NyxCache: Flexible and Efficient Multi-Tenant Persistent Memory Caching

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In-Memory Key-Value Caches are Crucial

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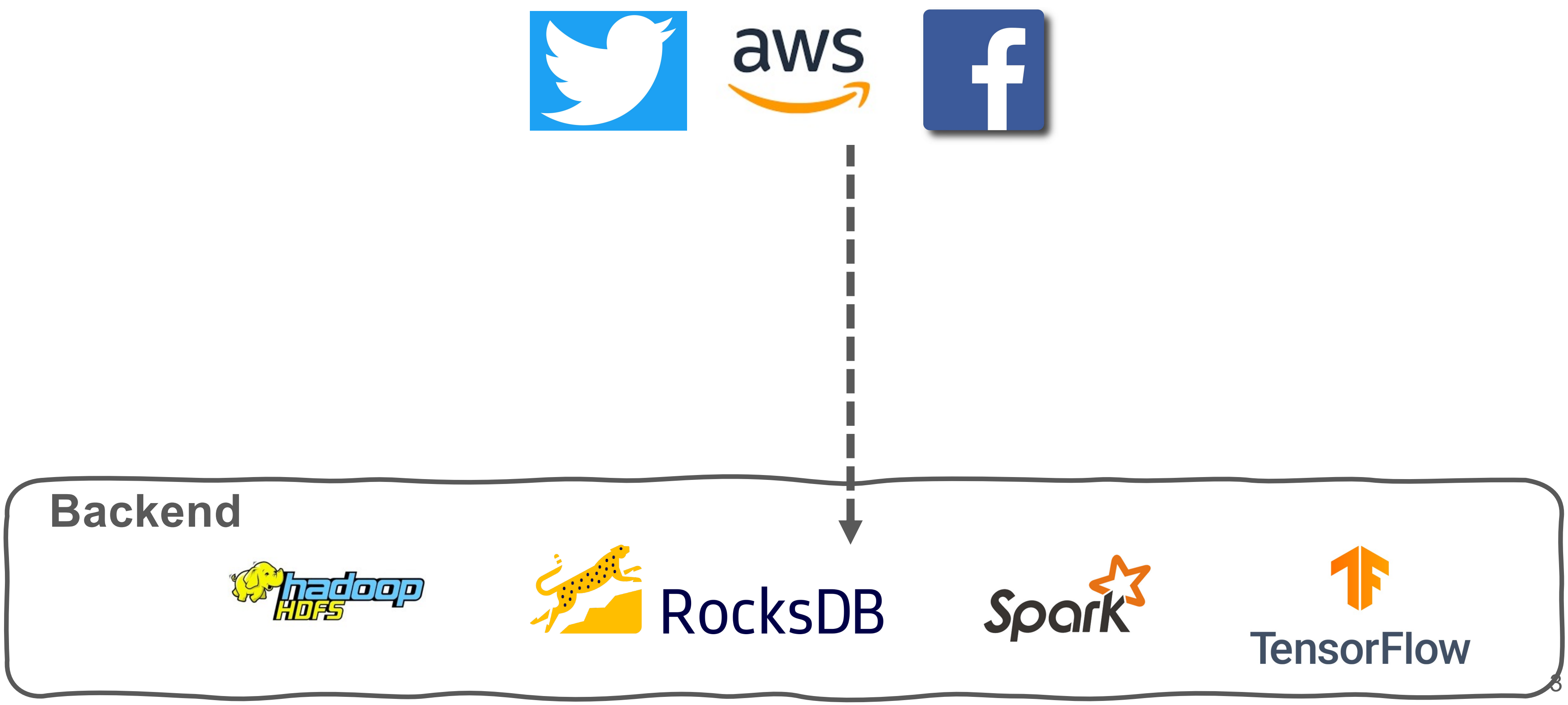

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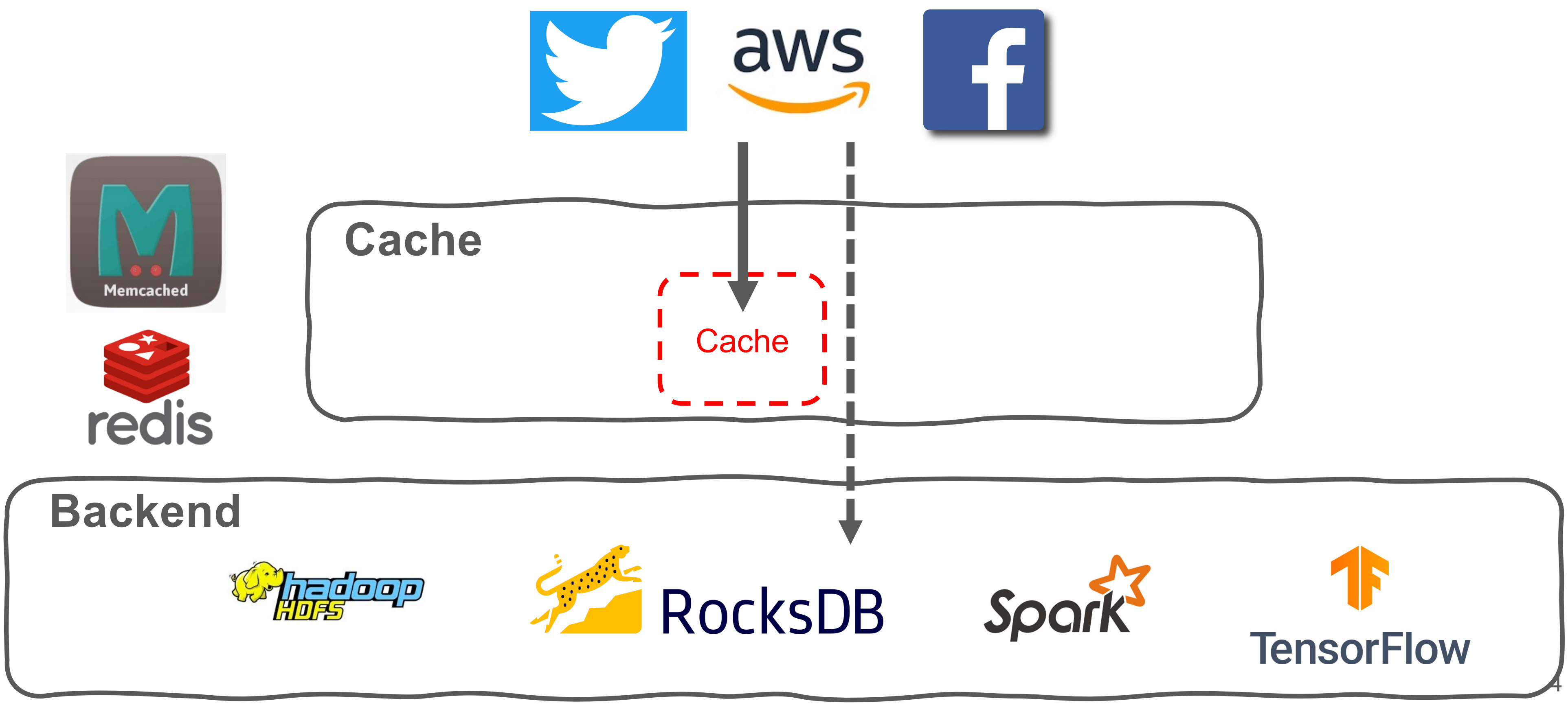
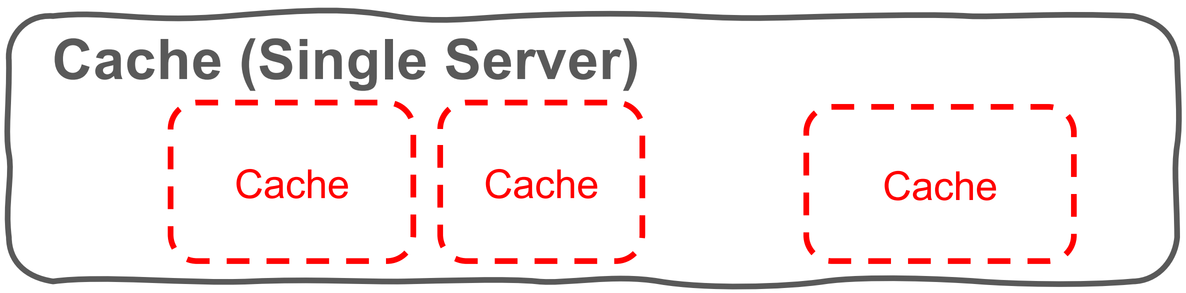


A Cache Server is Usually Multi-Tenant



Consolidated instances

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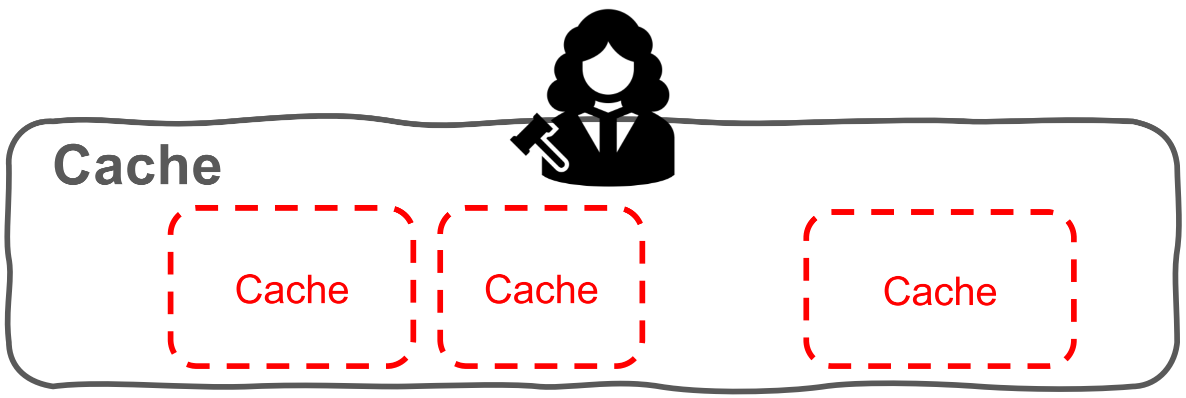

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Contention -> **regulation** required

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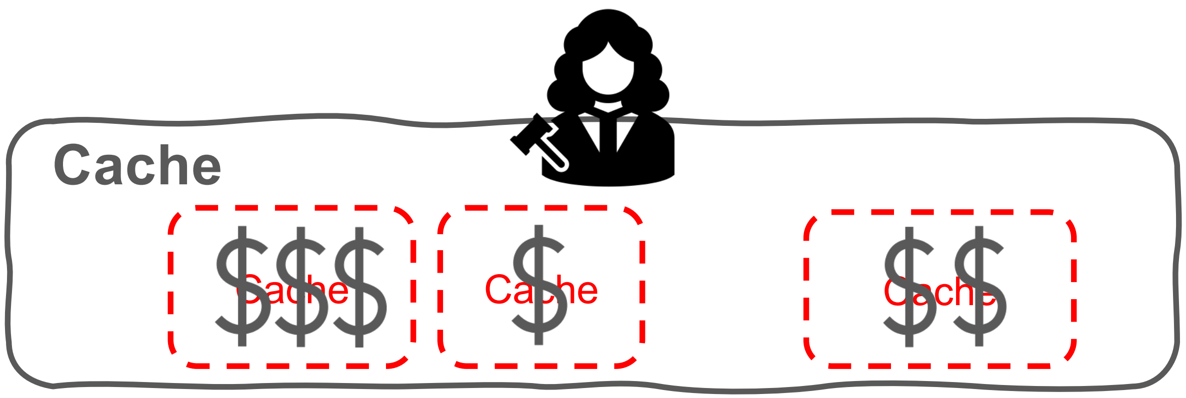

Consolidated instances

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Example sharing policies

- resource limit based on price tier,
- QoS
- proportional sharing, …

Persistent Memory for In-Memory KV Caches

Persistent Memory (PMEM)

- Intel Optane DC PMM (byte-addressable, memory bus, comparable performance to DRAM)

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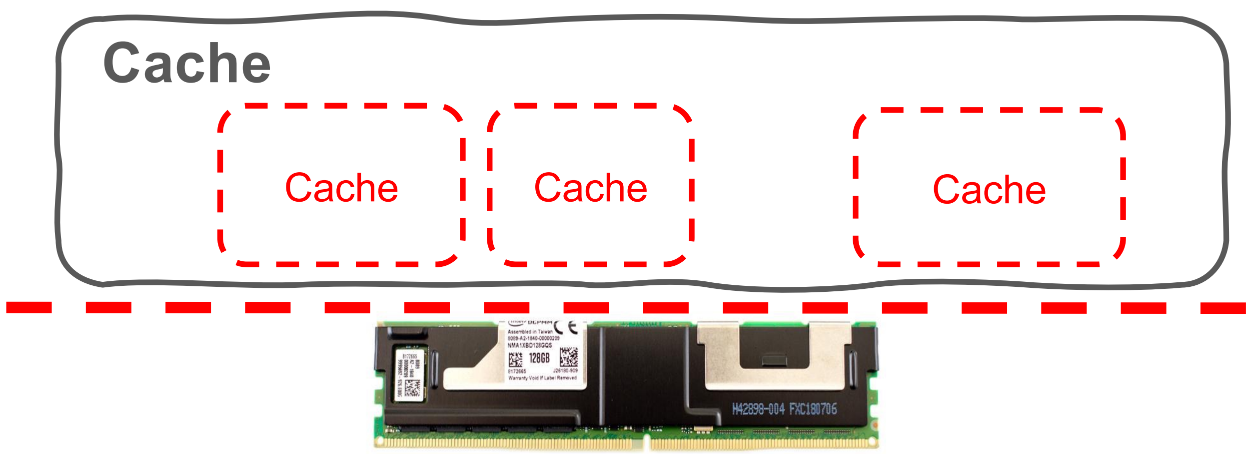
Appealing building blocks for in-mem KV caches

- Large capacity -> high hit rate
- Low cost per byte -> cheap, scale
- Energy-efficiency -> operational cost
- …

Challenges: Multi-tenancy over PMEM



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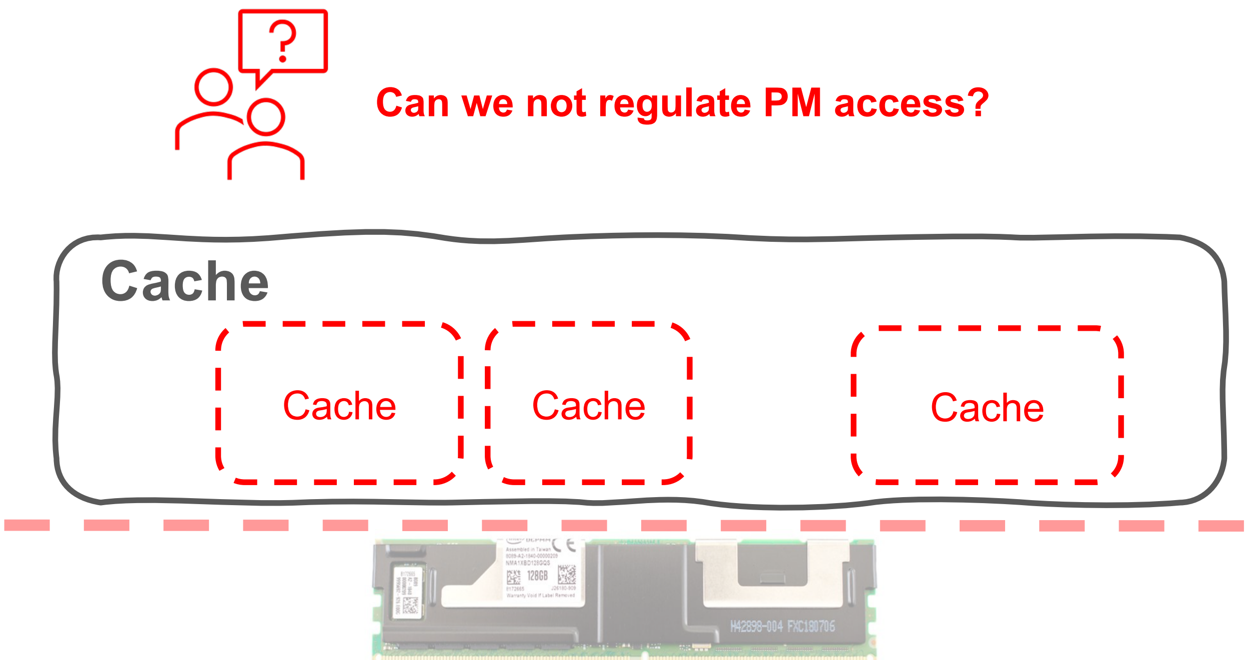

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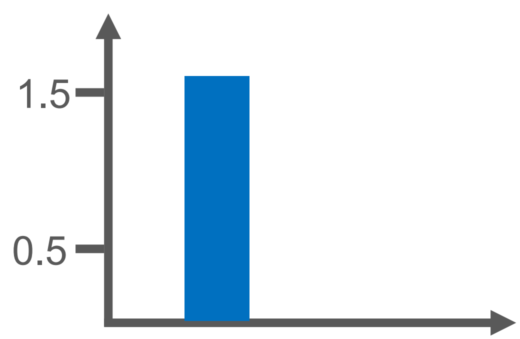
Read Throughput
(single thread 256B, GB/s)



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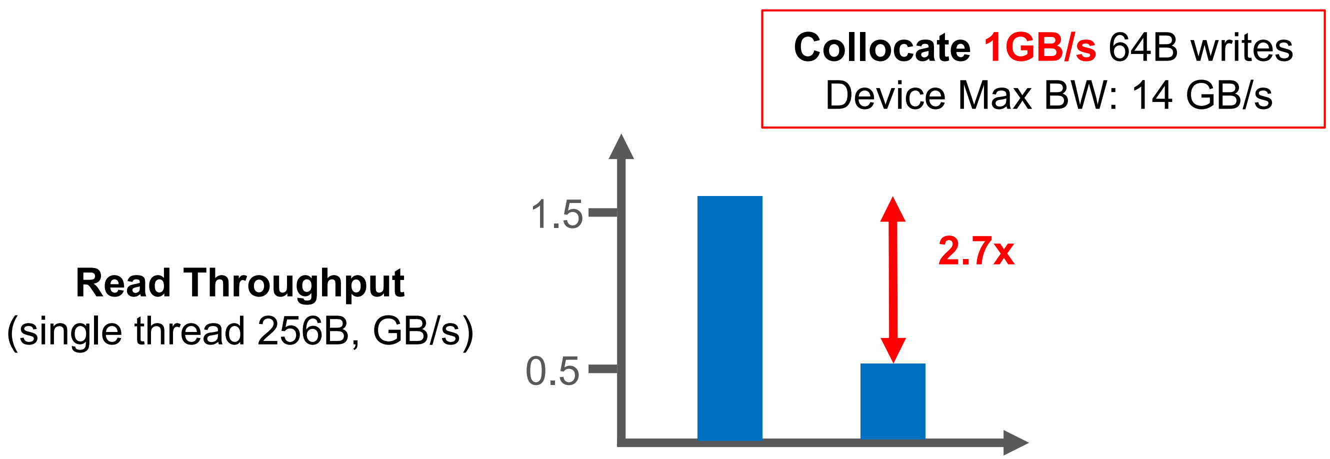

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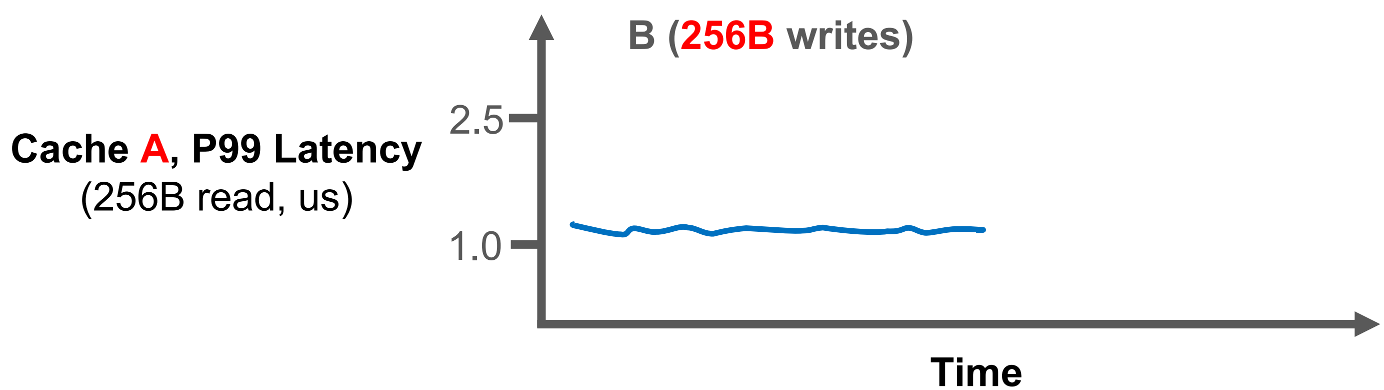

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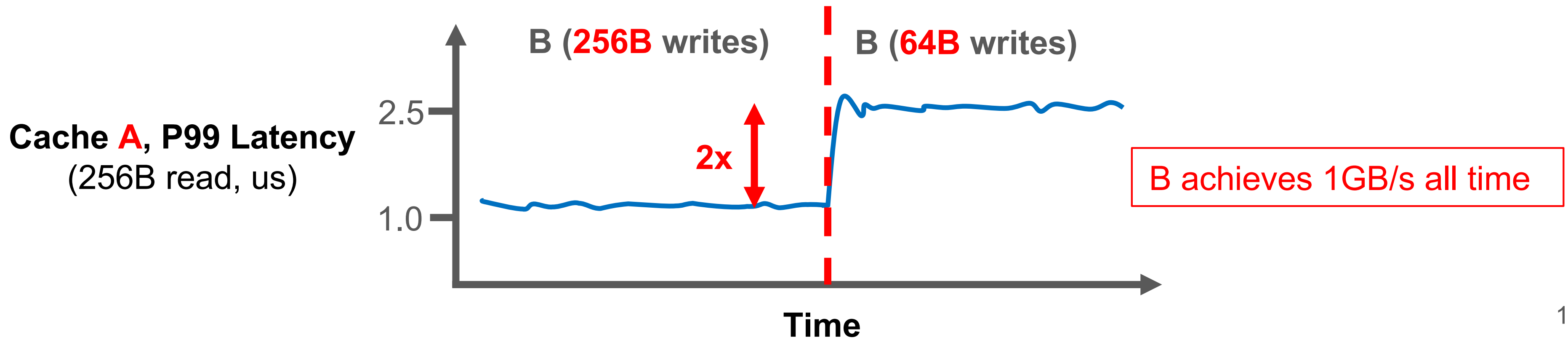
  - **Memory bandwidth limiting is ineffective due to** PMEM 256B internal access granularity



Goal: Design New PMEM Sharing Mechanisms

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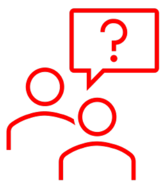

What mechanisms should we focus?

Many Sharing Goals …

Resource Limiting
- $ -> Resources

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Quality of Service (QoS)
- Latency-critical clients have latency guarantee
- Best-effort clients

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Proportional Sharing
- Weight -> Allocation

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Fair Slowdown

- Equalize client slowdowns
- Slowdown: $\frac{P_{alone}}{P_{share}}$

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Focus: Basic Mechanisms

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Mechanisms

M1: Request Regulation
- Control the rate a client can access PM

M2: Resource Usage Accounting
- How much PMEM resource (not bandwidth) does a client use?

M3: Interference Analysis
- Who interferes client A the most?

M4: Slowdown Estimation
- How much has a client been slowed as a result of sharing?: $\frac{P_{alone}}{P_{share}}$

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Contributions

Re-evaluate Key Mechanisms

- Analyze problems with existing mechanisms on PMEM

NyxCache: a flexible access regulation framework for any sharing goal

- Design new software mechanisms for PMEM sharing
- Revise four policy implementations based on new mechanisms

Contributions

This talk:

Interference Analysis

QoS Policy

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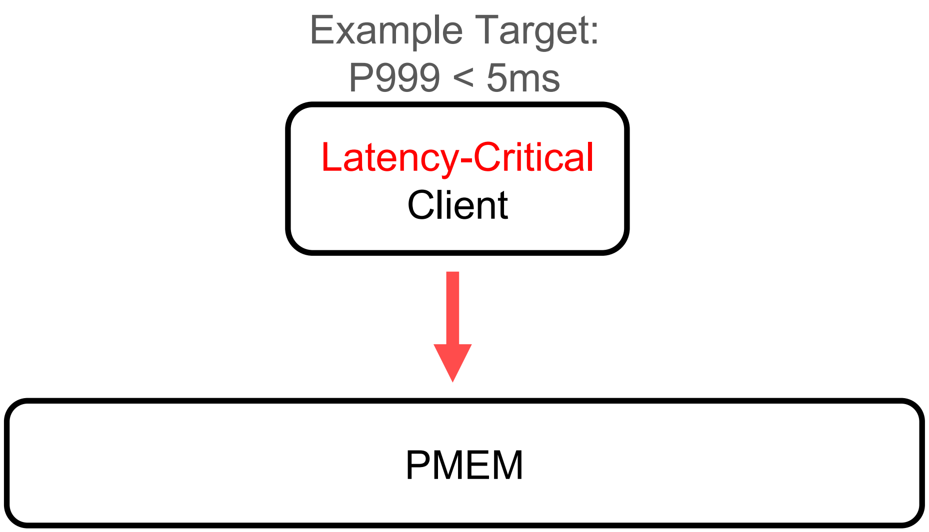
Interference Analysis

Use Case: Quality-of-Service policy

- **Latency-critical** clients (with tail latency guarantee) + Best-effort clients



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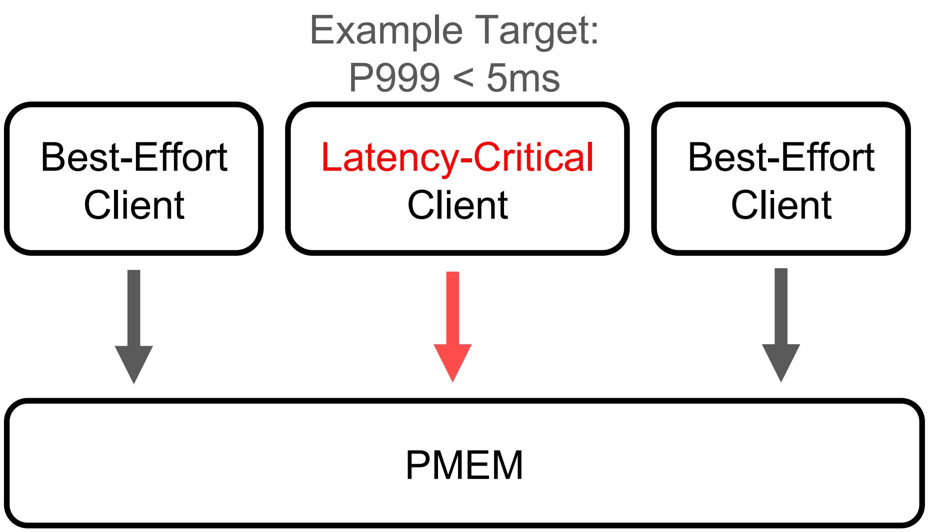

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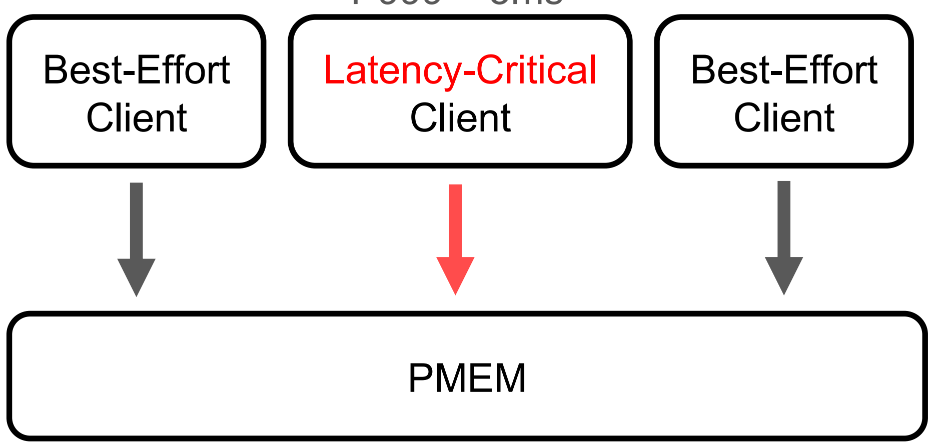
Latency target violated

Example Target:
P999 < 5ms



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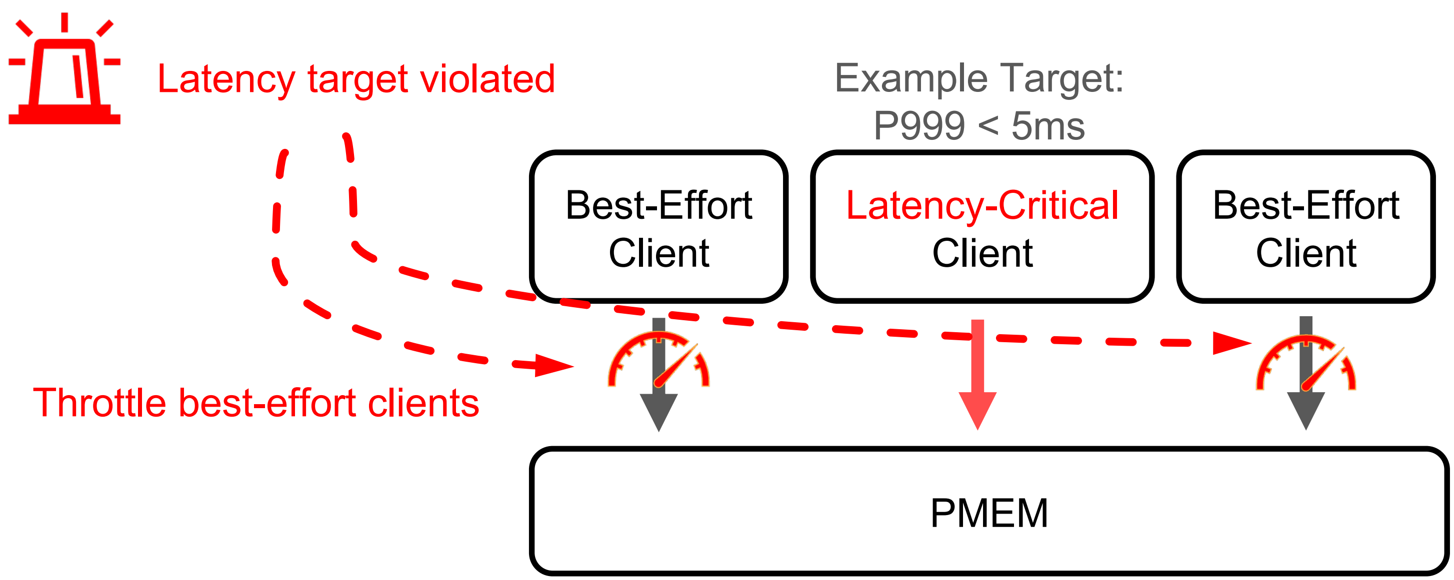

Interference Analysis

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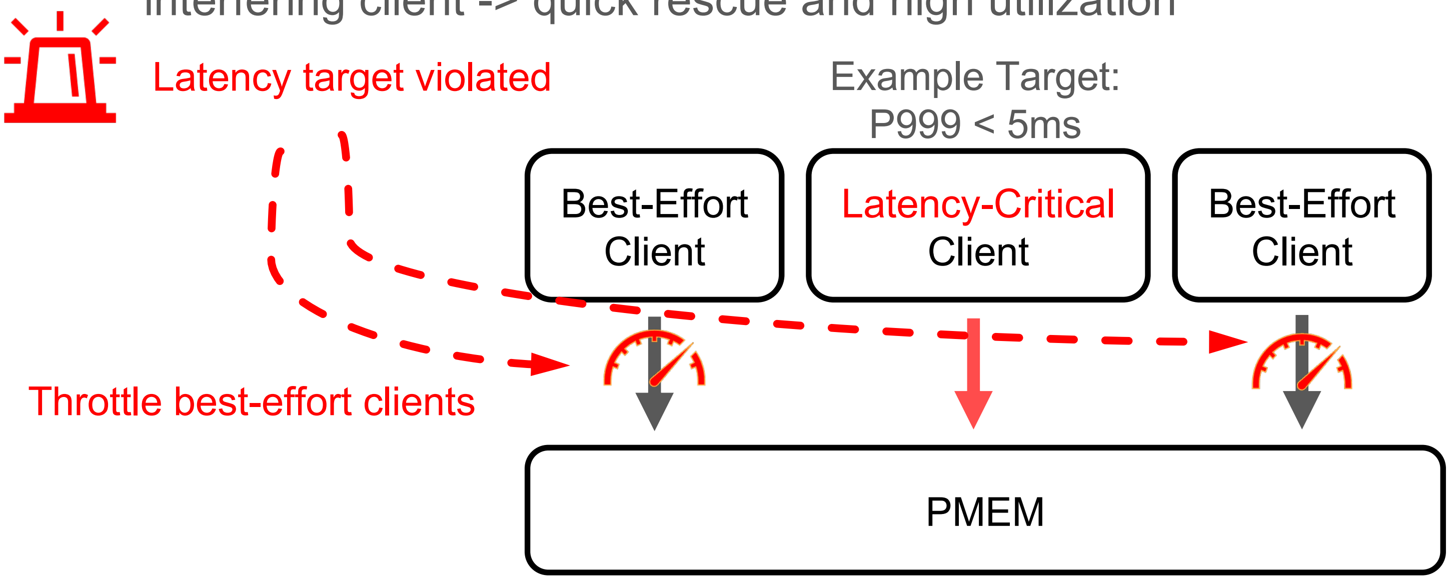
- **Latency-critical** clients (with tail latency guarantee) + Best-effort clients
- **Question: Who should we throttle? interference analysis** to find out the most interfering client -> quick rescue and high utilization



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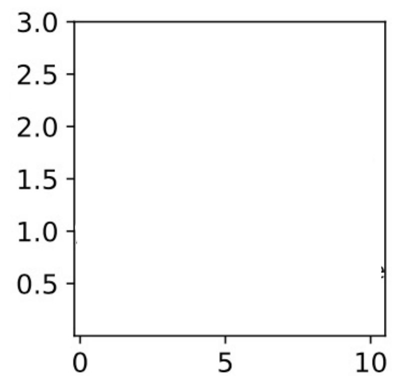
(256B read, us)



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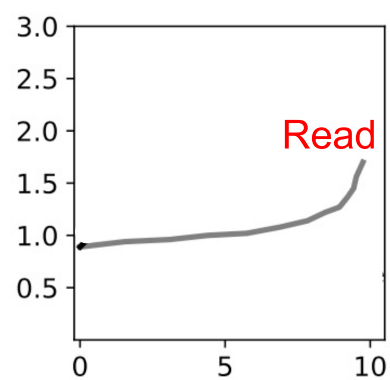

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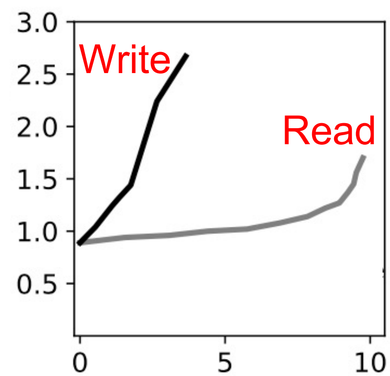

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e.g., 1GB/s 64B writes cause 2x the interference as 1GB/s 256B writes

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We need new high-fidelity interference analysis for PMEM sharing

Solutions: NyxCache – Interference Analysis

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Goal: Answer who is interfering the most with a given client

- **No special hardware** – software solution
- **Minimal device assumptions** – treat devices as black box

Solutions: NyxCache – Interference Analysis

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Solution: runtime micro-, controlled-experiments

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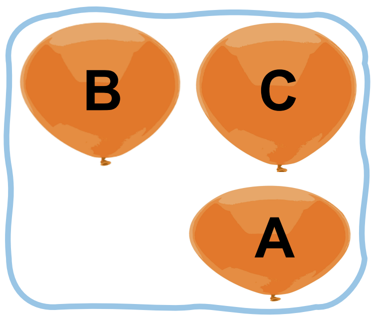
Current State

A Performance: L



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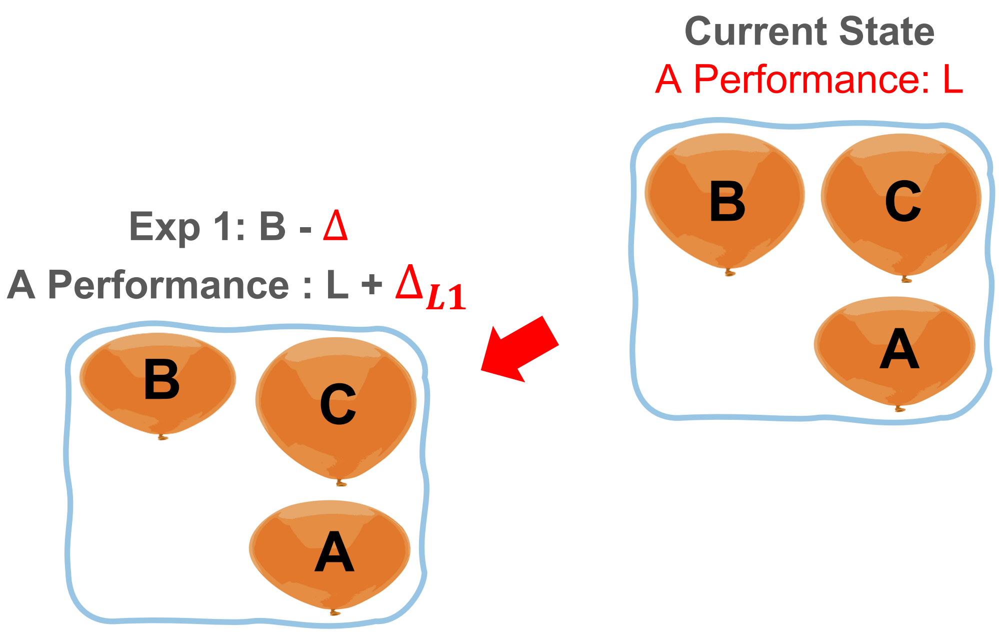

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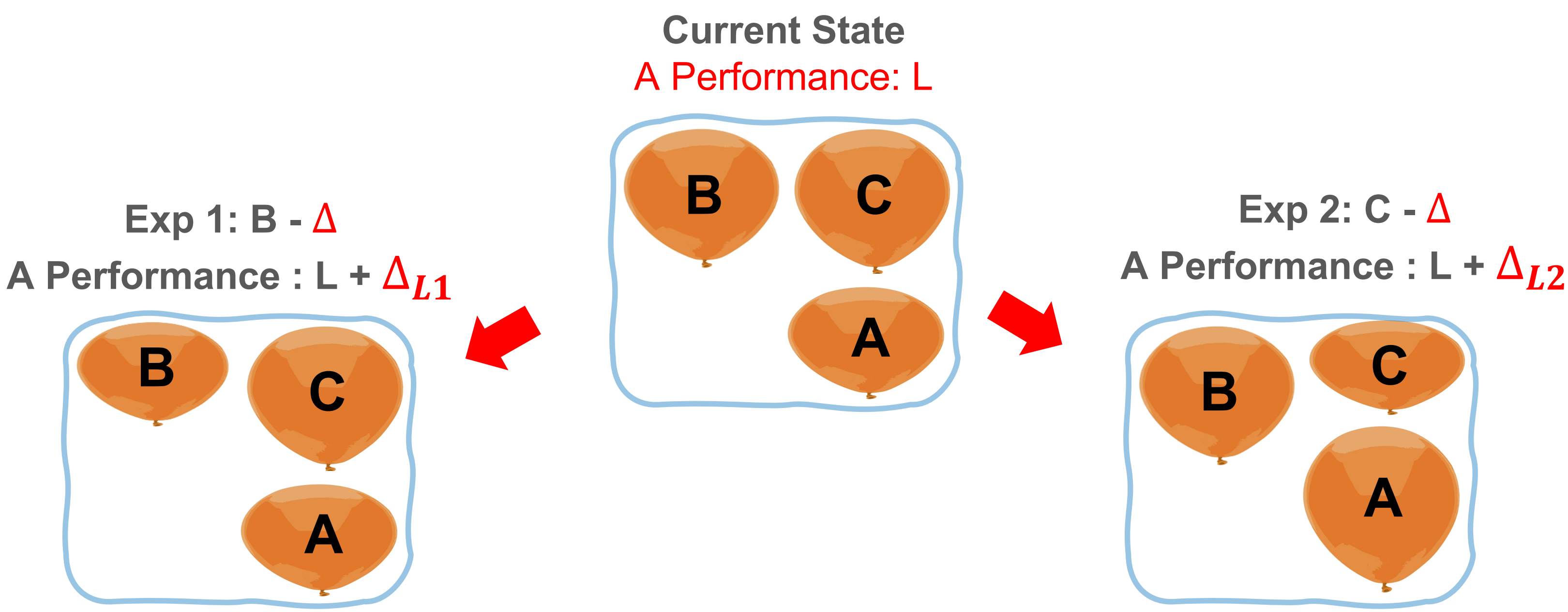

Solutions: NyxCache – Interference Analysis

Goal: who is interfering the most with a given client -> who yields the largest Δ_L

Solution: runtime micro-, controlled-experiments

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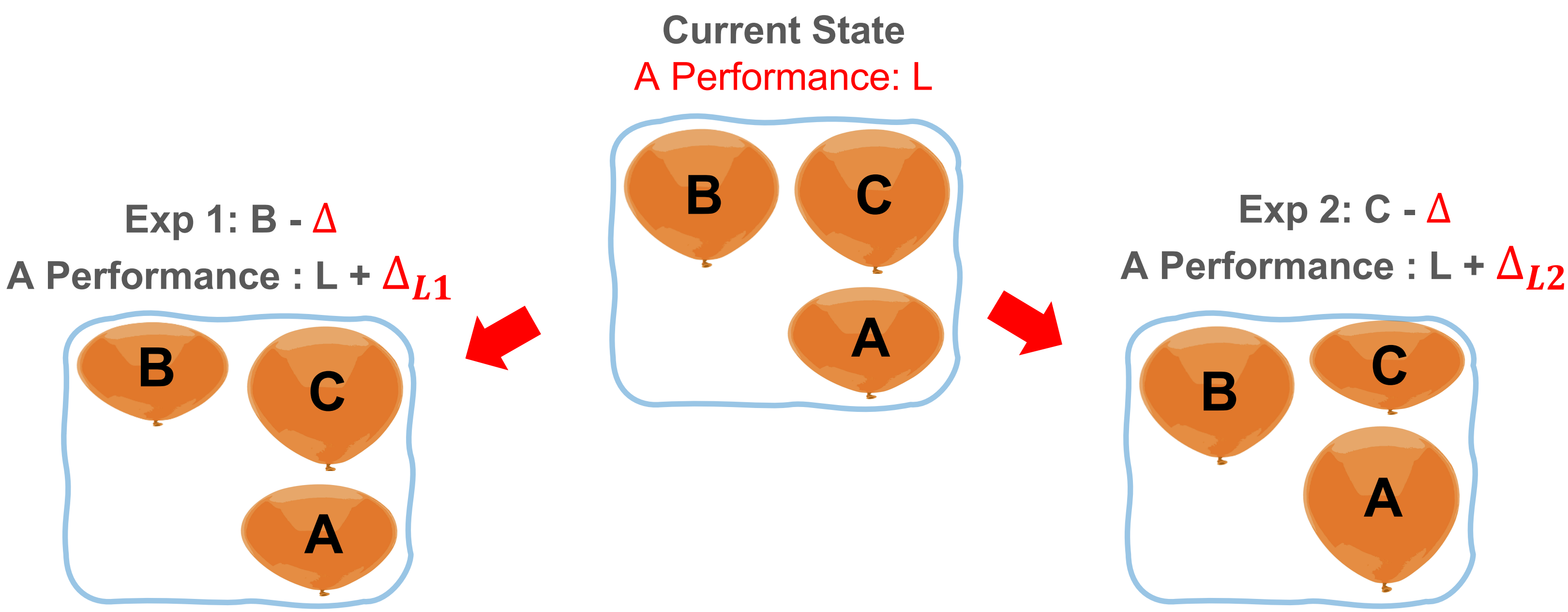
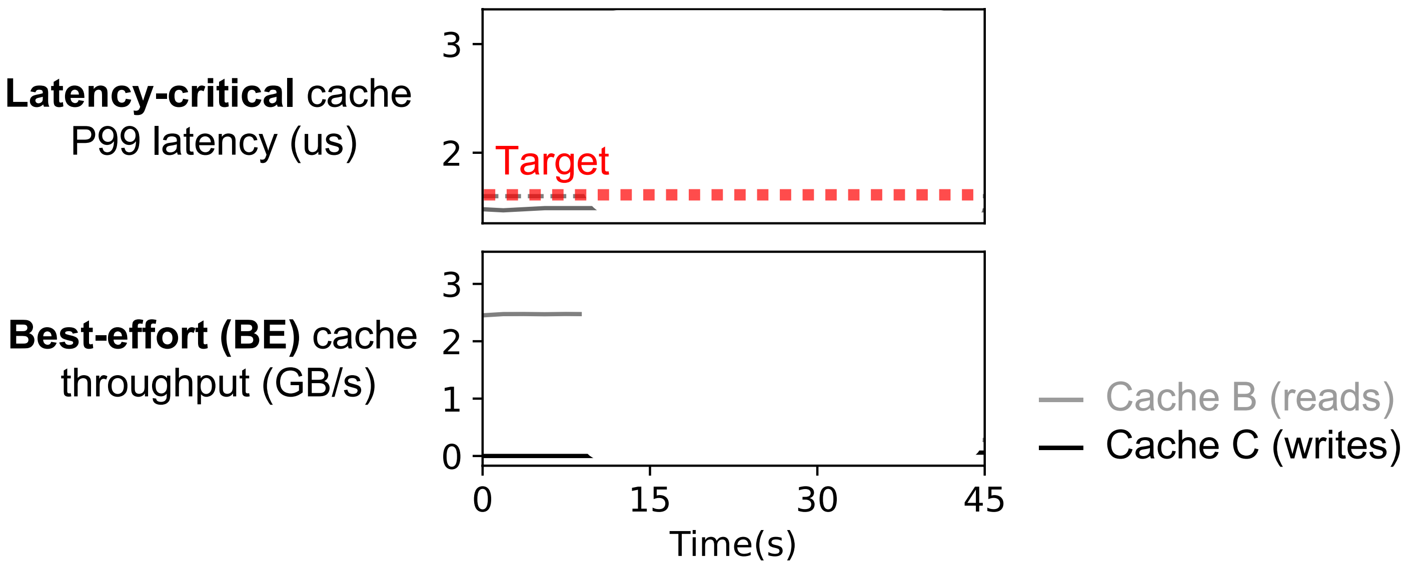


Evaluation: NyxCache – QoS

What's the benefit of NyxCache interference analysis mechanism?

- **Setup**: cache A, B, C
  - **- Cache A:** latency-critical cache (fixed)
  - **- Cache B: read-dominant** best-effort cache (fixed)
  - **- Cache C: write-dominant** best-effort cache (dynamic)

NyxCache Ensures QoS and High Utilization



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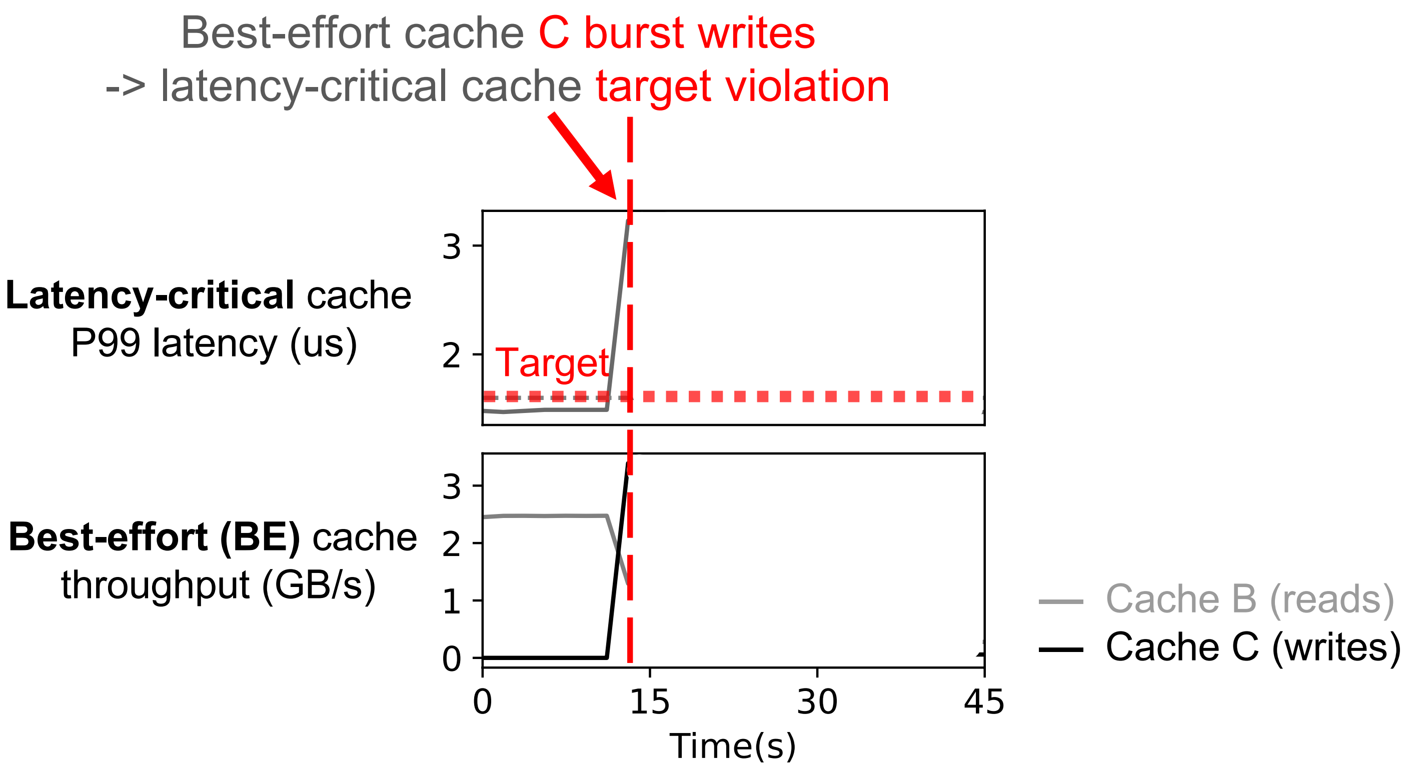

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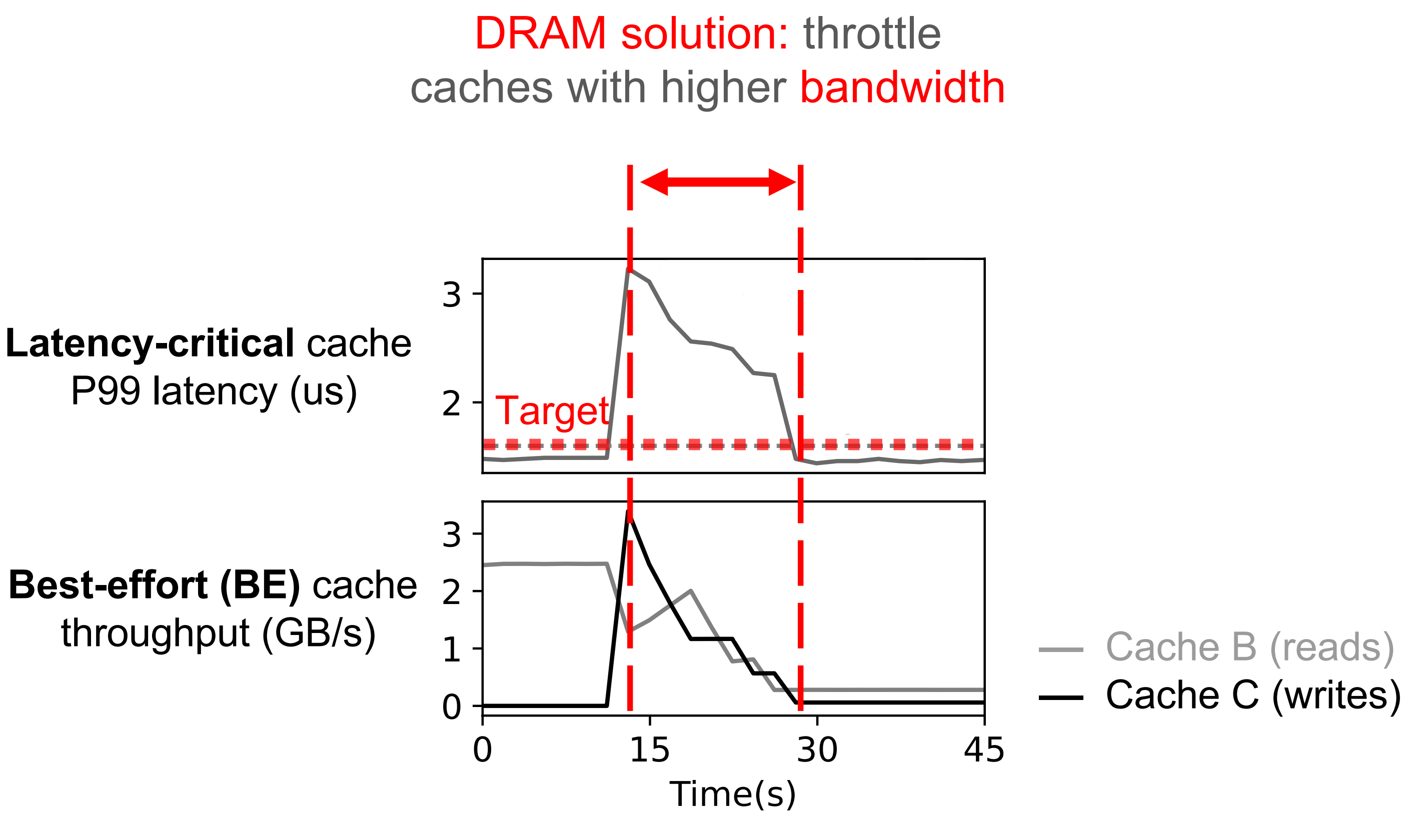
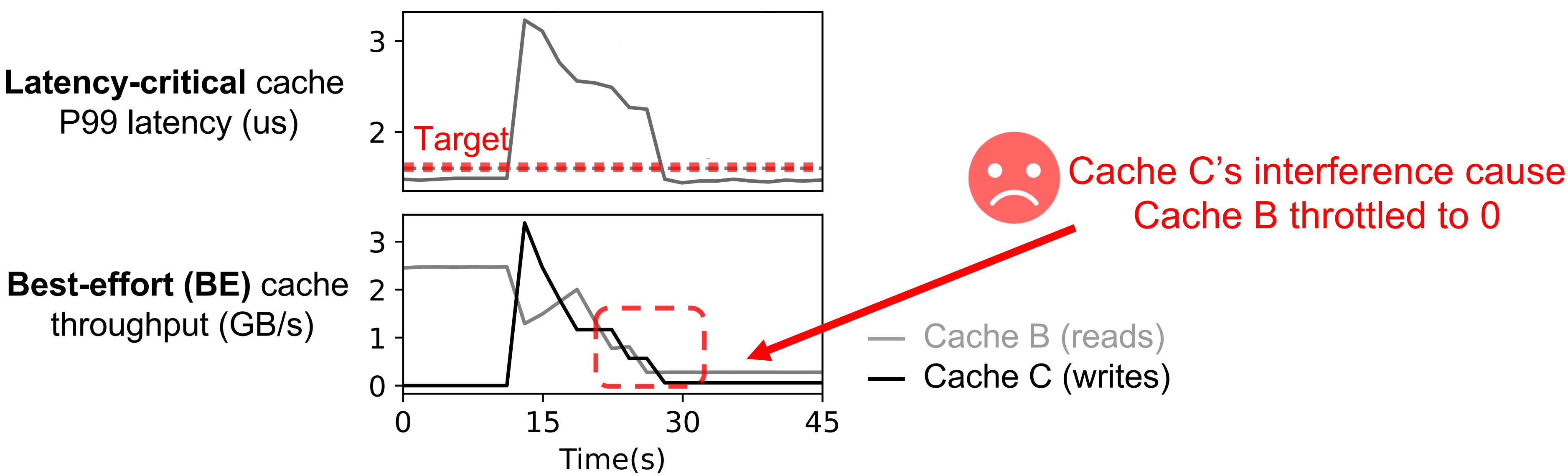


NyxCache Ensures QoS and High Utilization

DRAM solution: throttle caches with higher bandwidth



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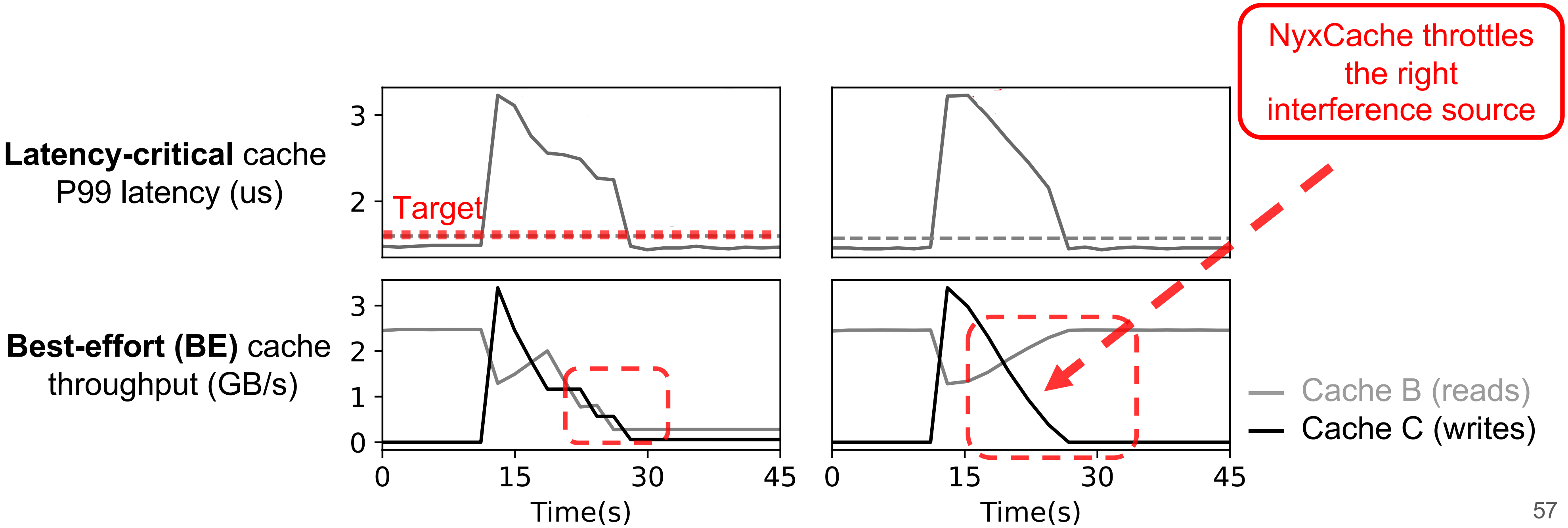

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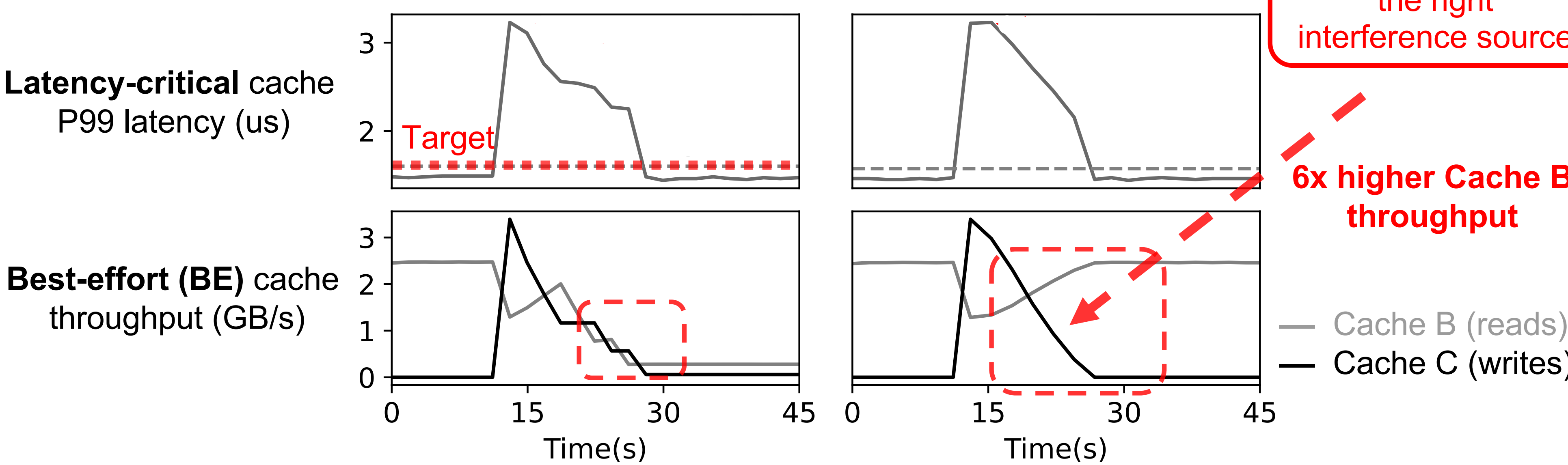

NyxCache throttles the right interference source

6x higher Cache B throughput

NyxCache Summary

PMEM sharing necessitates evolving software/hardware stack.

Our contributions:

- **Define** what are important sharing mechanisms (the subtrate)
- Analyze **problems** with existing mechanisms on **PMEM**
- **NyxCache –** design **new** software PMEM sharing **mechanisms**
- **NyxCache – revise policy** implementations based on new mechanisms

Nyx–QoS	Nyx–resource limiting	Nyx–fair slowdown	Nyx–proportional sharing
6x system utilization	5x better perf. isolation	2x better fairness	Interference-aware idle resource donation

Future Directions

- **Hardware Redesigns and Hardware/Software Codesigns for PMEM Sharing**

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Code: cs.wisc.edu/~kanwu