Lazy Persistency: a High-Performing and Write-Efficient Software Persistency Technique

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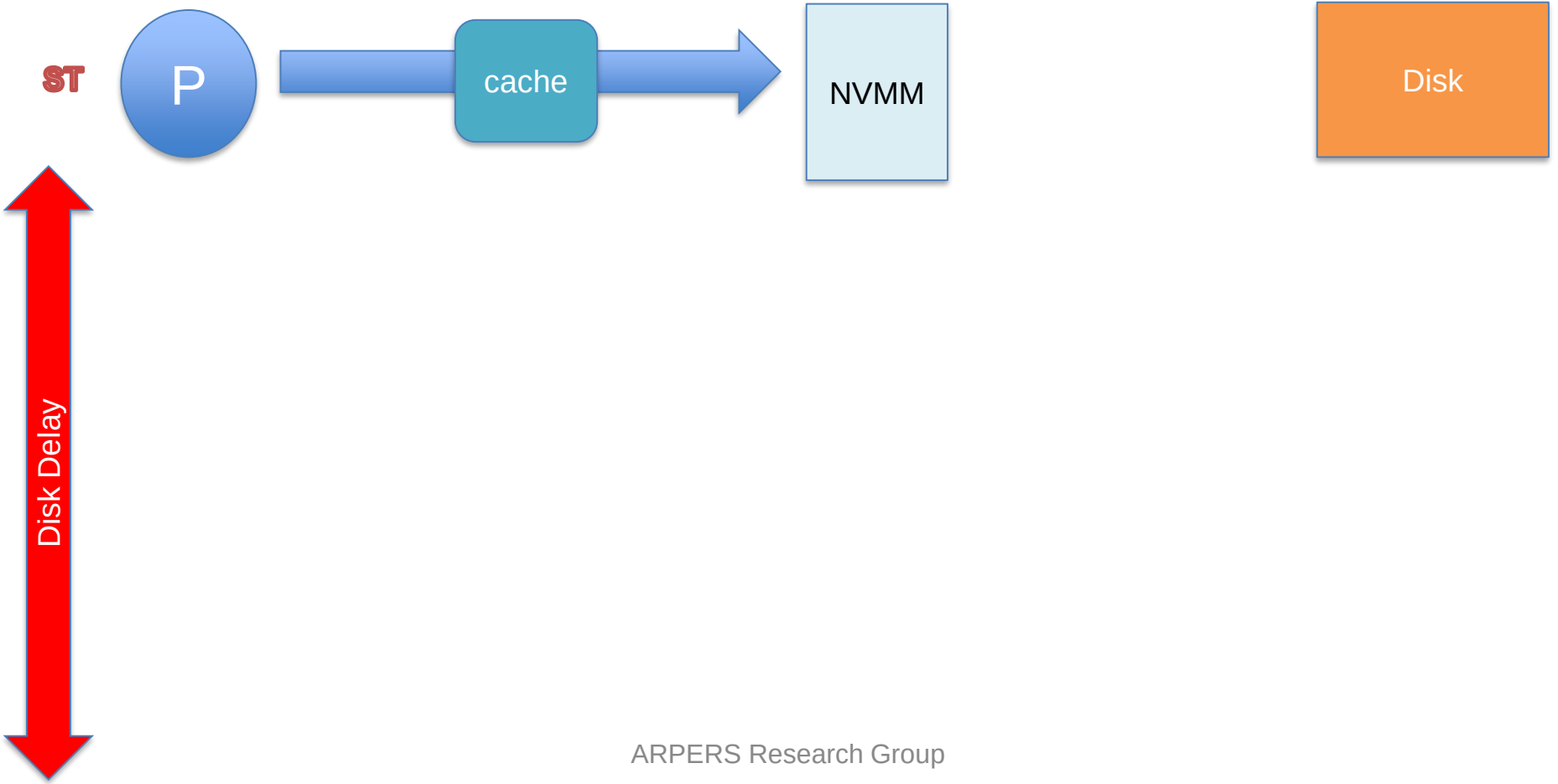
ARPERS Research Group

Introduction

- Future systems will likely include Non-Volatile Main Memory (NVMM)
- NVMM can host data persistently across crashes and reboots
- Crash consistent data requires persistency models, which define when stores reach NVMM (i.e. become durable)
  - E.g. Intel PMEM: CLFLUSH, CLFLUSHOPT, CLWB, SFENCE


ST
P
Disk
Disk Delay


ST
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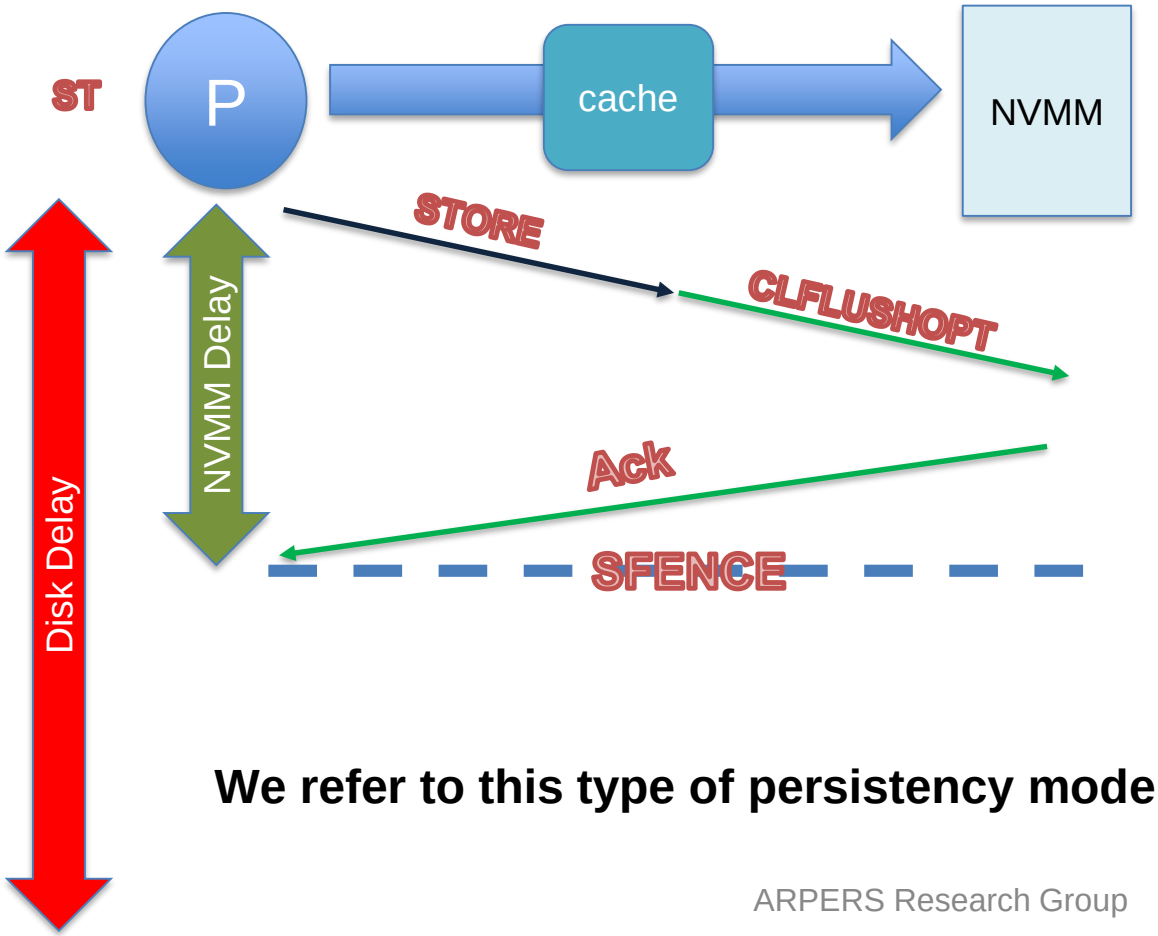


- CLFLUSHOPT flushes a cache block to NVMM
- SFENCE orders CLFLUSHOPT with other stores

We refer to this type of persistency models as Eager Persistency

Our Solution: Lazy Persistency

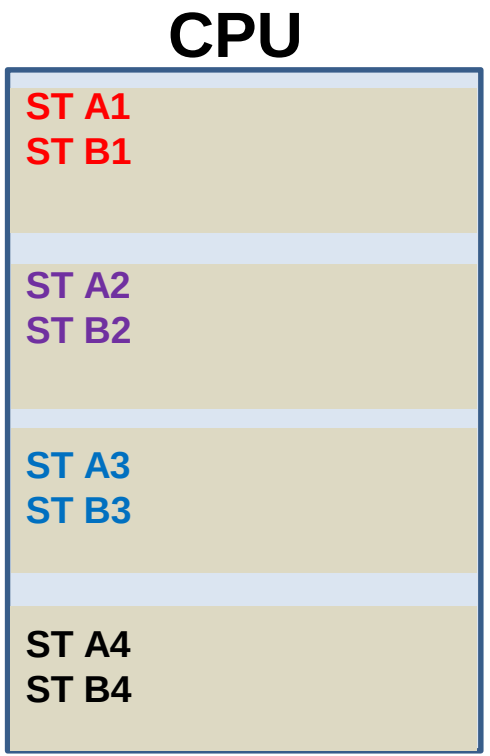
- Principle: Make the Common Case Fast
- Software technique
- Code is broken into Lazy Persistency (LP) regions
  - Each LP region protected by a checksum
  - Checksum enables persistency failure detection after a crash
  - On recovery, failed regions are re-executed

- **Lazily relies on natural cache evictions**

  No persist barriers (CLFLUSHOPT, SFENCE) needed

Lazy Persistency Details

- Programs are divided into associative LP regions
- Programmers choose LP region granularity
- A checksum covers updates in an LP region
  - Stored at the end of the LP region



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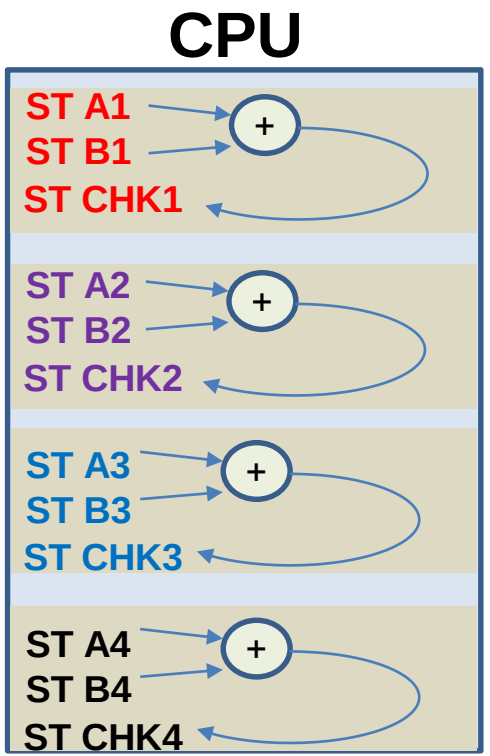

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2      for ( ii = starting_ii ;  ii <n; ii +=bsize) {
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4          for ( jj =0; jj <n; jj +=bsize) {
5              for (i=ii ; i<(ii+bsize); i++) {
6                  for (j=jj ; j<(jj+bsize); j++) {
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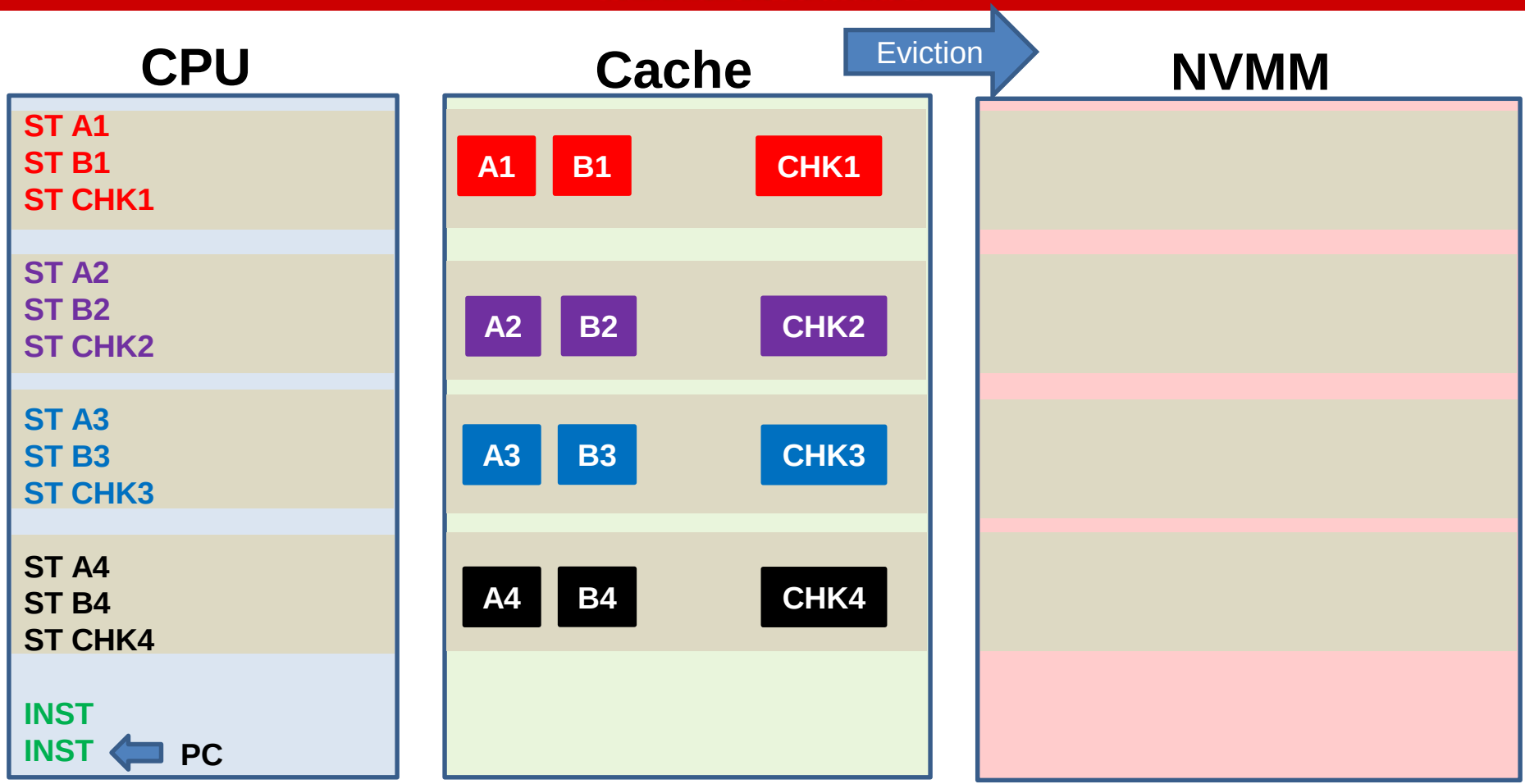
➔ Update during each iteration in the region

➔ Store the checksum to the corresponding location

LP Region


CPU
Cache
Eviction
NVMM
ST A1
ST B1
ST CHK1
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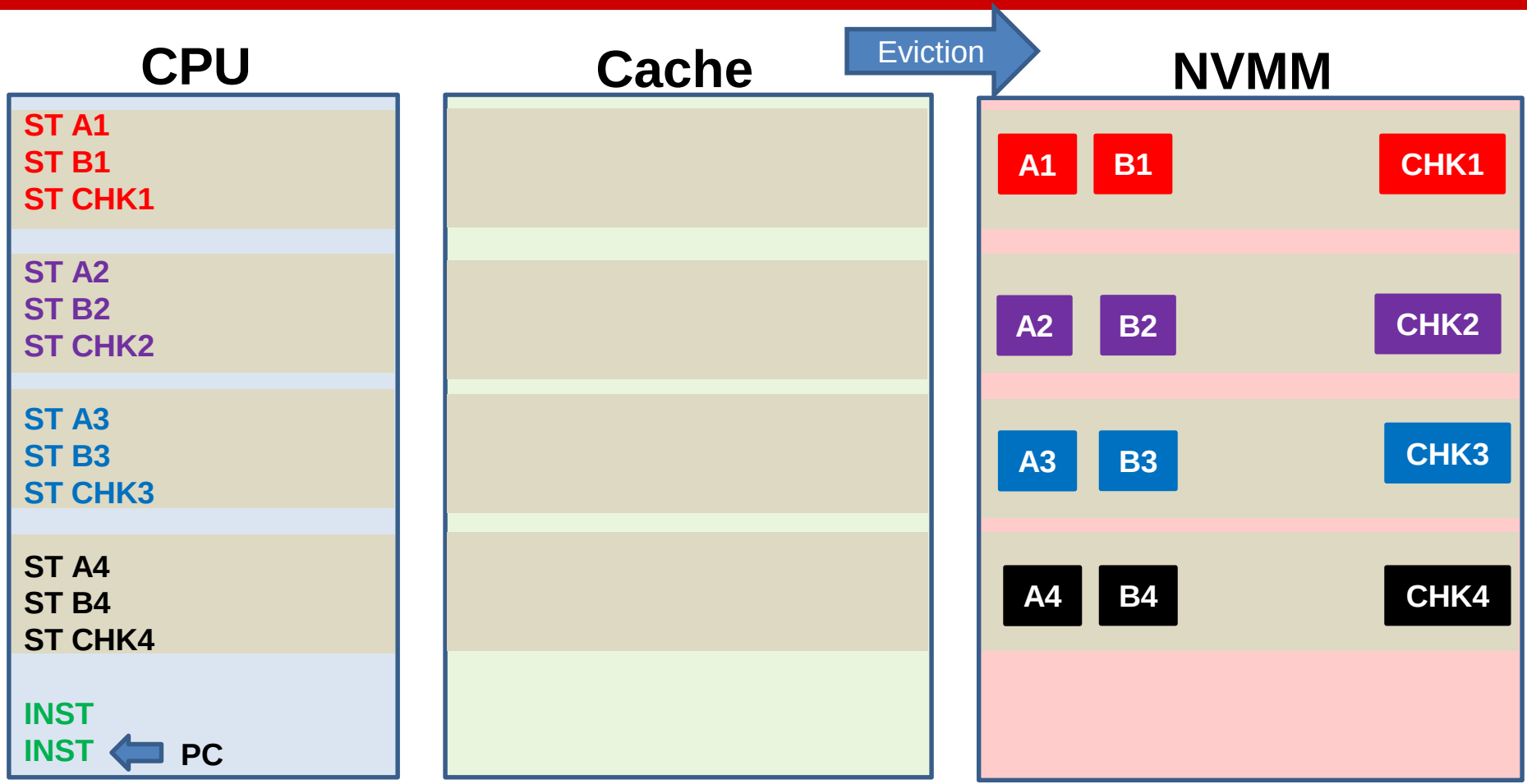
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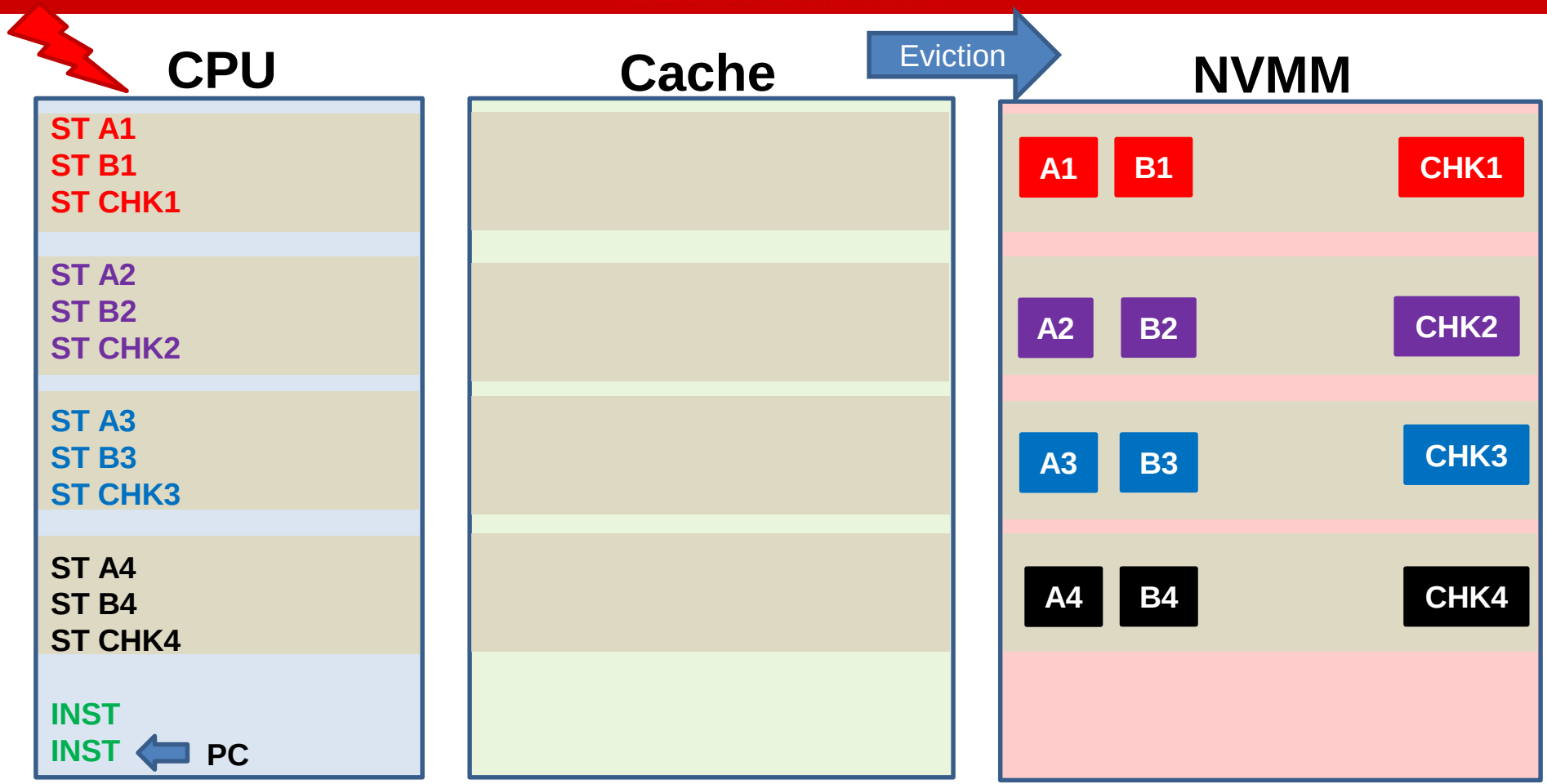
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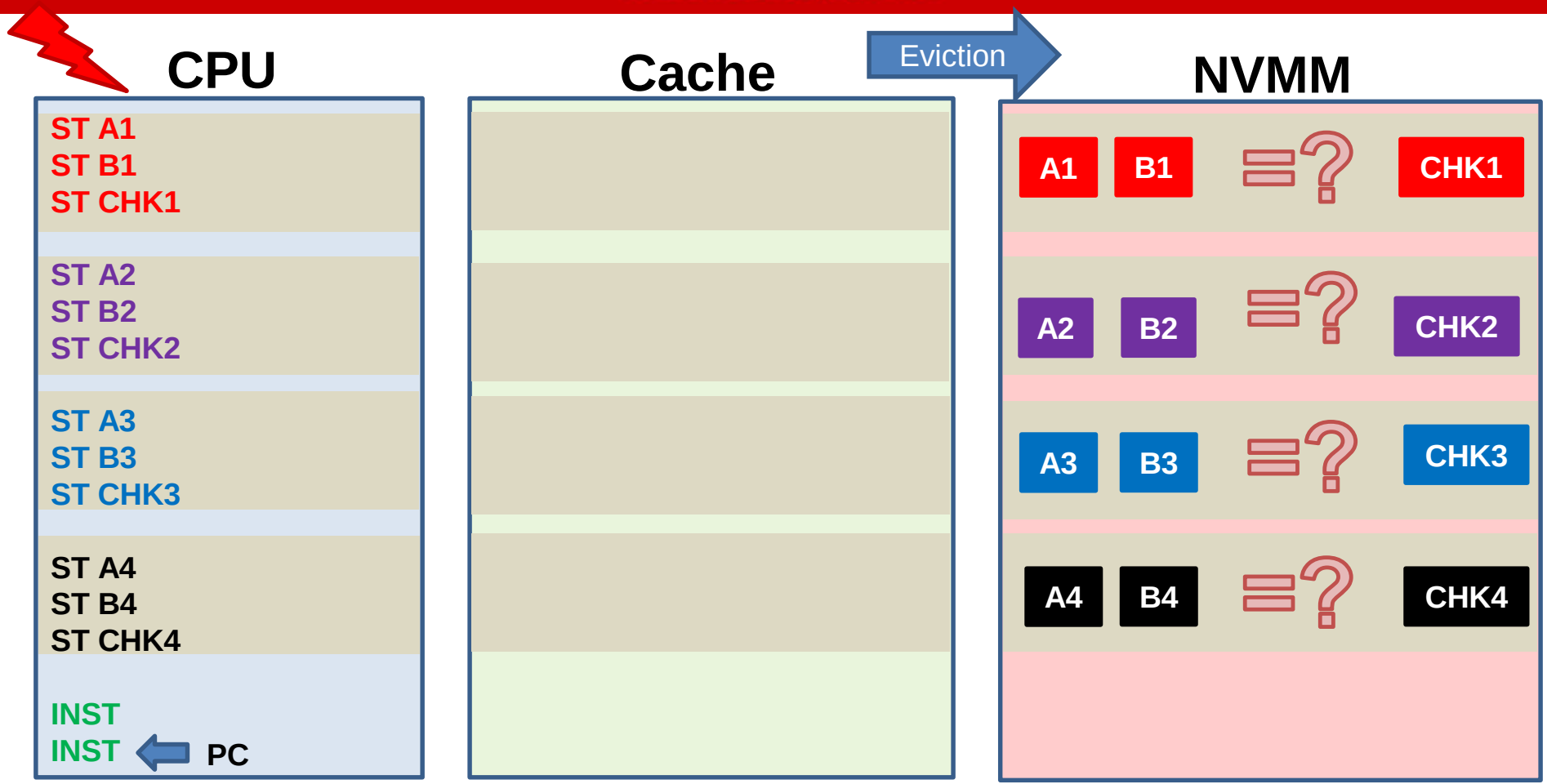
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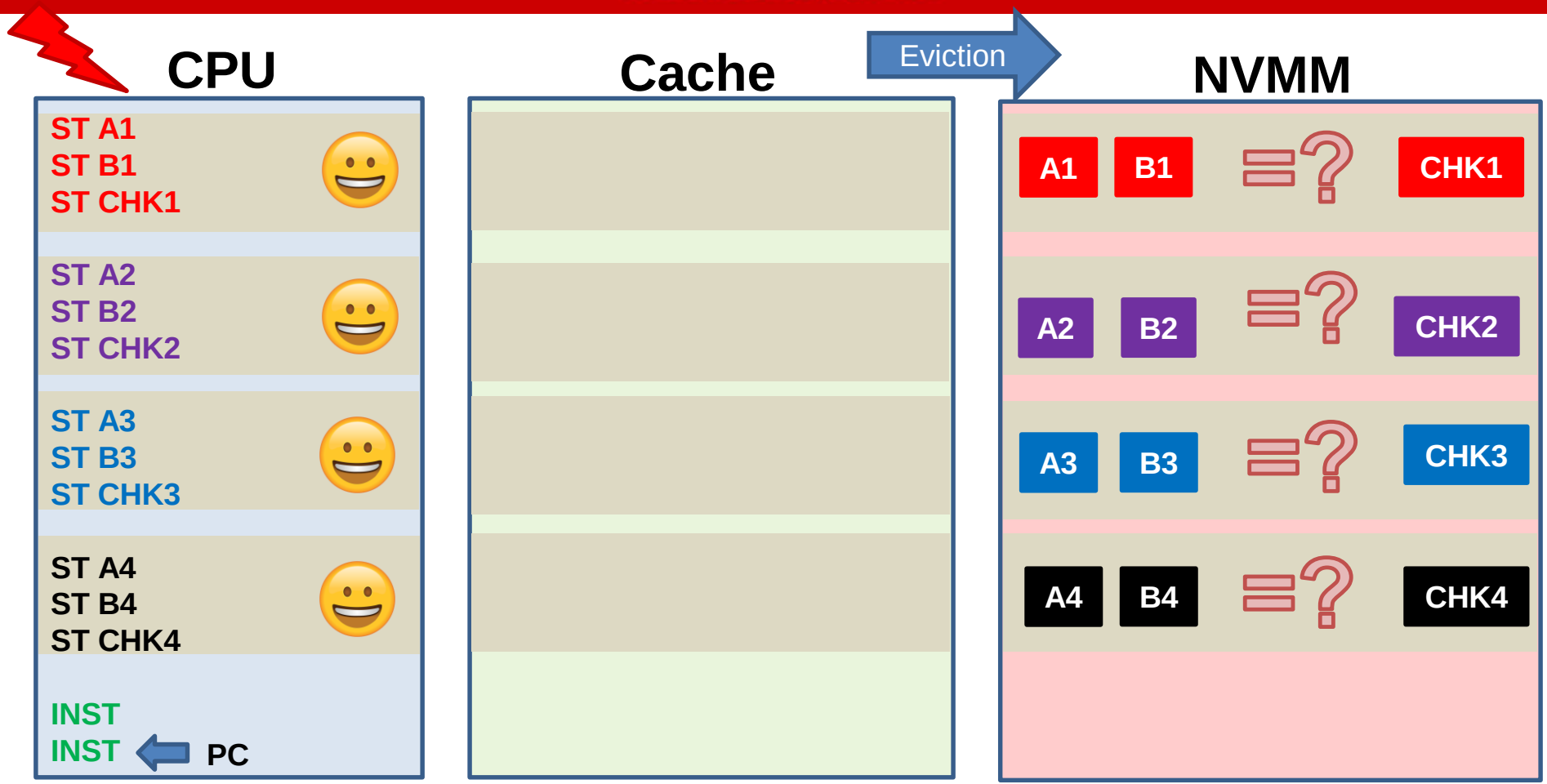
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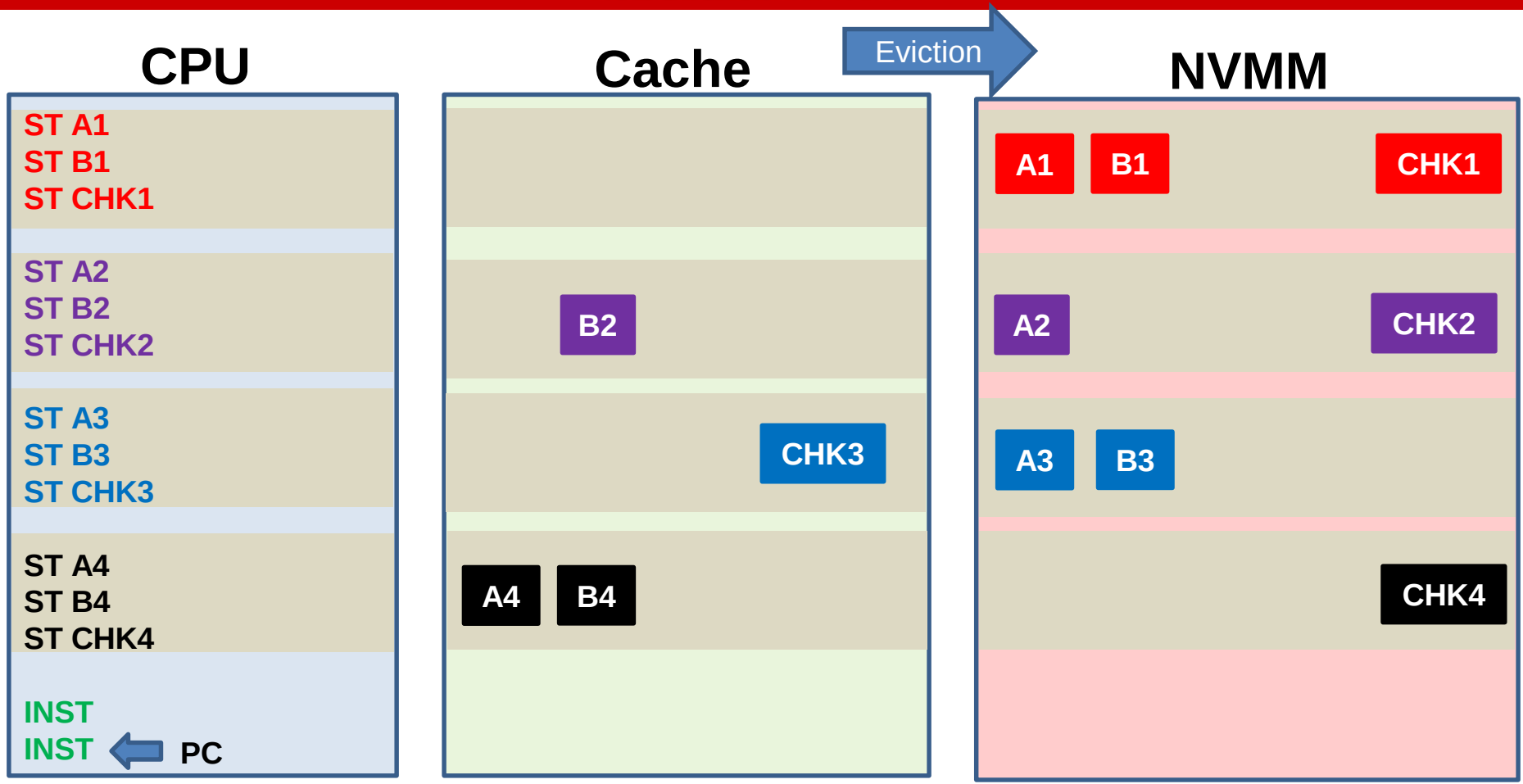
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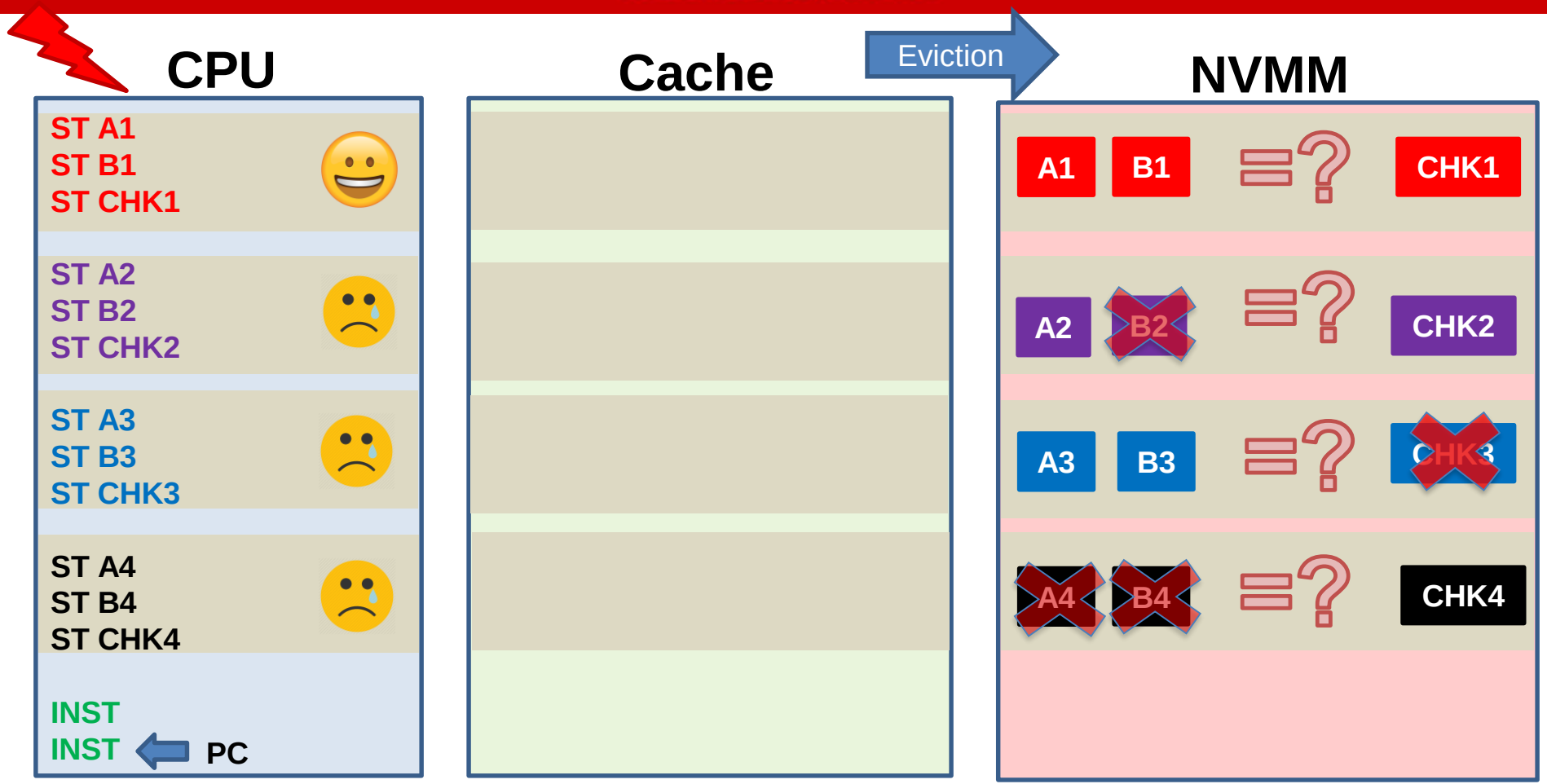
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A1
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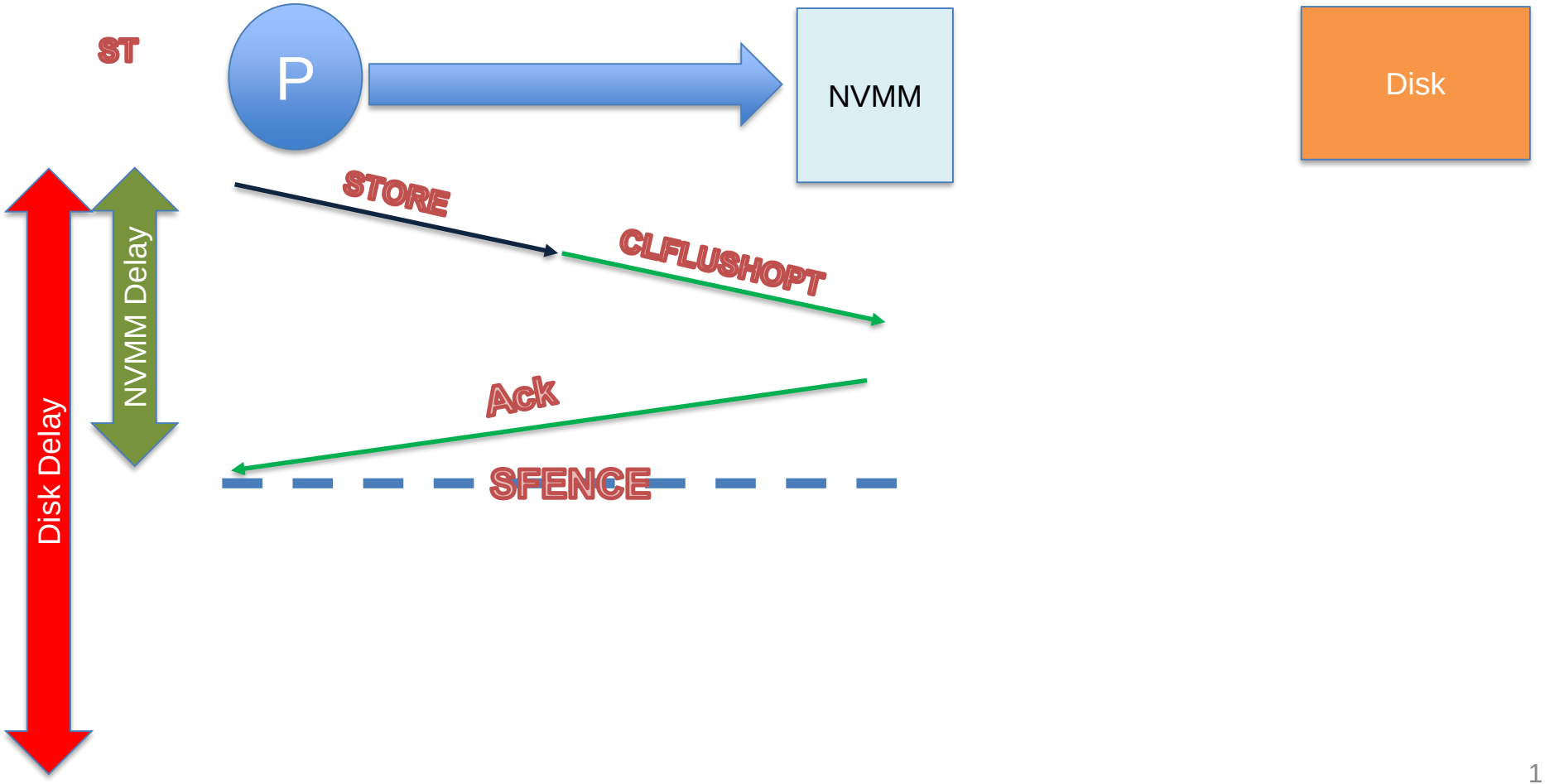
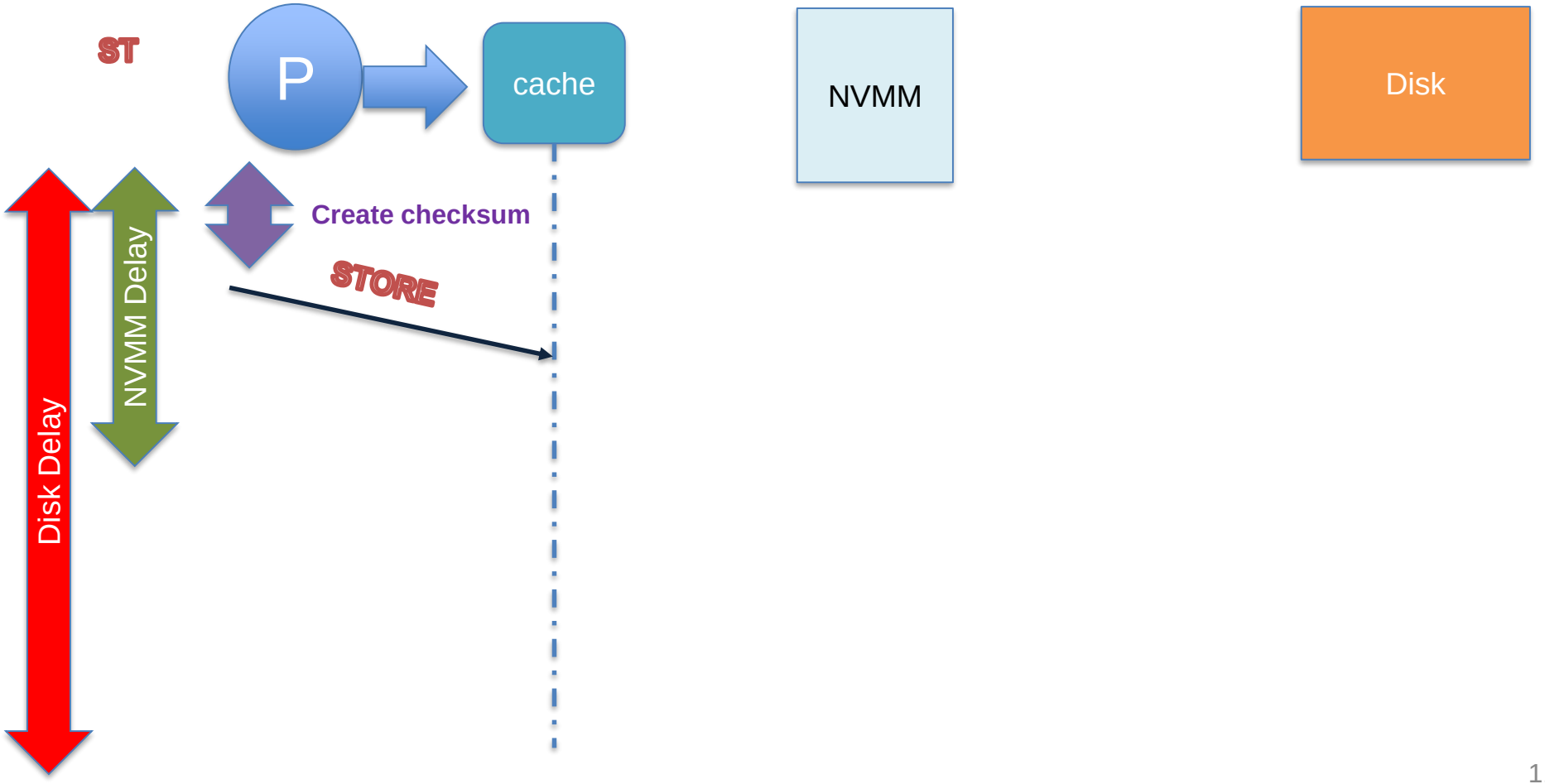
CHK1
A2
B2
CHK2
A3
B3
CHK3
A4
B4
CHK4

Recovering From a Crash

- On a crash, checksums are validated to detect regions that were not persisted
- Failed regions are recomputed
- Finally, program resumes execution in normal mode


ST
P
NVMM
Disk
STORE
CLFLUSHOPT
Ack
SFENCE
NVMM Delay
Disk Delay


ST
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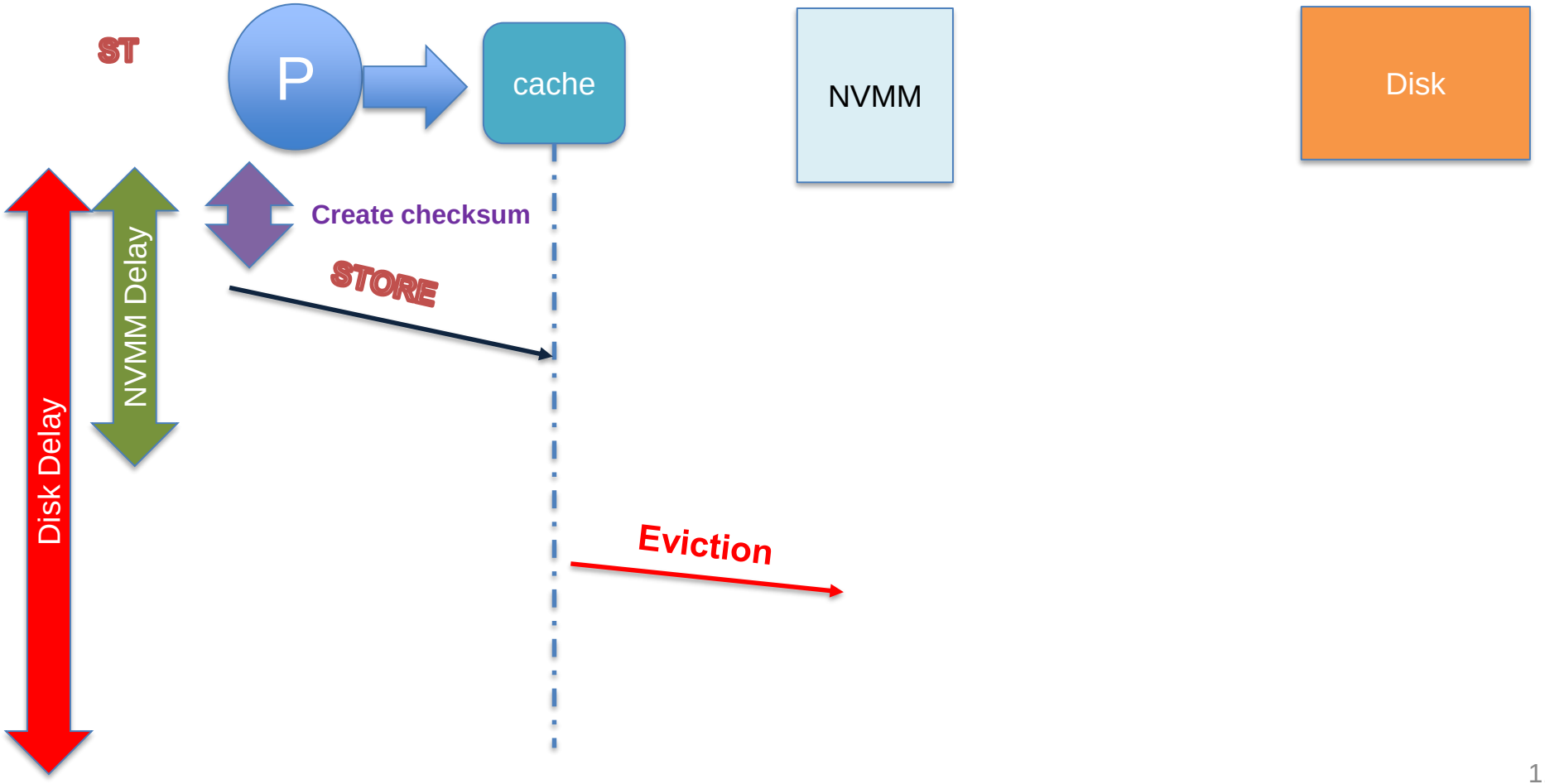
cache
NVMM
Disk
Create checksum
STORE
NVMM Delay
Disk Delay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Disk Delay
Eviction

Limitations of Lazy Persistency

- LP regions need to be associative, i.e. (R1, R2), R3 = R1, (R2, R3)
  - Most HPC kernels contain loop iterations that satisfy this requirement
  - Can be relaxed in some situations (see the paper)
- Recovery code needed for LP regions
  - Solution: Prior work can be exploited [PACT'17]
- Amount of recovery may be unbounded (e.g. due to hot blocks)
  - Solution: Periodic Flushes (Next Slide)

Bounding the Amount of Recovery

- Cache blocks may stay in the cache for a long time (e.g. hot blocks)
  - Getting worse the larger the cache
- Regions with such blocks may fail to persist
- Upper-bound is needed for the time a block might remain dirty in the cache
- This is needed to guarantee forward progress

Solution: Periodic Flushes

- A simple hardware support
- All dirty blocks in the cache are written back periodically, in the background
- Modest increase in the number of writes (see paper for details)
- The periodic flush interval puts an upper bound for recovery work

Evaluation

Methodology

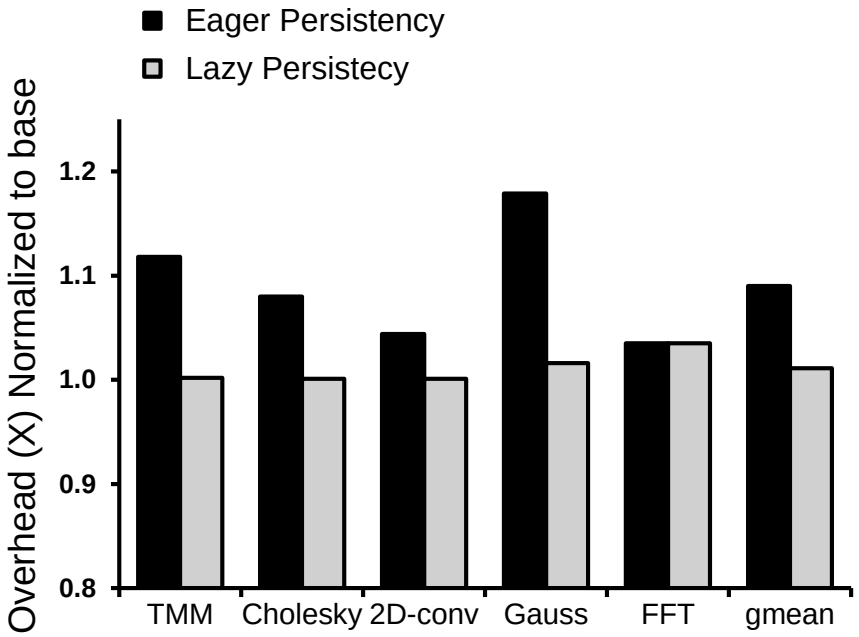
- Simulations on a modified version of gem5. Supports most Intel PMEM instructions (e.g. CLFLUSHOPT)
- Detailed out-of-order CPU model. Ruby memory system. 8 threads is the default for all experiments
- Evaluation was also done on 32-core DRAM-based real hardware machine

Evaluation

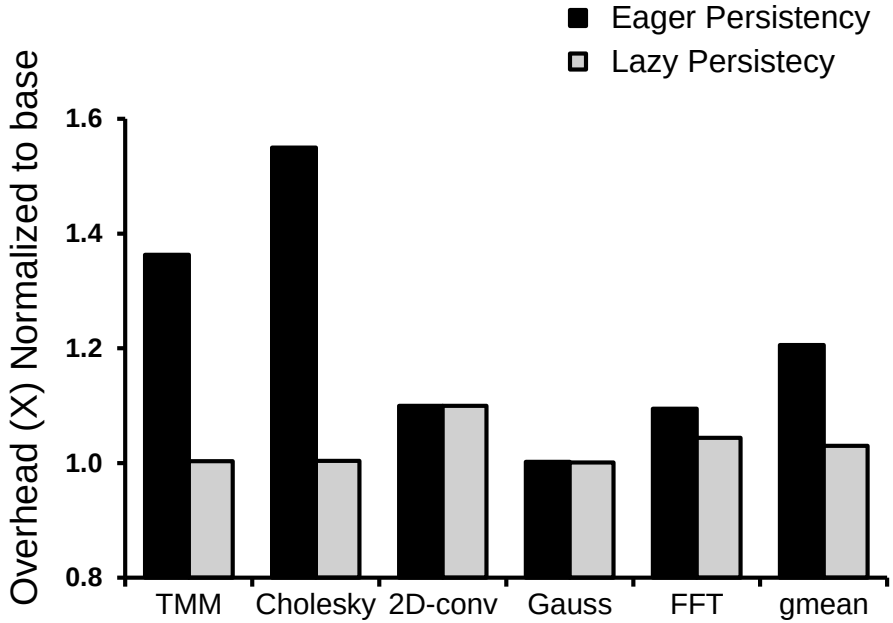
Multi-Threaded Benchmarks

- Tiled Matrix Multiplication
- Cholesky Factorization
- 2D convolution
- Fast Fourier Transform
- Gauss Elimination

Evaluation: All Benchmarks

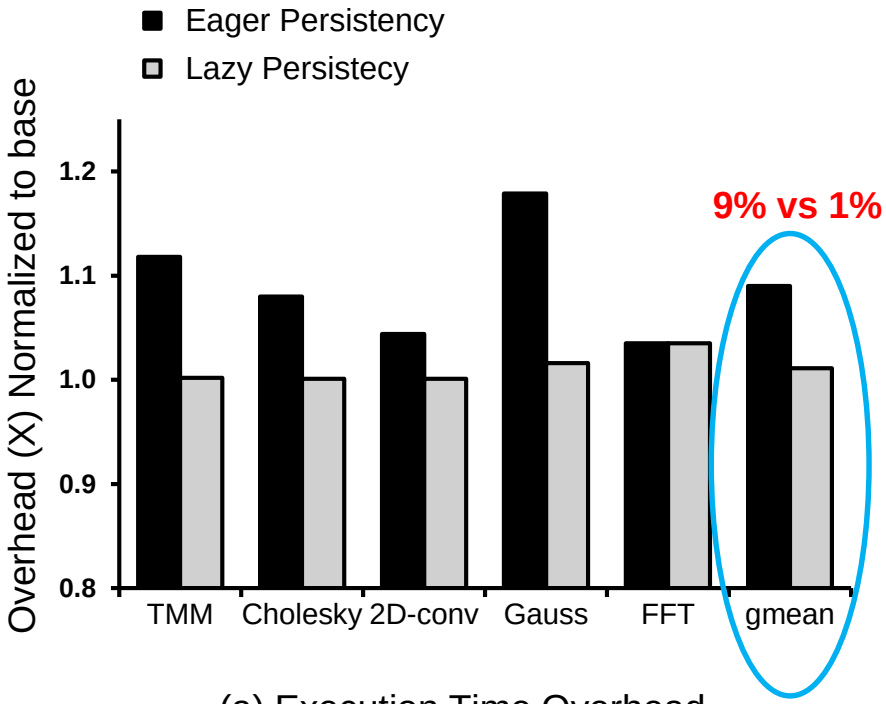


(a) Execution Time Overhead



(b) Number of Writes Overhead

Evaluation: All Benchmarks



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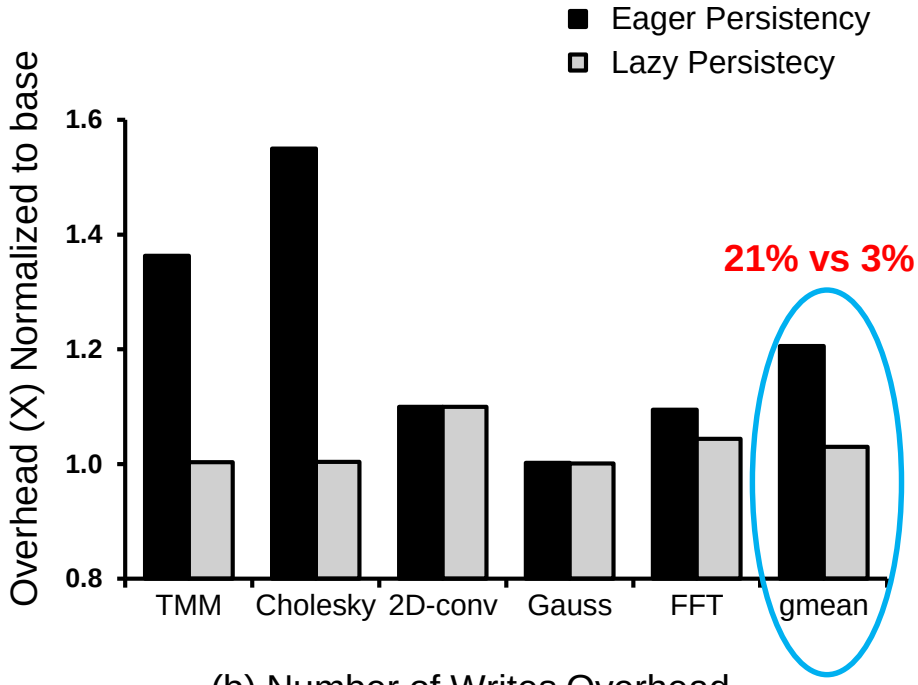

(b) Number of Writes Overhead

More Evaluations

We performed other interesting evaluations that can be found in the paper:

- Sensitivity study with varying the read/write latency for NVMM
- Sensitivity study with varying the number of threads
- Evaluating the execution time for all the 5 benchmark on real hardware
- Sensitivity study with varying the Last Level Cache size
- Analysis for the Number of Writes of Periodic Flushes hardware support
- Evaluating the execution time overhead when trying different error detection mechanisms

Summary

- Lazy Persistency is a software persistency technique that relies on natural cache evictions (No stalls on SFENCE)
- It reduces the execution time and write amplification overheads, from 9% and 21%, to only 1% and 3%, respectively.
- A simple hardware support can provide an upper-bound on the recovery work

Questions?