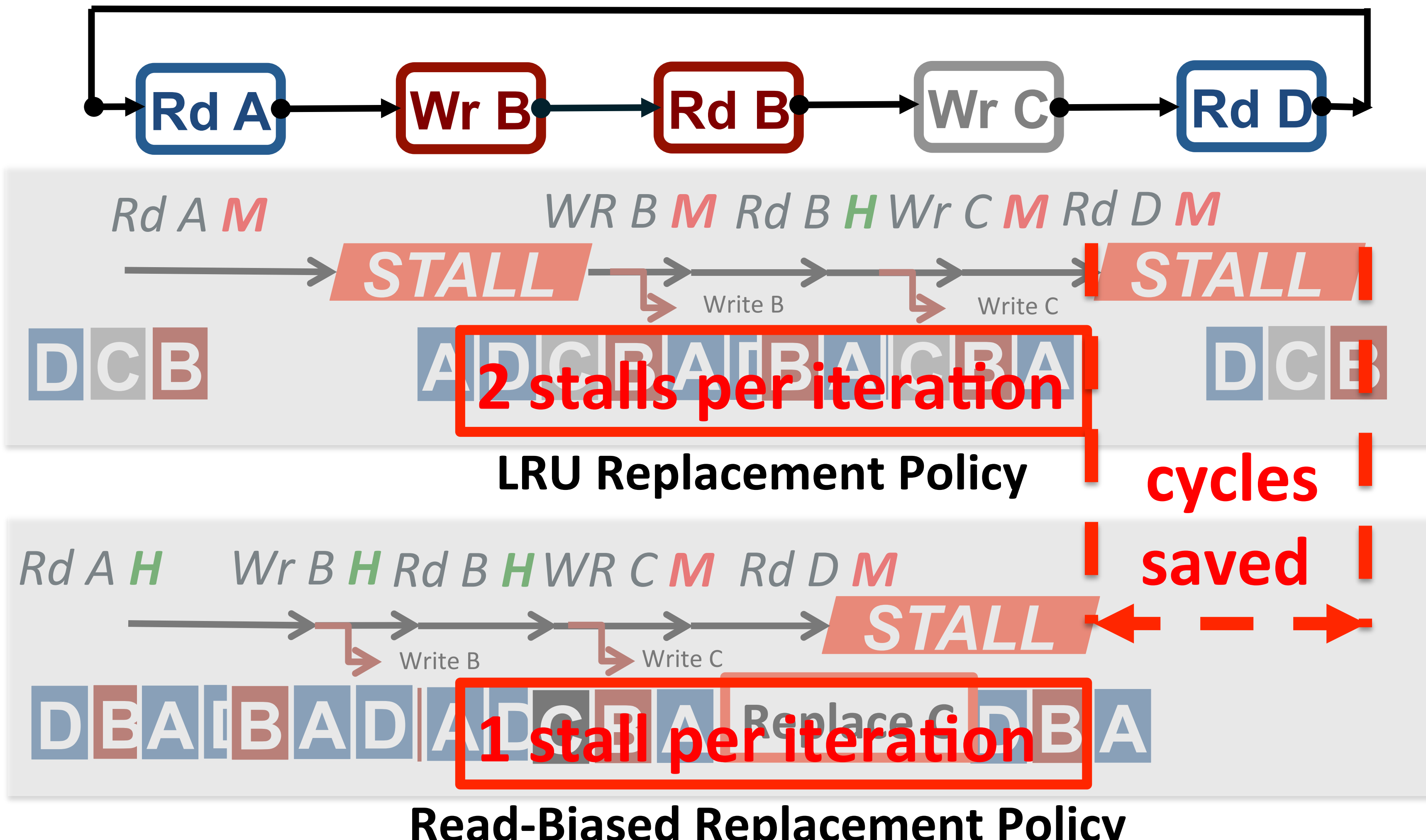
Cache management does not exploit the disparity between read-write requests

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



An Example



Evicting lines that are only written to can improve performance

Dirty lines are treated differently depending on read requests

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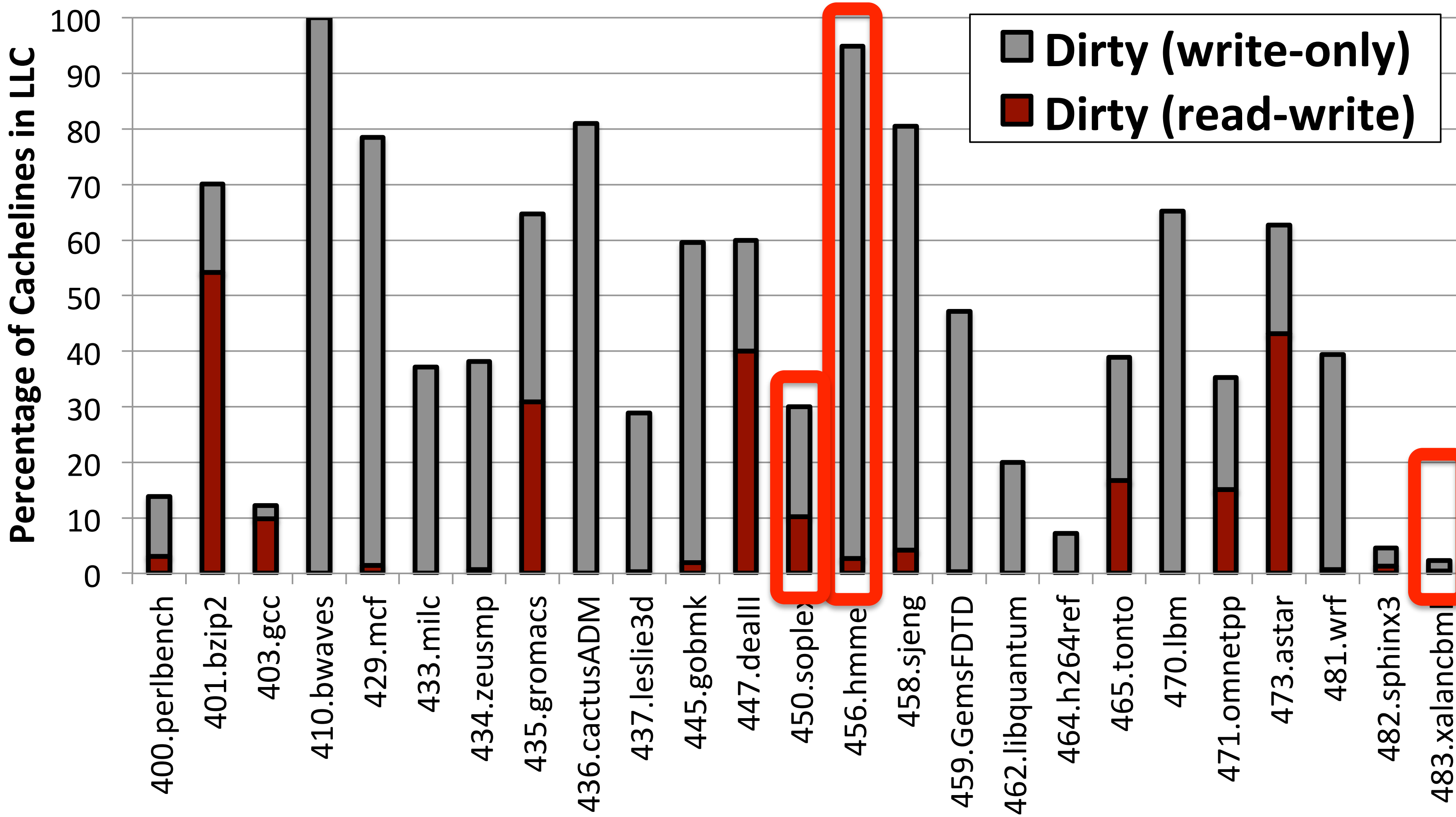
Reuse Behavior of Dirty Lines

- 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 read/write behavior in dirty lines

On average 37.4% lines are write-only, 9.4% lines are both read and written

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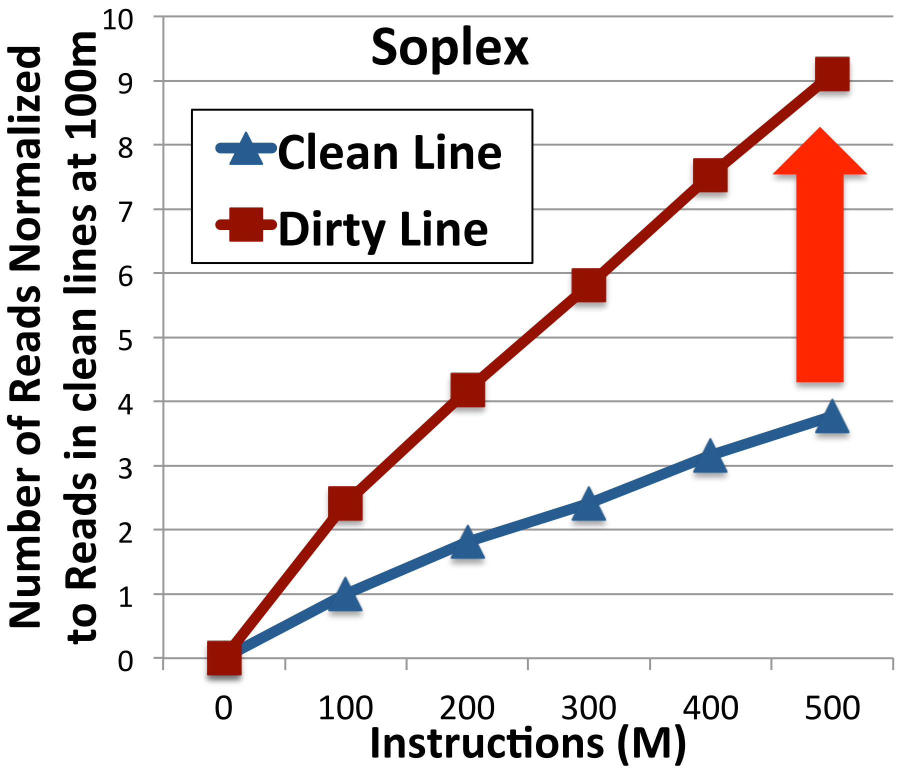
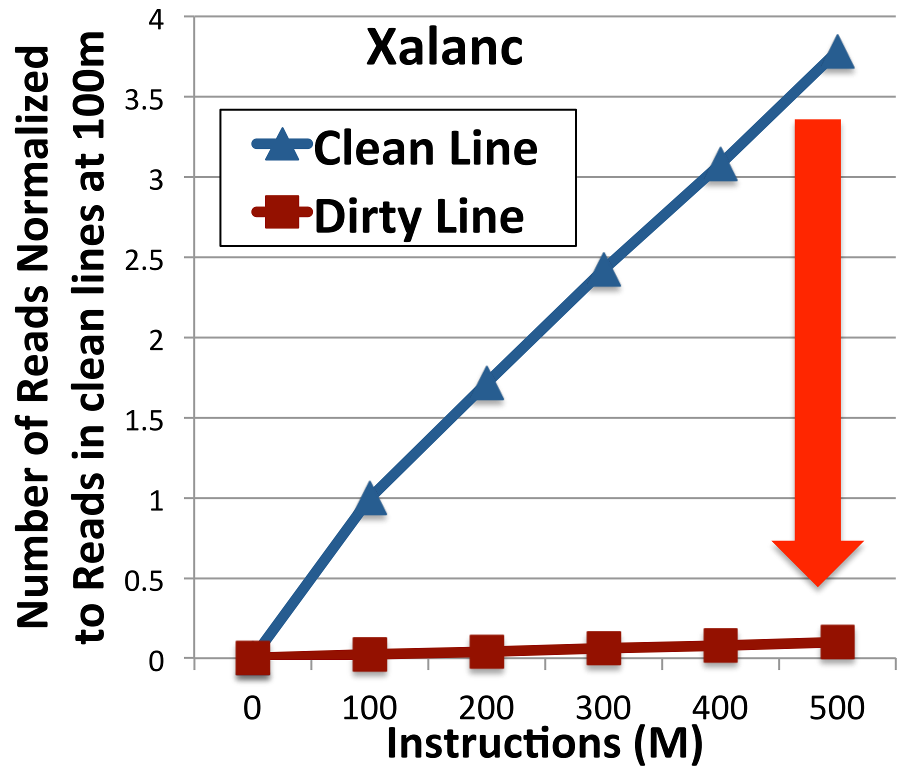
Read-Write Partitioning

- **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

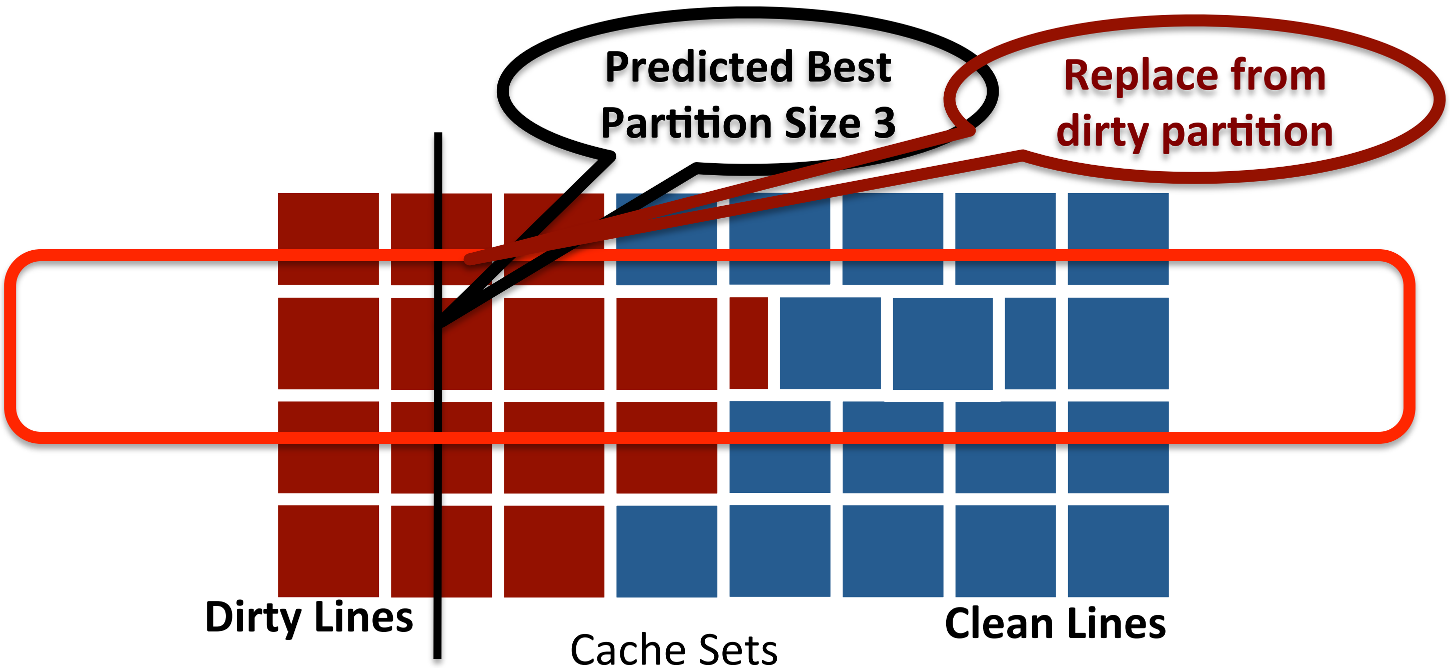




Applications have significantly different read reuse behavior in clean and dirty lines

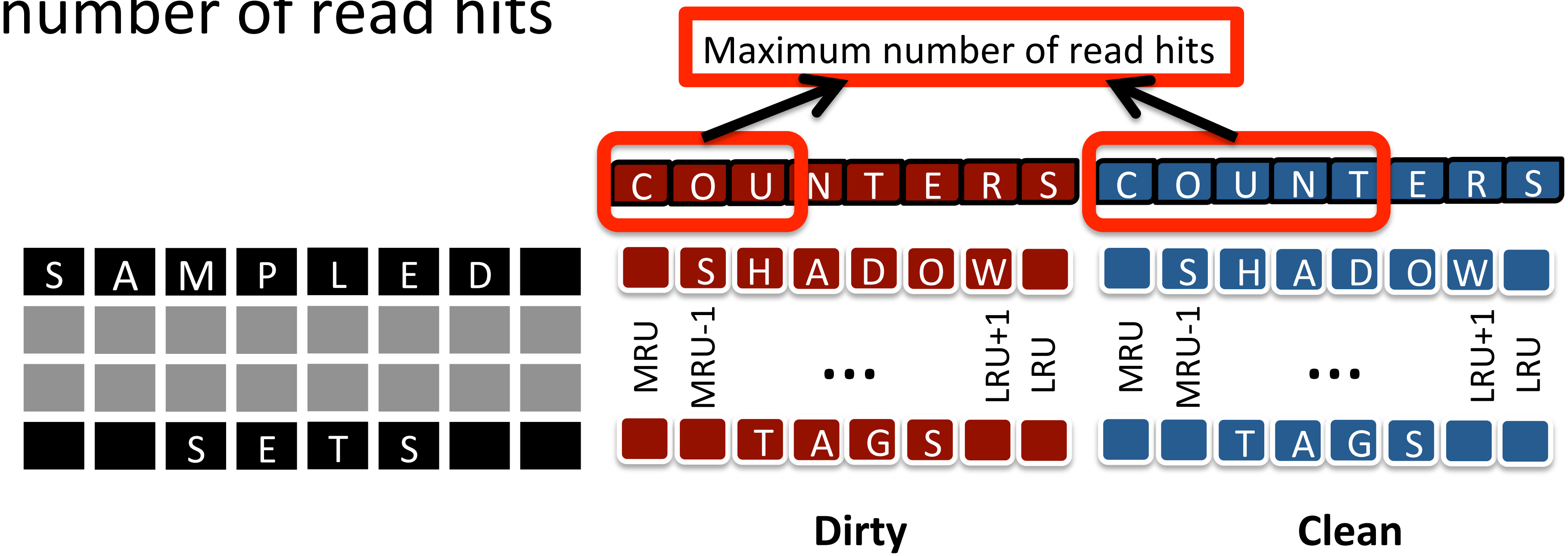
Read-Write Partitioning

- 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

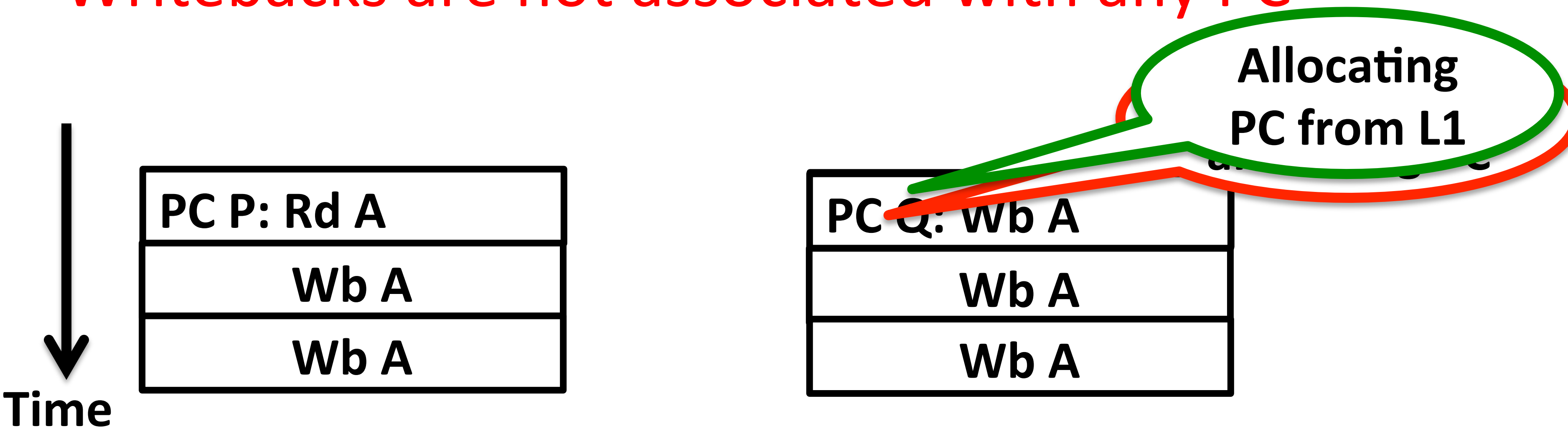
- CMP$im x86 cycle-accurate simulator [Jaleel *et al.* 2008]
- 4MB 16-way set-associative LLC
- 32KB I+D L1, 256KB L2
- 200-cycle DRAM access time
- 550m representative instructions
- Benchmarks:
  - 10 memory-intensive SPEC benchmarks
  - 35 multi-programmed applications

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)

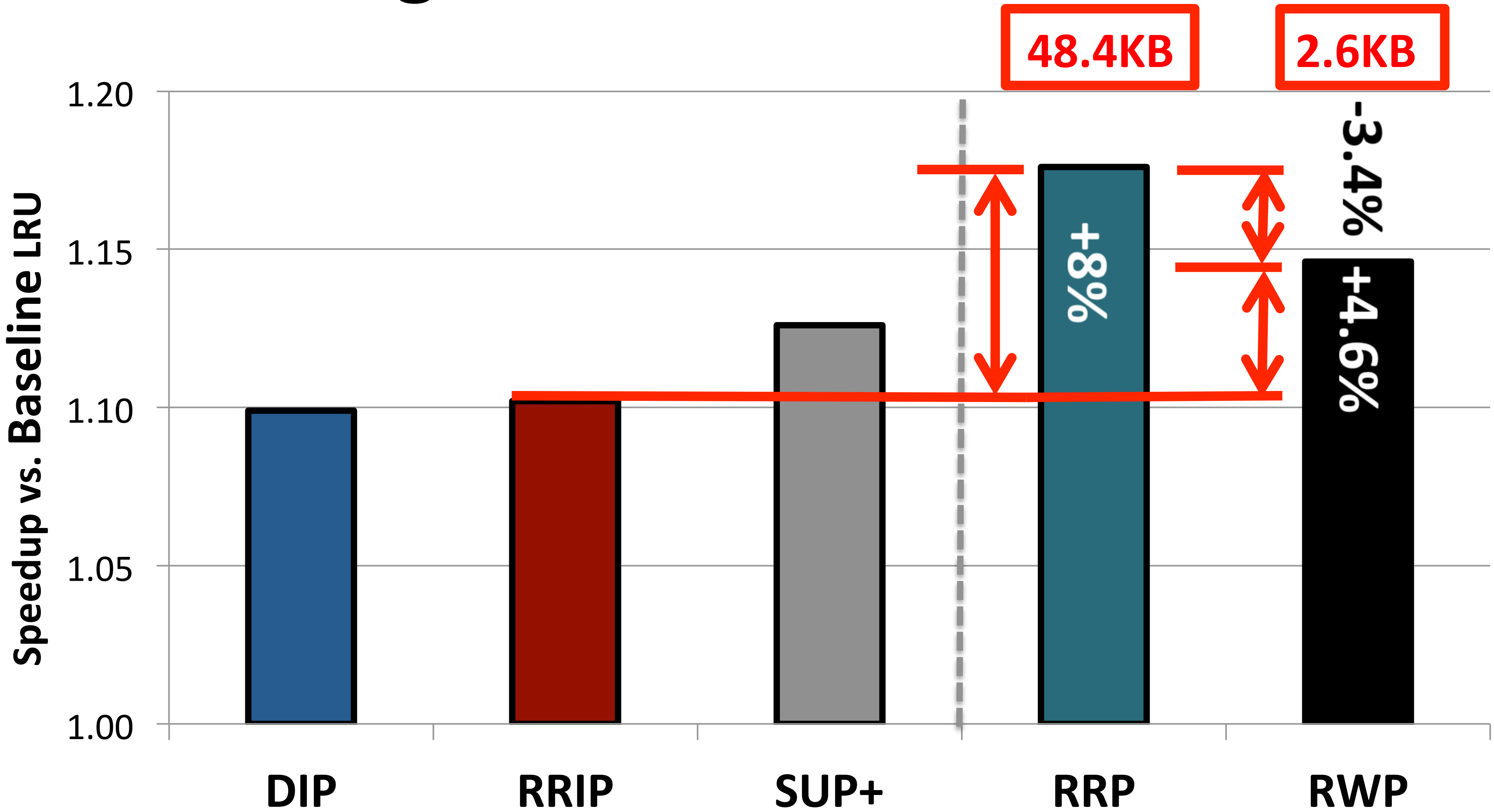
- A new predictor inspired by prior works [Tyson *et al.* 1995, Piquet *et al.* 2007]
- Identifies read and write-only lines by allocating PC
  - Bypasses write-only lines
- Writebacks are not associated with any PC



Associates the allocating PC in L1 and passes PC in L2, LLC

Marks P as a PC that is not read again

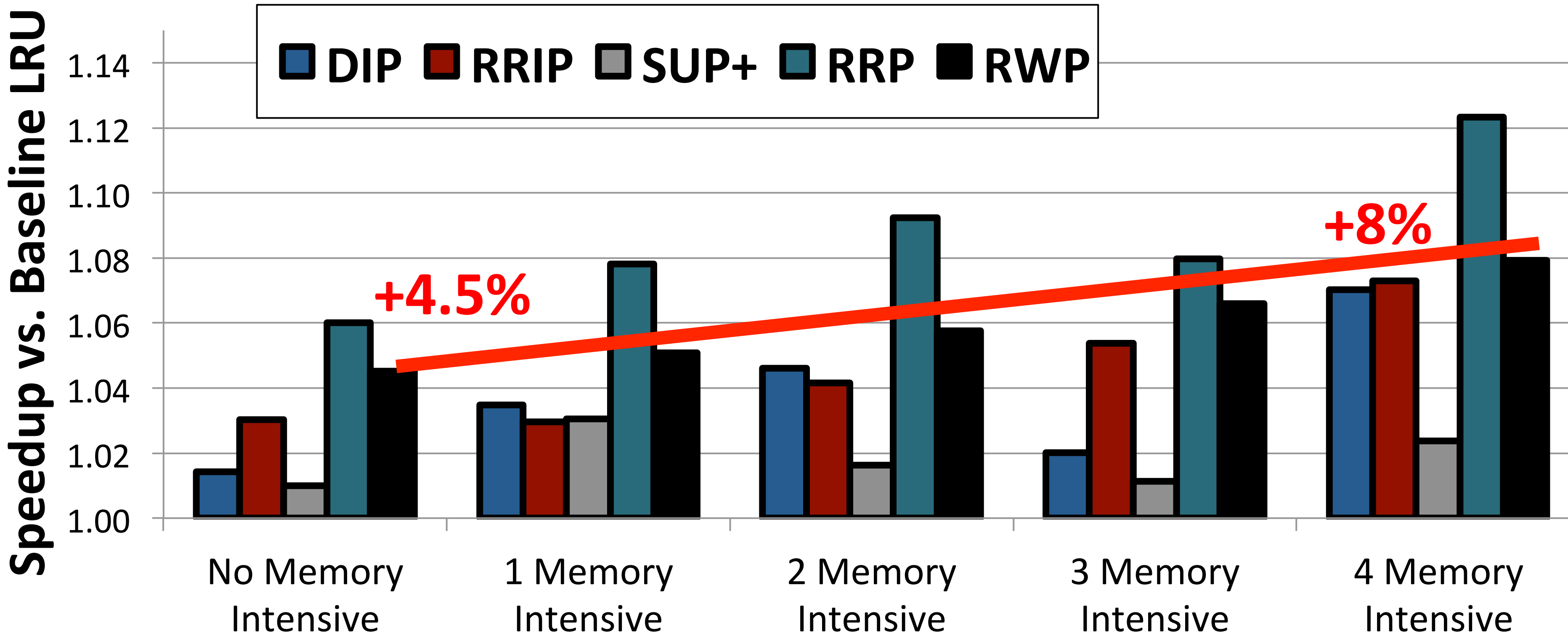
Single Core Performance



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

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

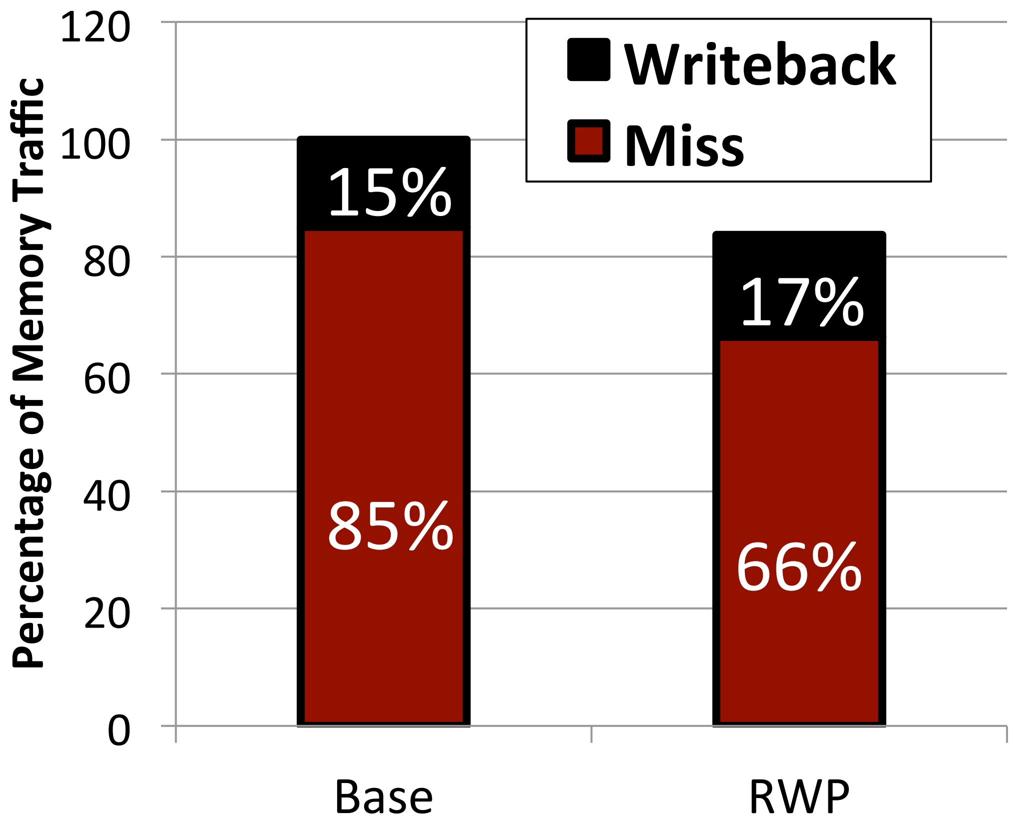
4 Core Performance



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

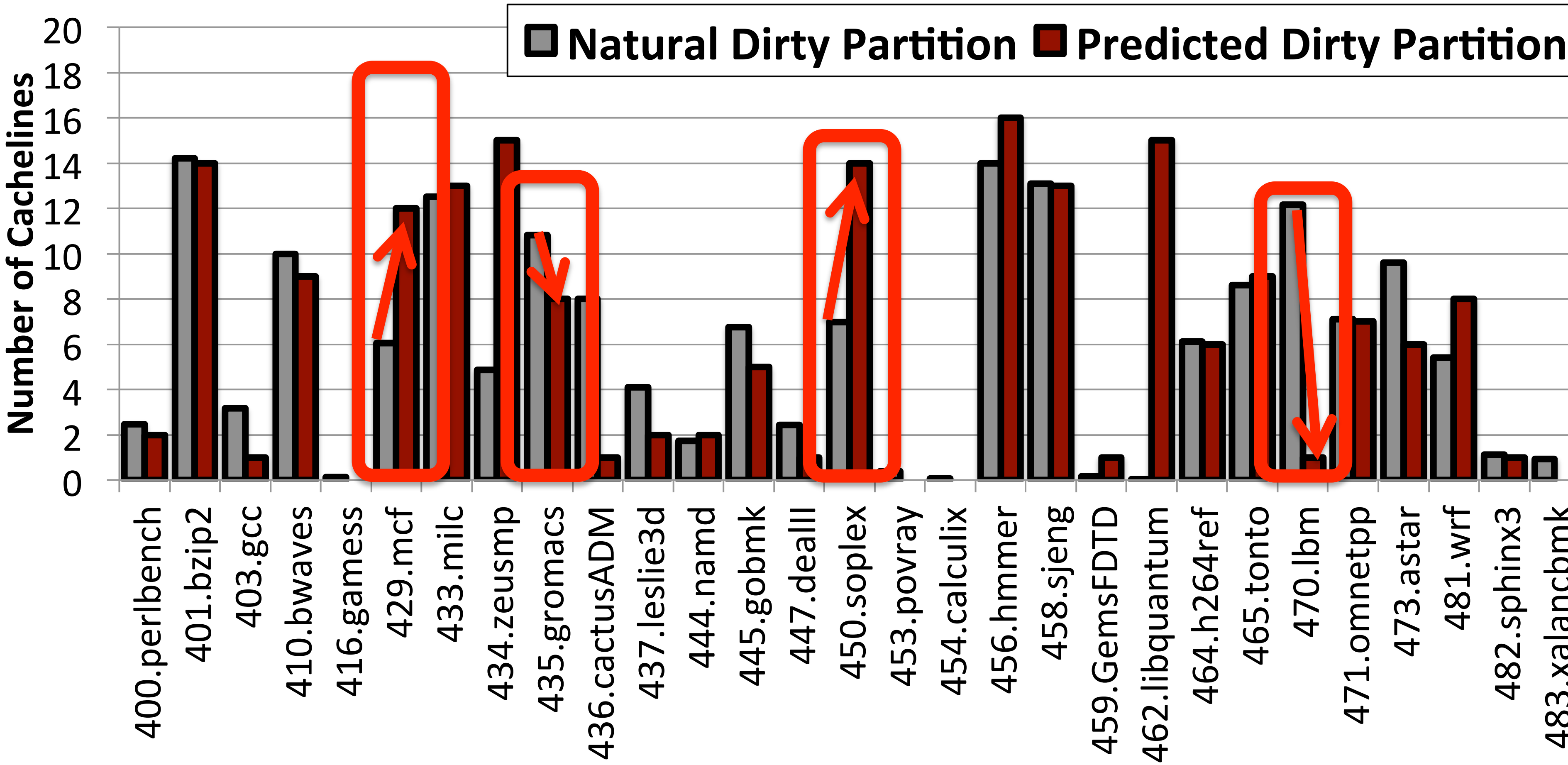
More benefit when more applications are memory intensive

Average Memory Traffic



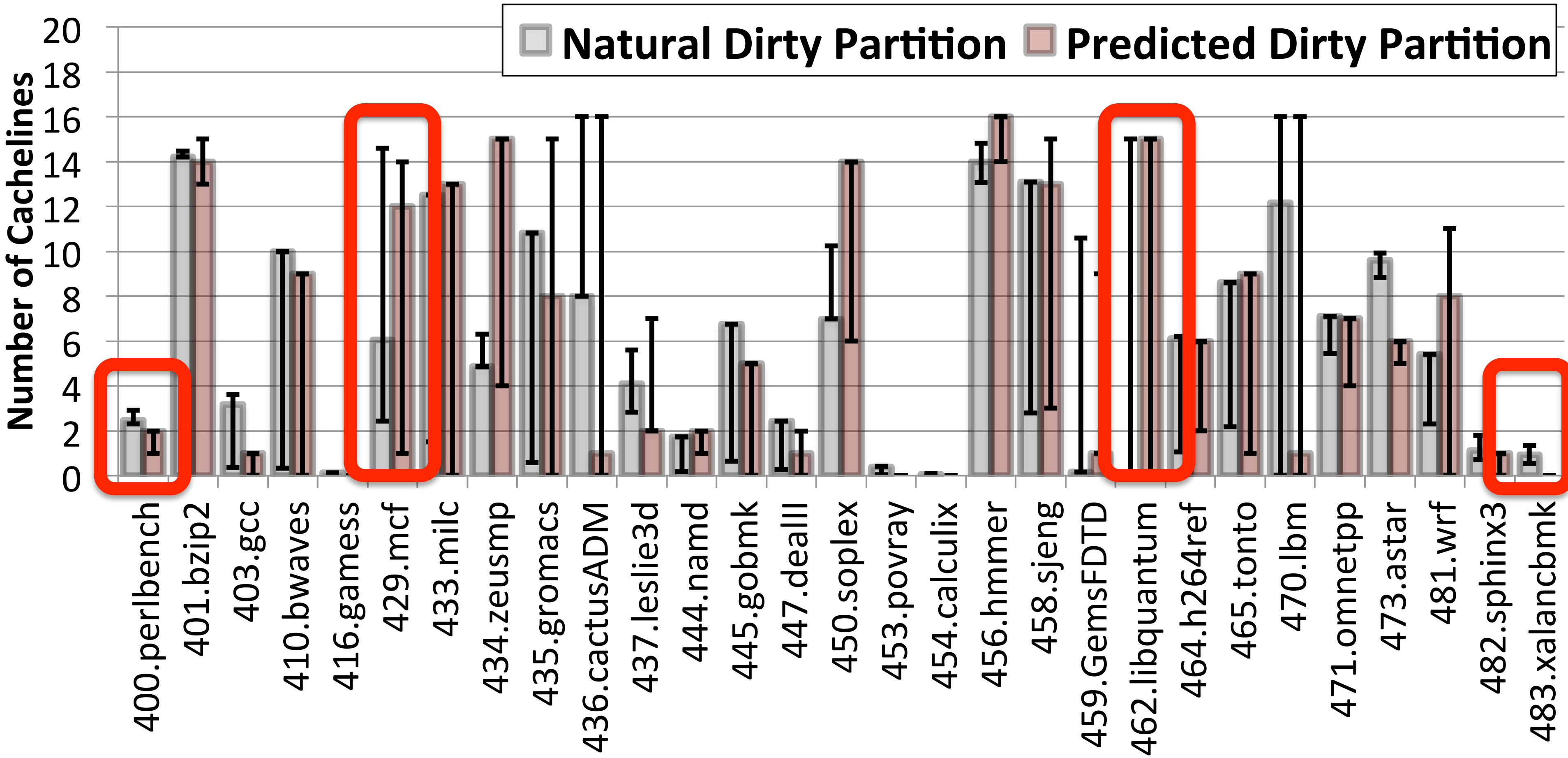
Increases writeback traffic by 2.5%, but reduces overall memory traffic by 16%

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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Carnegie Mellon intel ATM

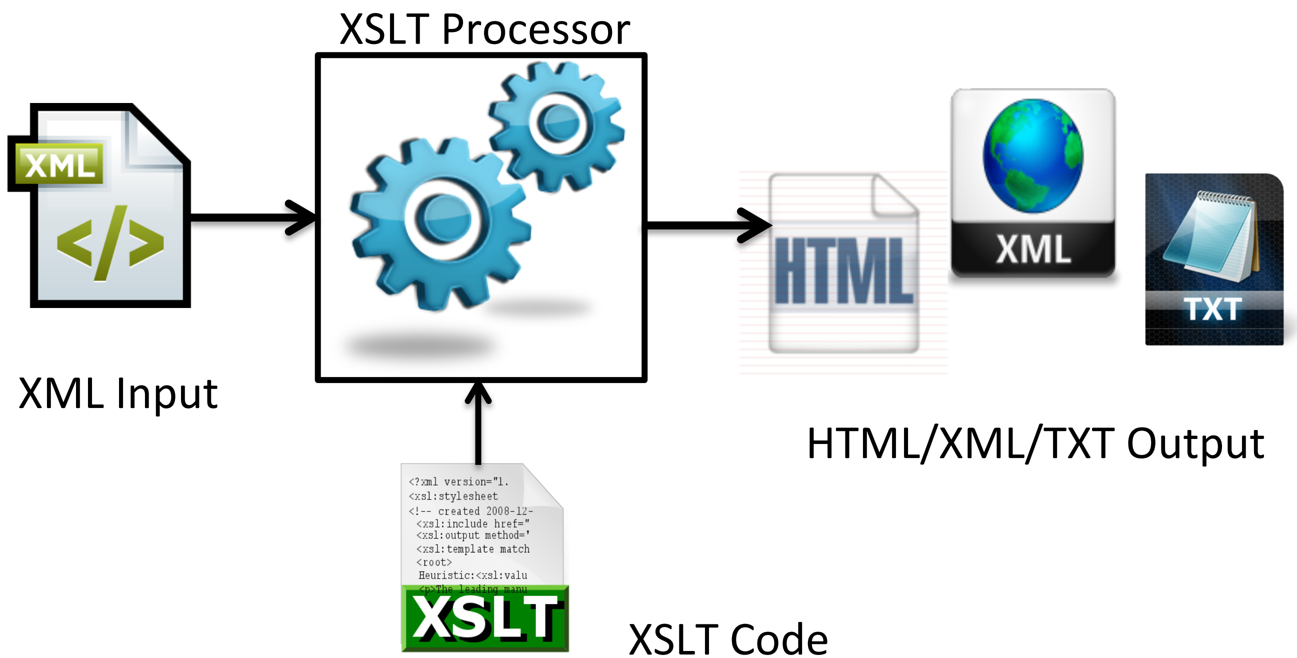
Extra Slides

Reuse Behavior of Dirty Lines in LLC

- Different read reuse behavior in dirty lines
  - **Read Intensive/Non-Write Intensive**
    - Most accesses are reads, only a few writes
    - Example: 483.xalancbmk
  - **Write Intensive**
    - Generates huge amount of intermediate data
    - Example: 456.hmmer
  - **Read-Write Intensive**
    - Iteratively reads and writes huge amount of data
    - Example: 450.soplex

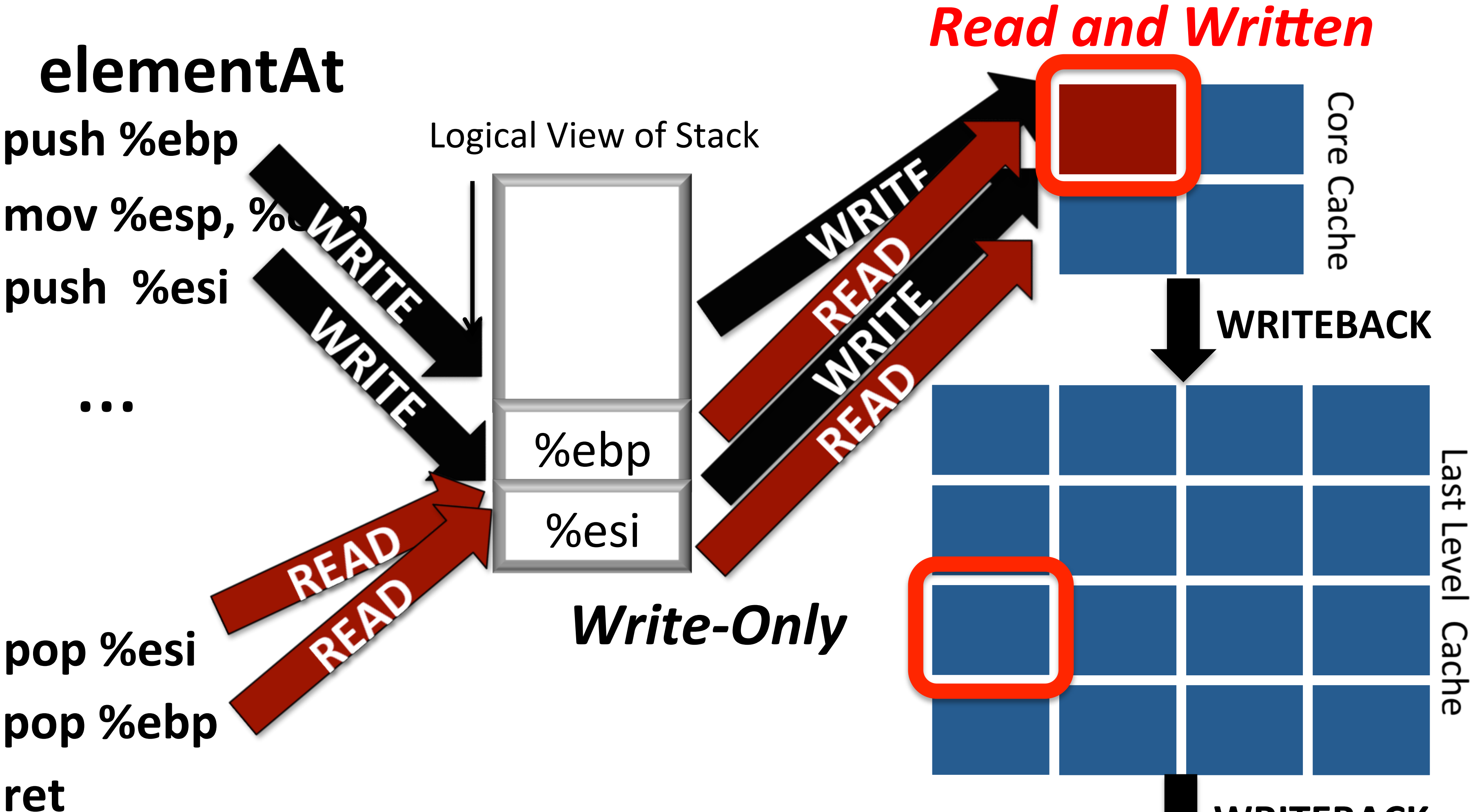
Read Intensive/Non-Write Intensive

- Most accesses are reads, only a few writes
- 483.xalancbmk: *Extensible stylesheet language transformations* (XSLT) processor



- 92% accesses are reads
- 99% write accesses are stack operation

Non-Write Intensive

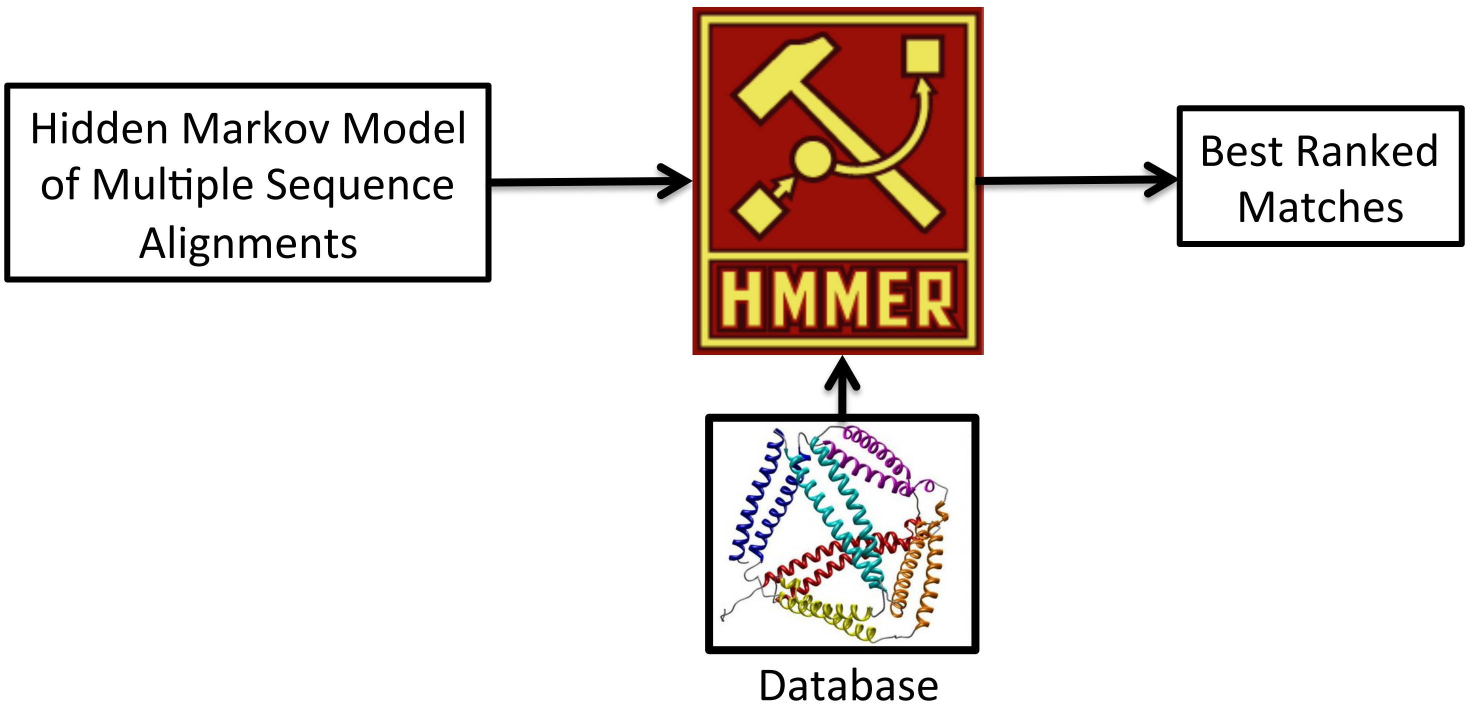


1.8% lines in LLC are write-only

These dirty lines should be evicted

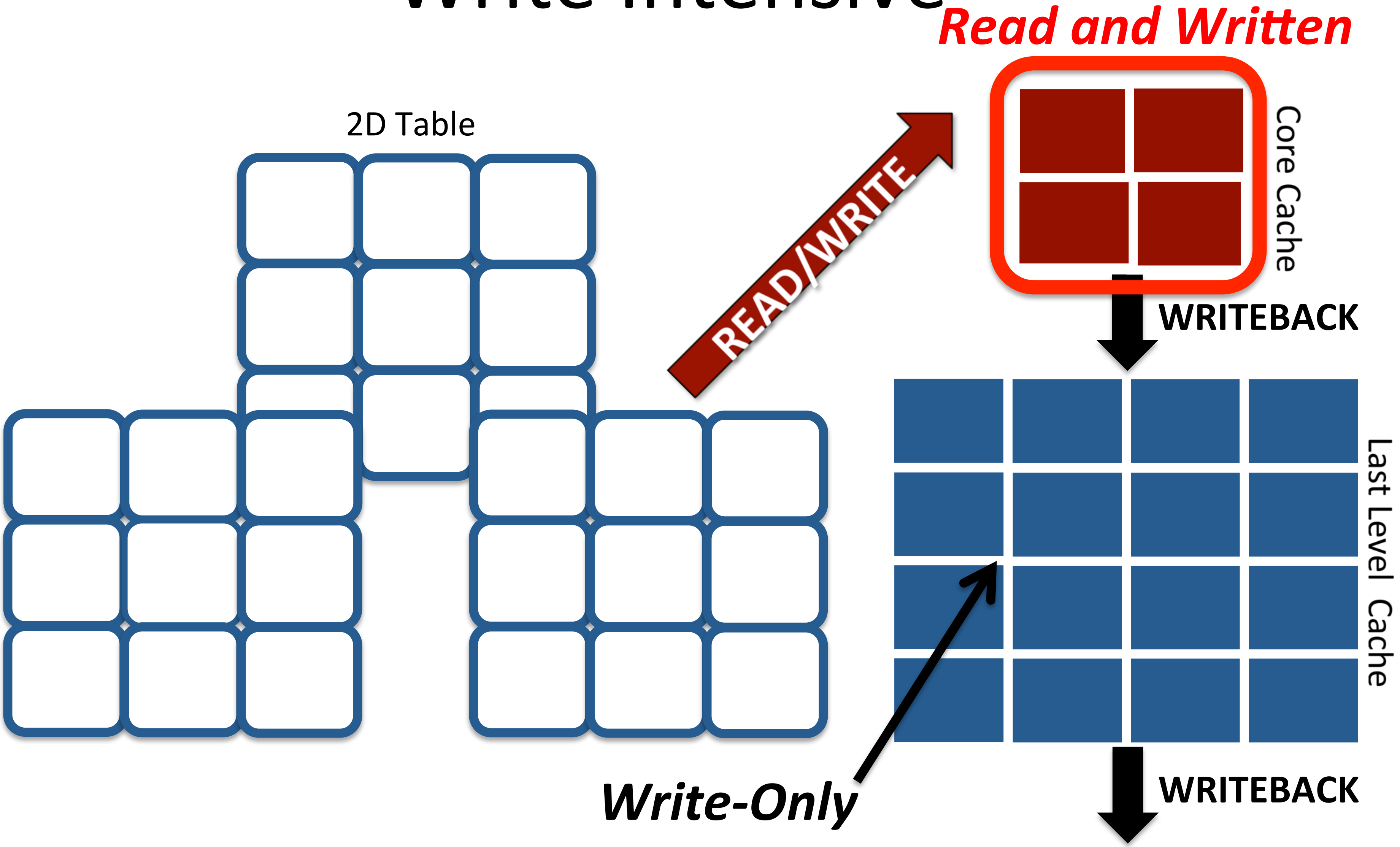
Write Intensive

- Generates huge amount of intermediate data
- 456.hmmer: Searches a protein sequence database



- Viterbi algorithm, uses dynamic programming
- Only 0.4% writes are from stack operations

Write Intensive

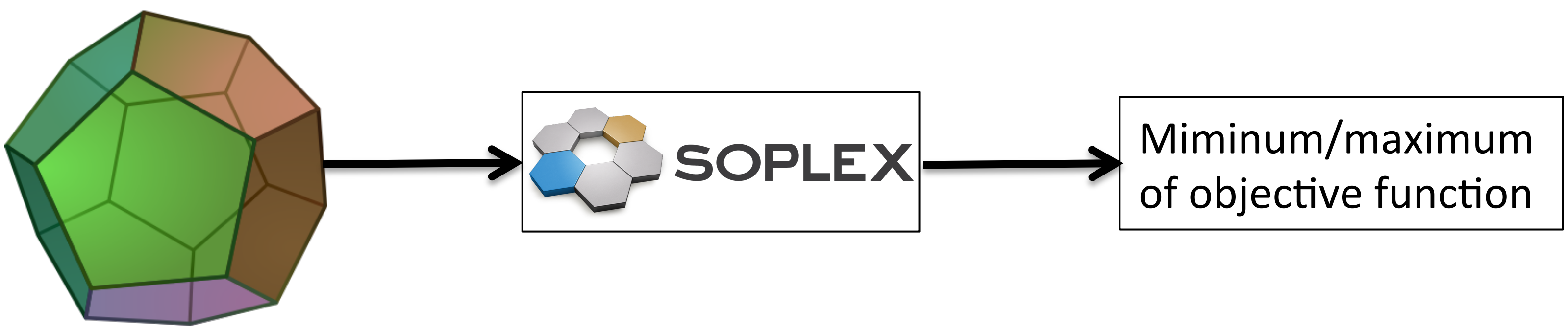


92% lines in LLC are write-only

These lines can be evicted

Read-Write Intensive

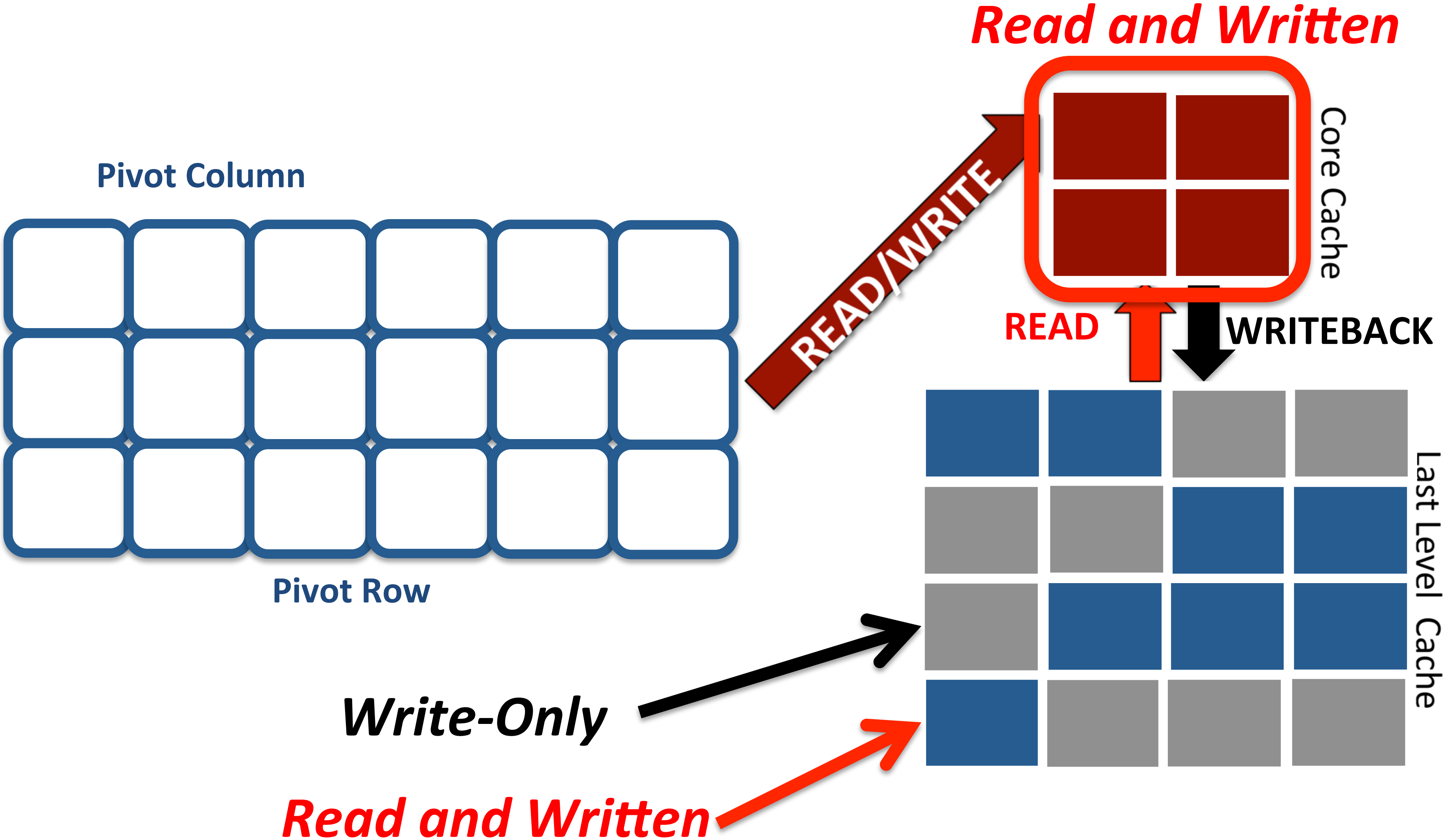
- Iteratively reads and writes huge amount of data
- 450.soplex: Linear programming solver



Inequalities and objective function

- Simplex algorithm, iterates over a matrix
- Different operations over the entire matrix at each iteration

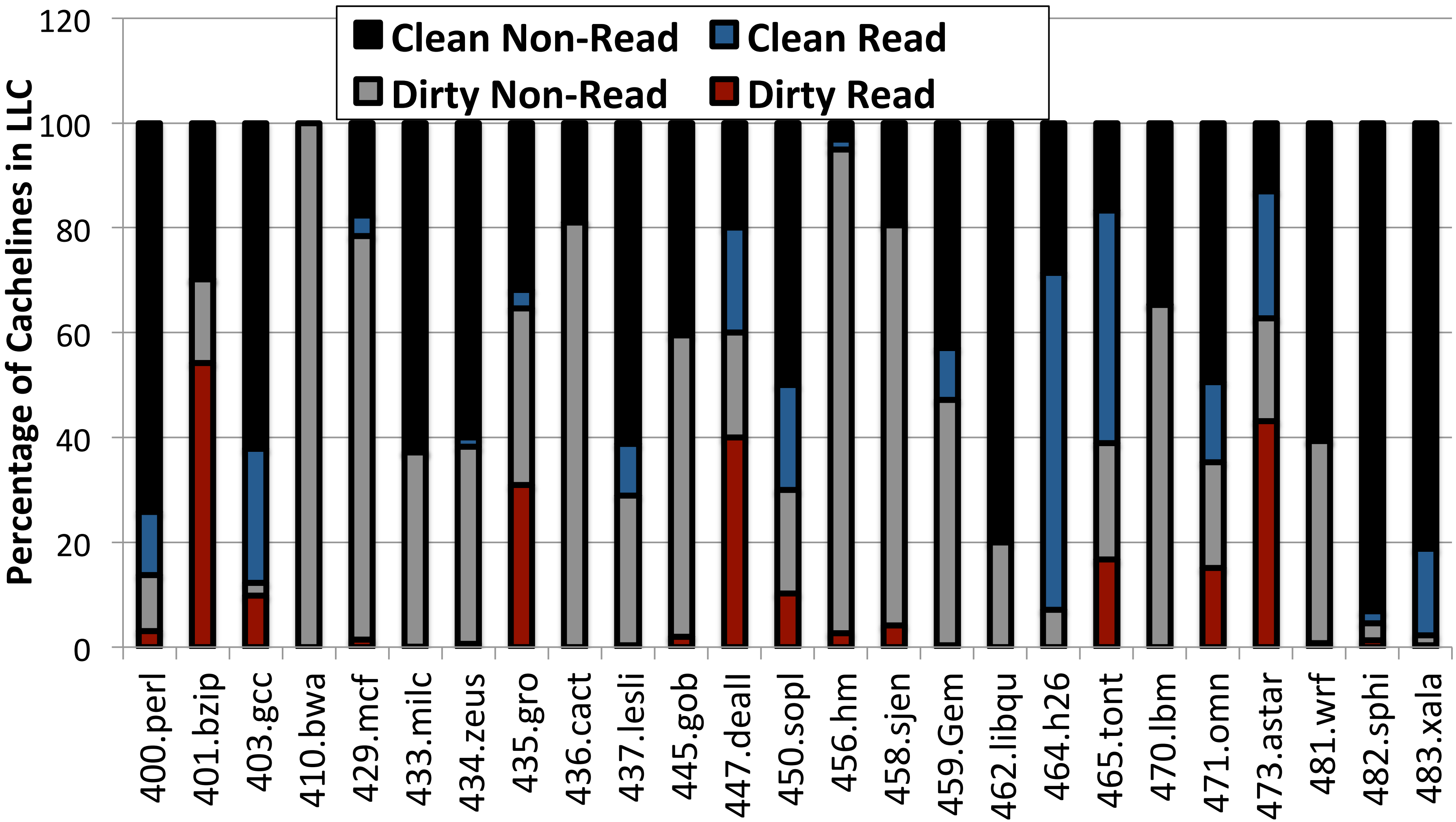
Read-Write Intensive



19% lines in LLC write-only, 10% lines are read-written

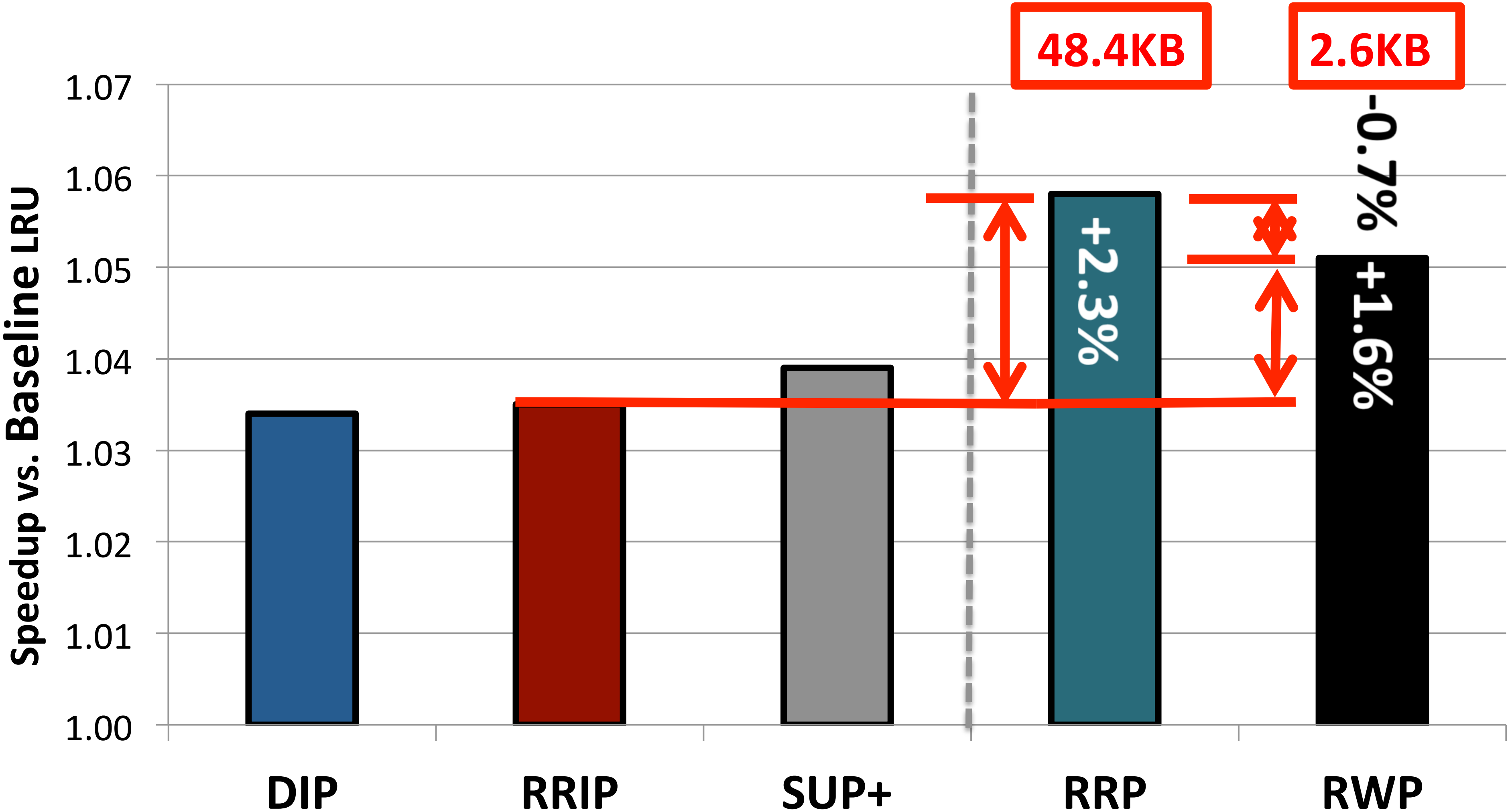
Read and written lines should be protected

Read Reuse of Clean-Dirty Lines in LLC



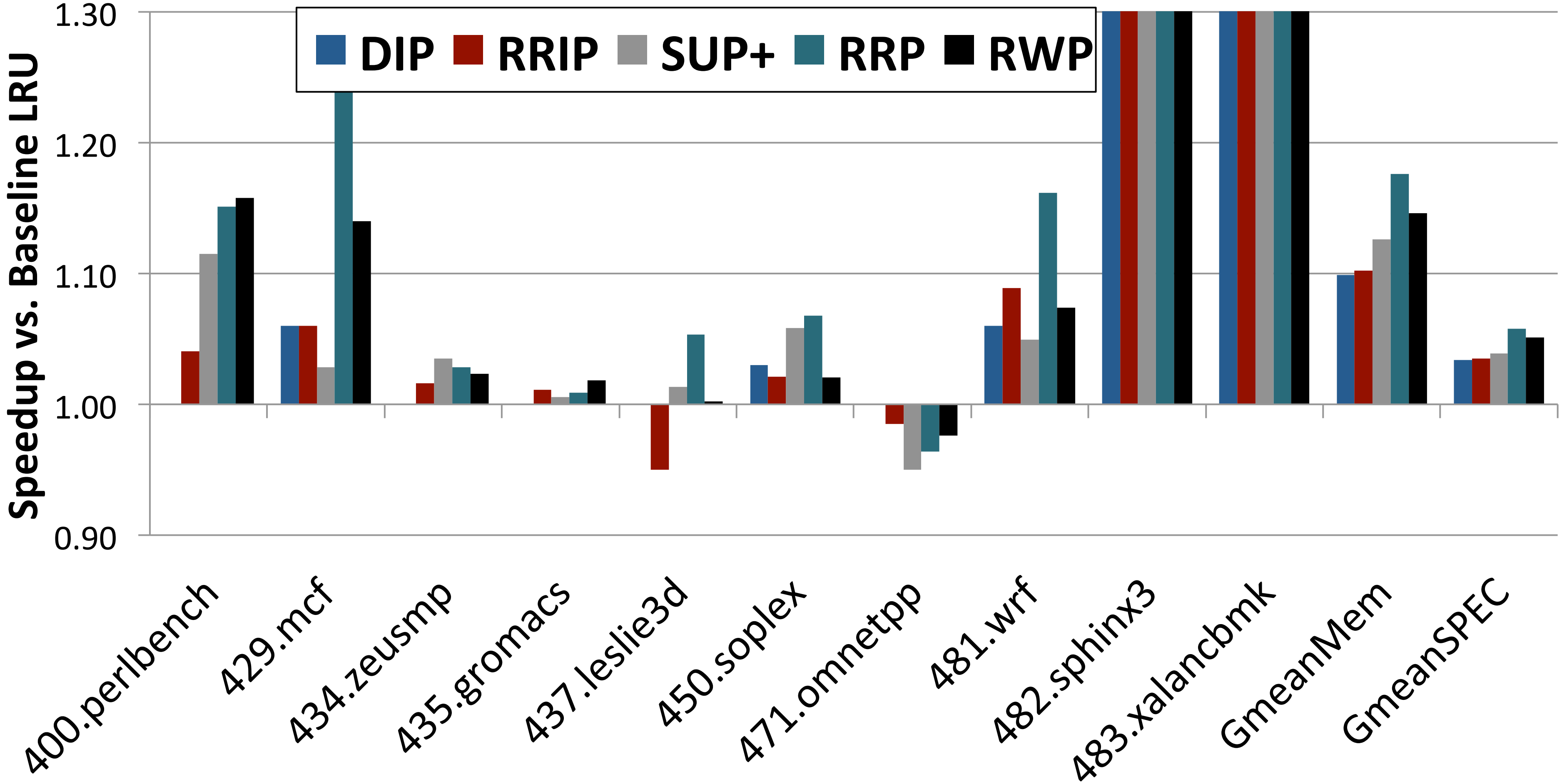
On average 37.4% blocks are dirty non-read and 42% blocks are clean non-read

Single Core Performance



5% speedup over the whole SPECCPU2006 benchmarks

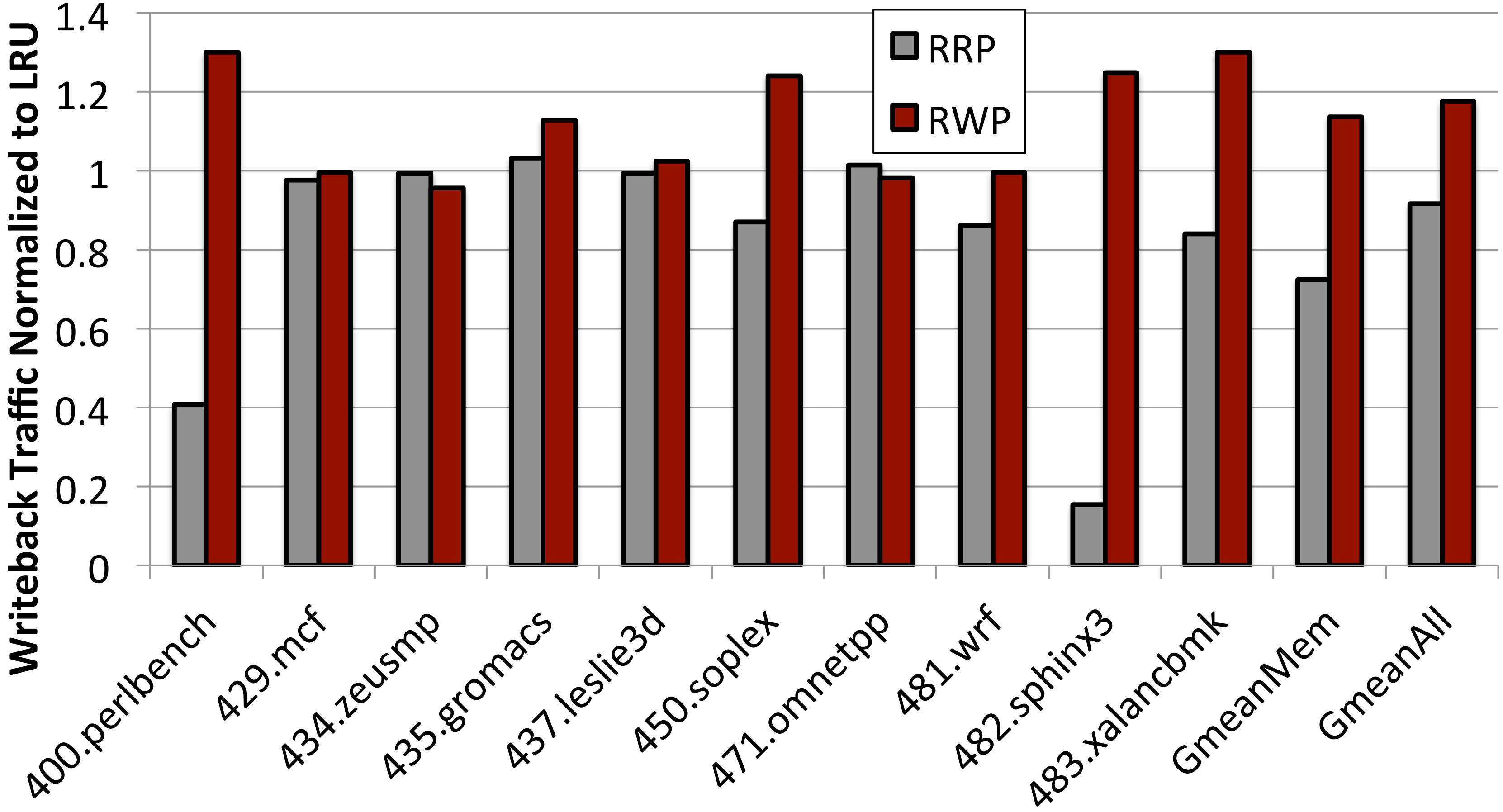
Speedup



On average 14.6% speedup over baseline

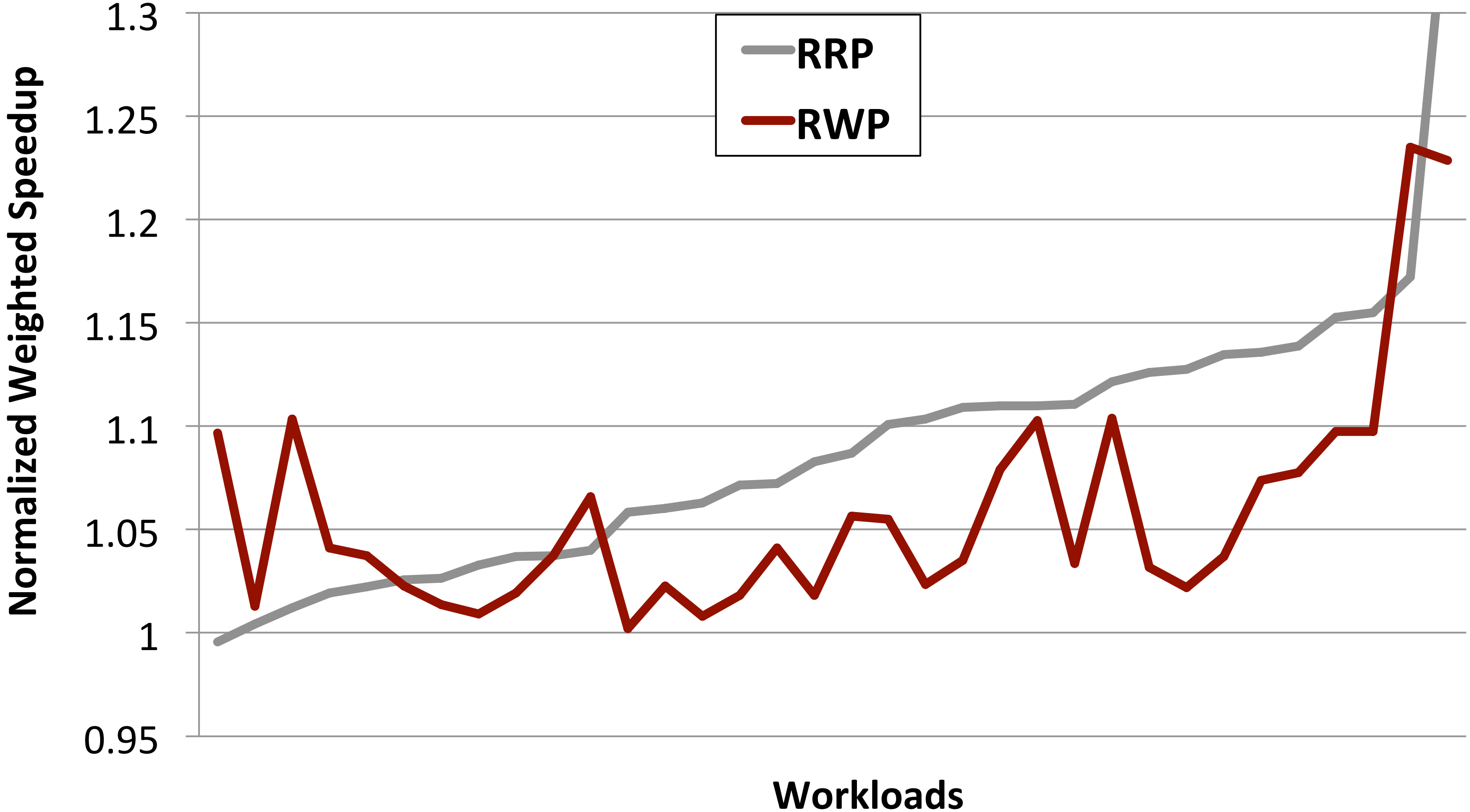
5% speedup over the whole SPECCPU2006 benchmarks

Writeback Traffic to Memory



Increases traffic by 17% over the whole SPECCPU2006 benchmarks

4-Core Performance



Change of IPC with Static Partitioning