Pond: CXL-Based Memory Pooling Systems for Cloud Platforms

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The Public Cloud Memory Setting

- Cloud providers targets
  - *Performance* comparable to on-premise datacenters
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  - *Performance* comparable to on-premise datacenters
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- Memory allocation gold standard
  - VM memory is ***statically pinned*** to the *same NUMA node*
- DRAM is costly
  - ***~50%*** **of the server cost** for Azure!

Stranded and Untouched Cloud Memory

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  - No free CPU cores but memory left

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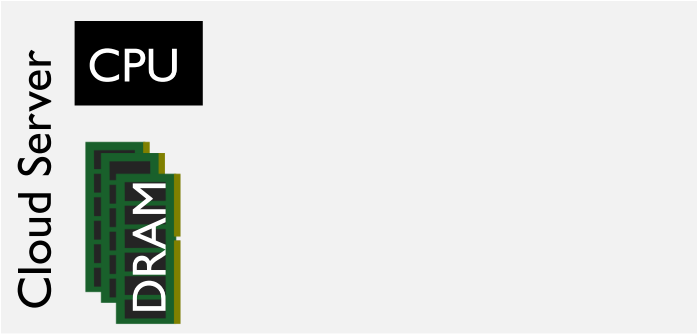

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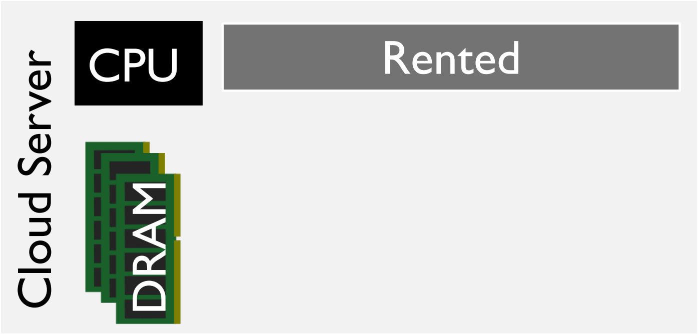

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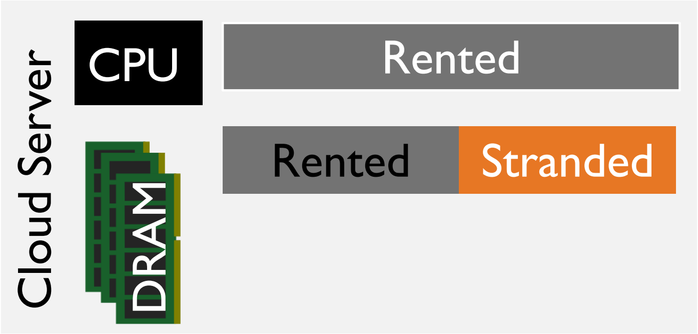

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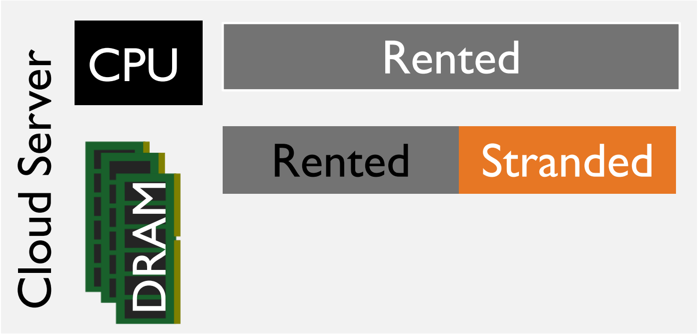

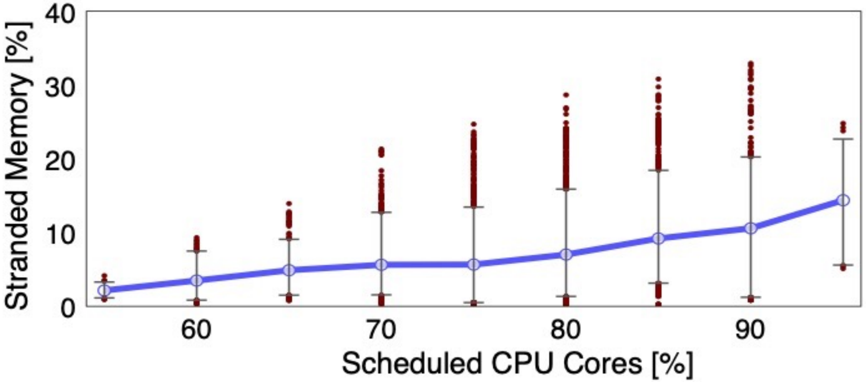

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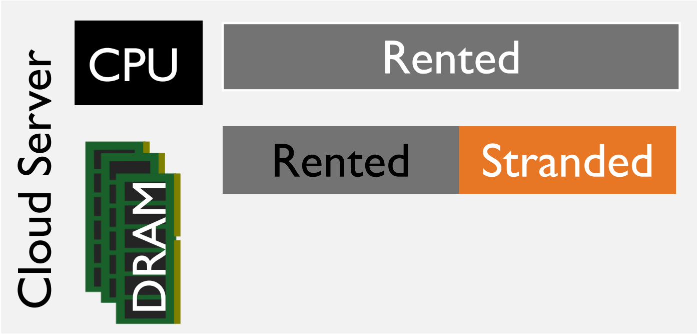

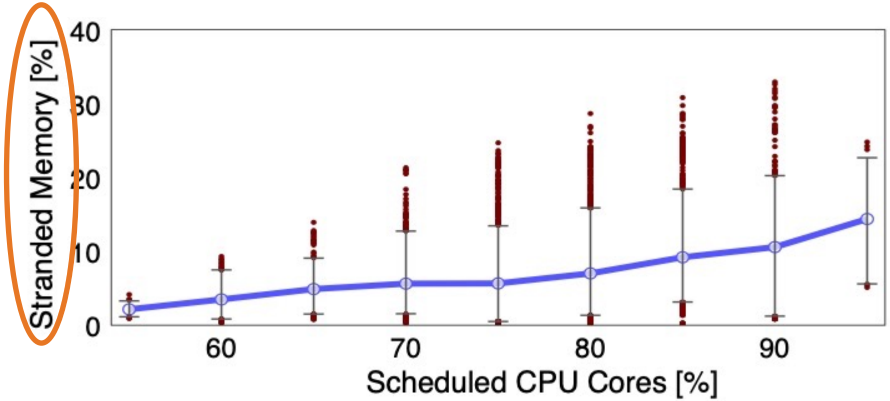

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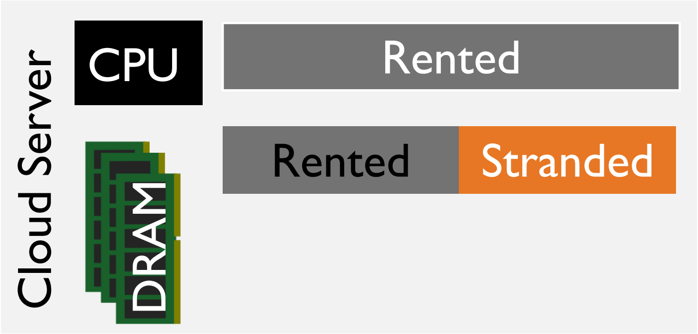

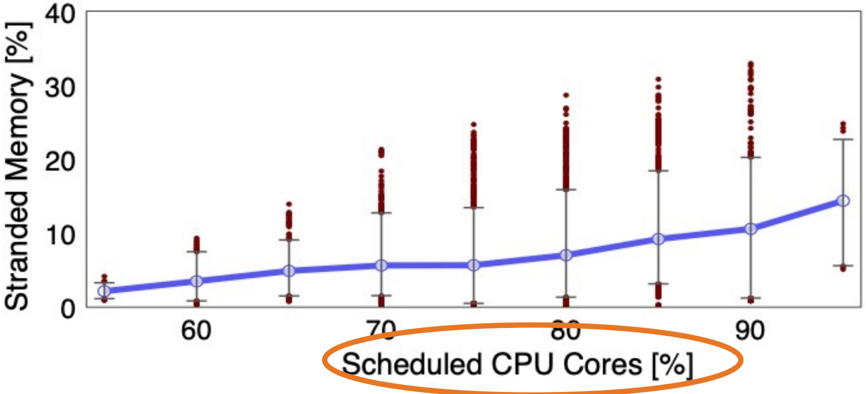

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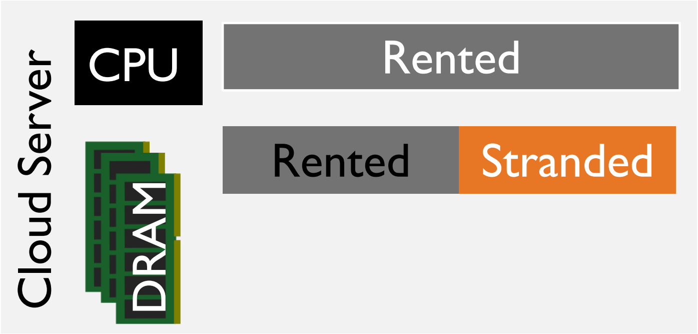

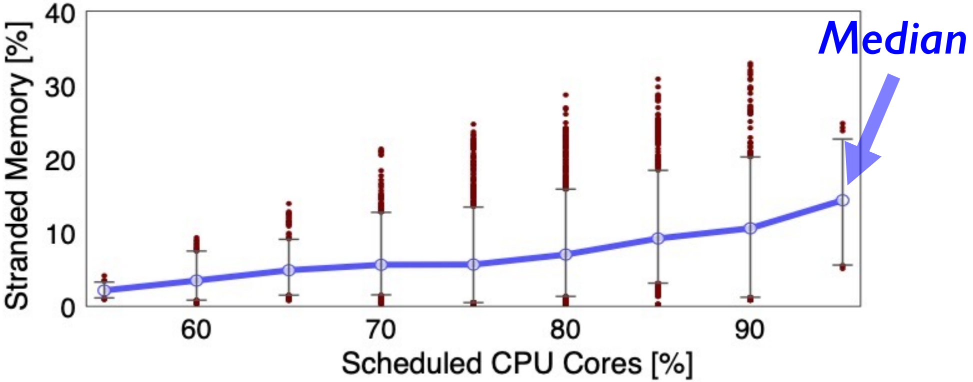

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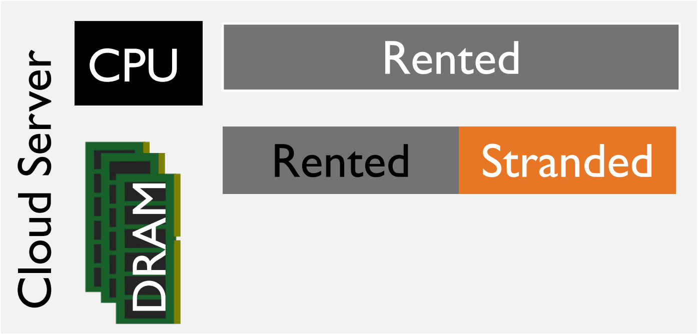

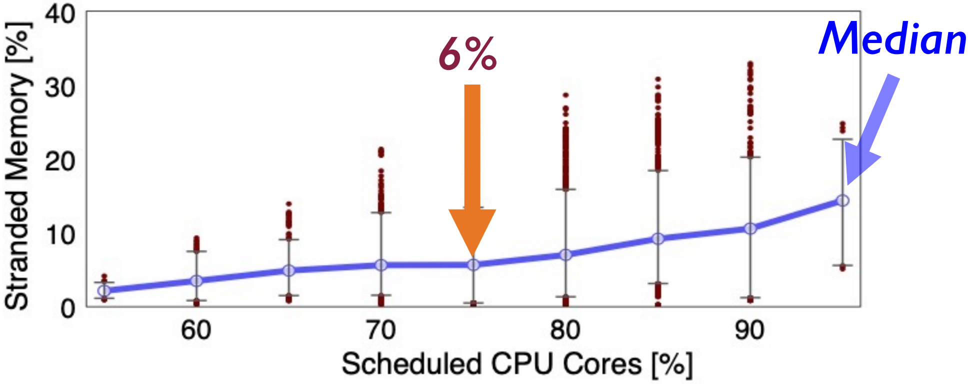

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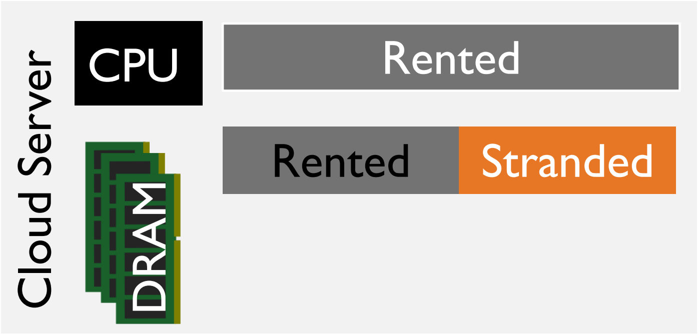

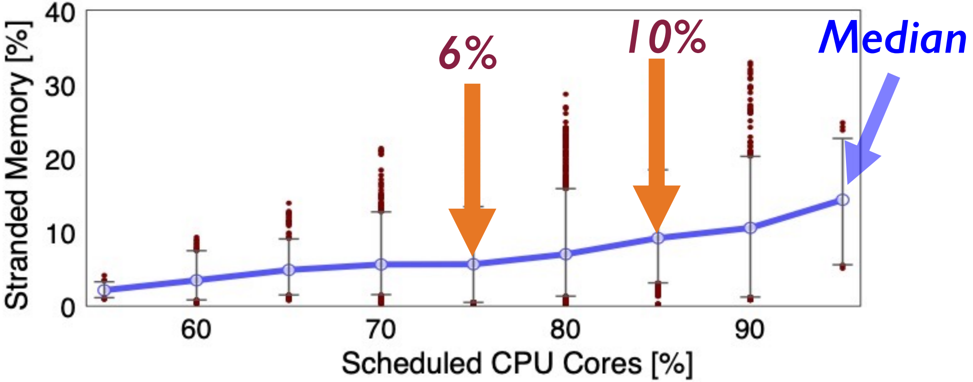

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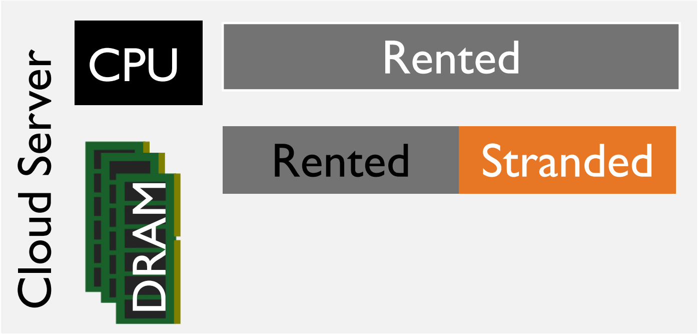

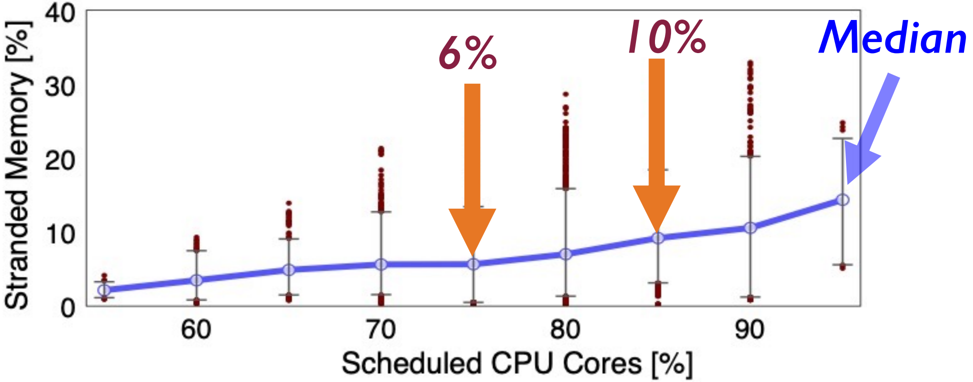

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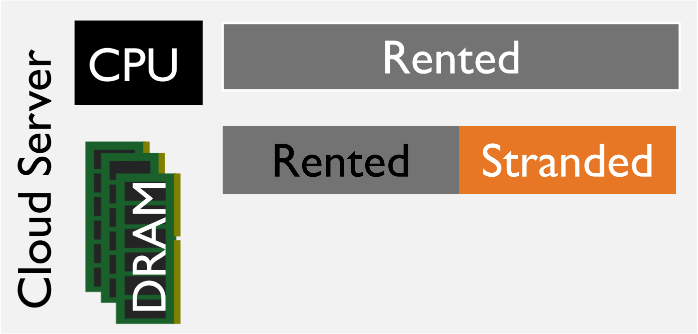

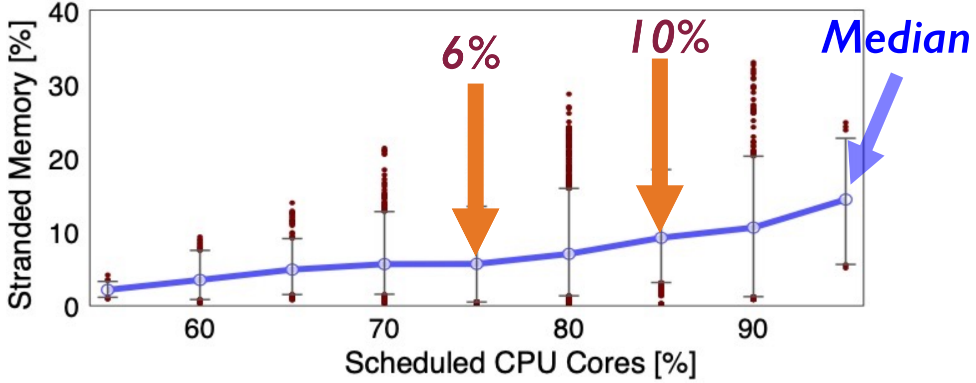

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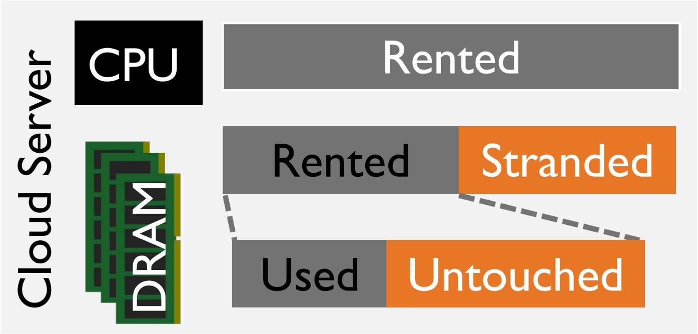

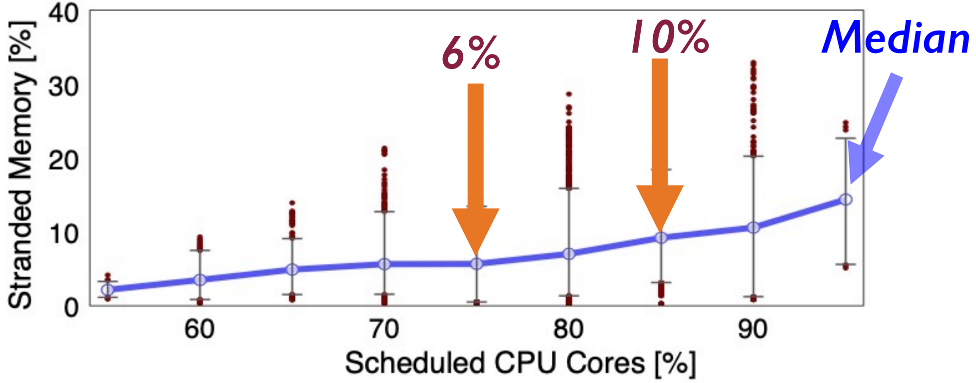

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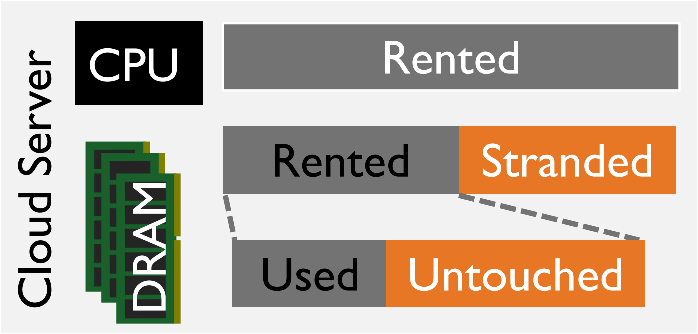
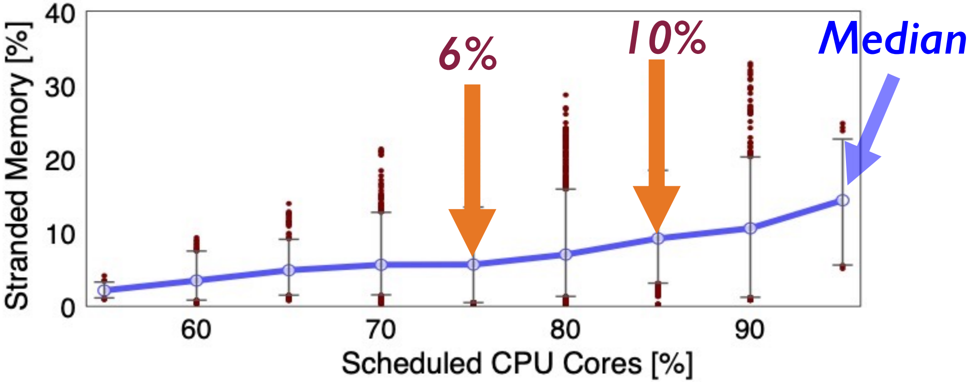
  - 45% of untouched memory for half of the VMs





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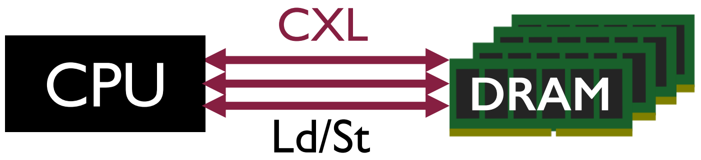

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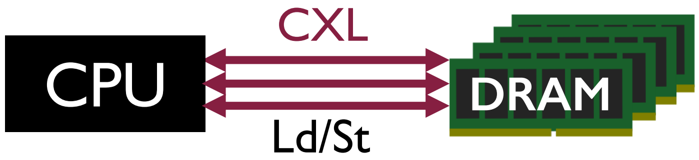

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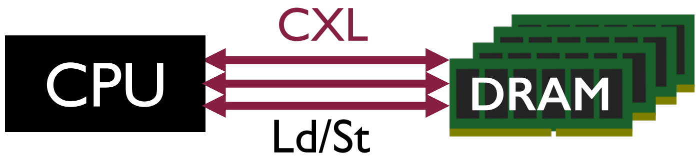

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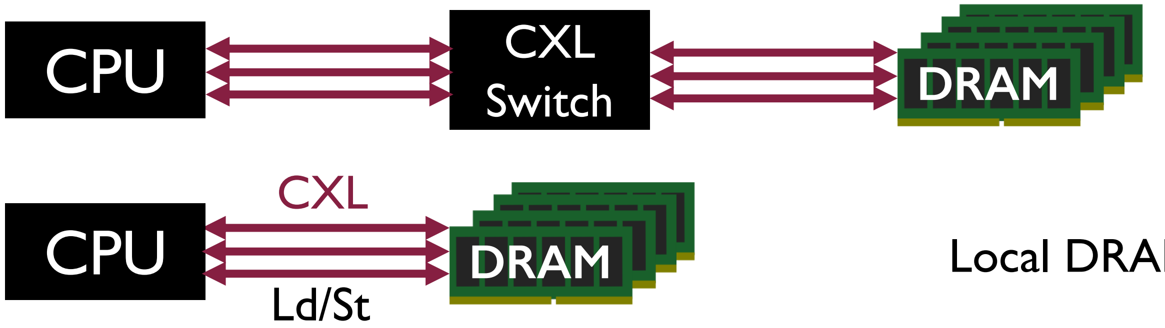

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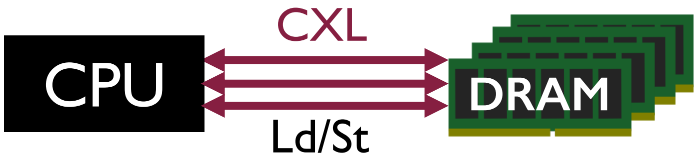
  - ***Latency-sensitive workloads will suffer from CXL latencies***



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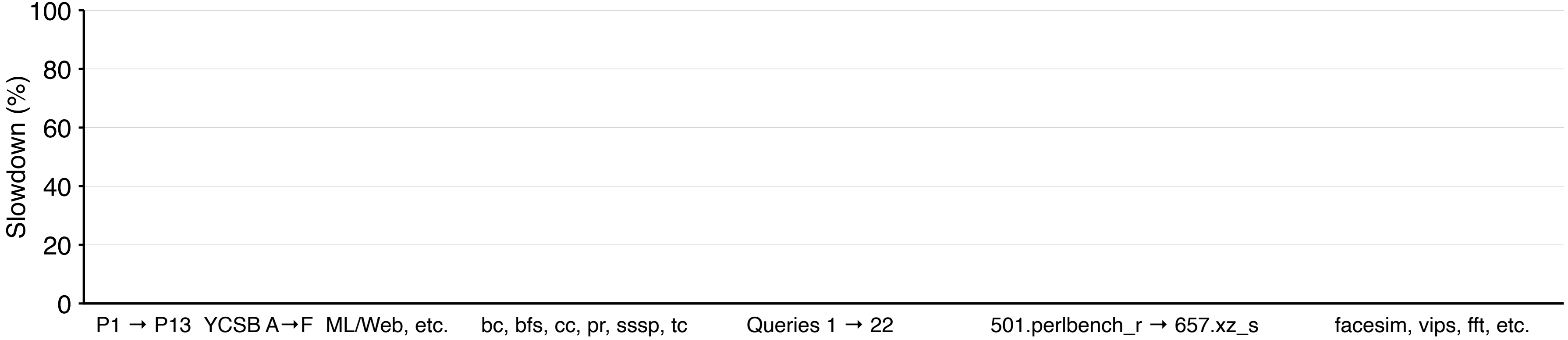
CXL Performance Impact



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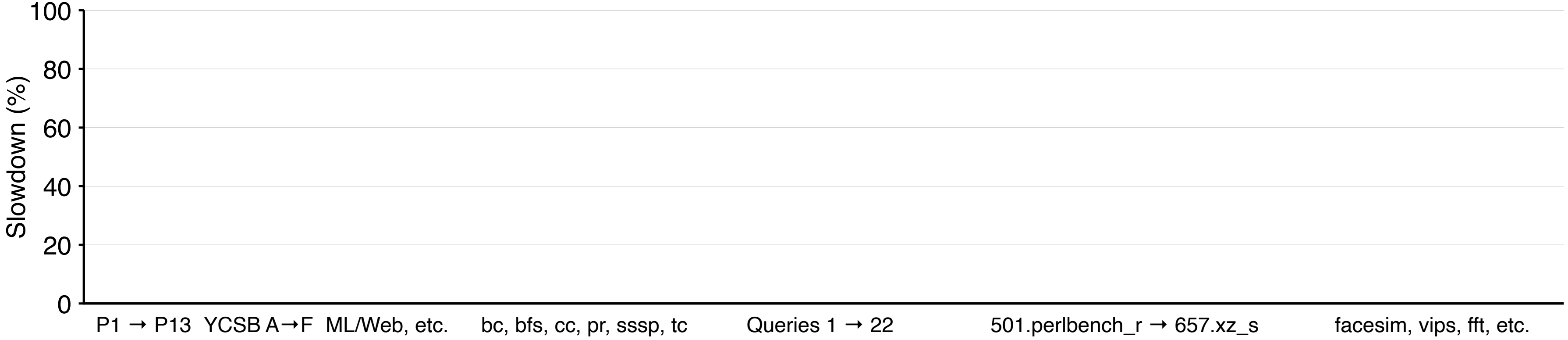

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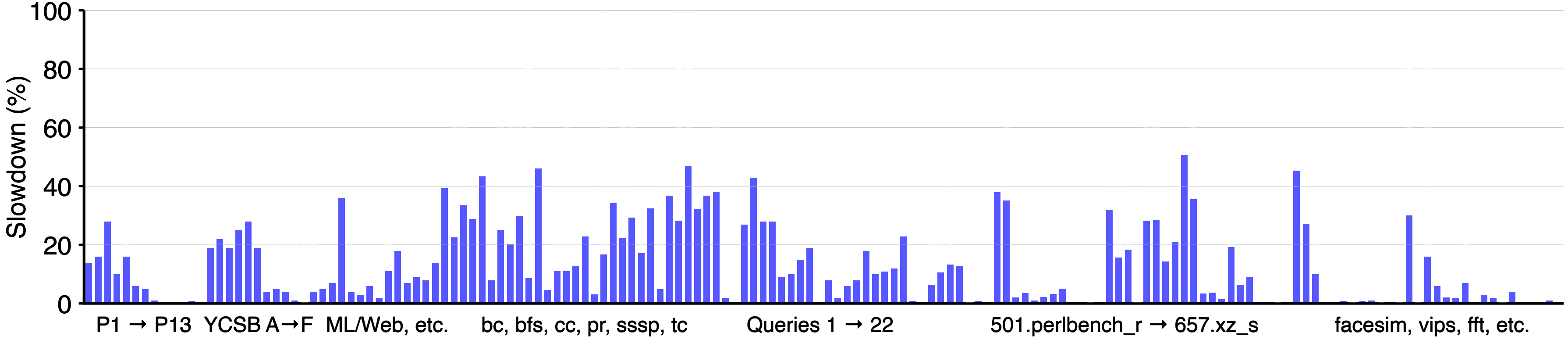
Approximated CXL latencies: 142ns (*182%*),



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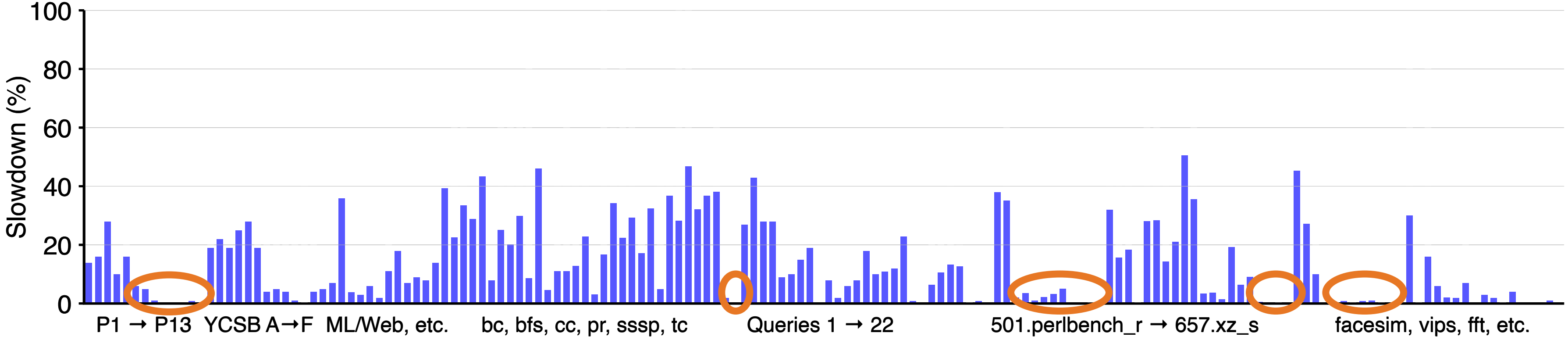

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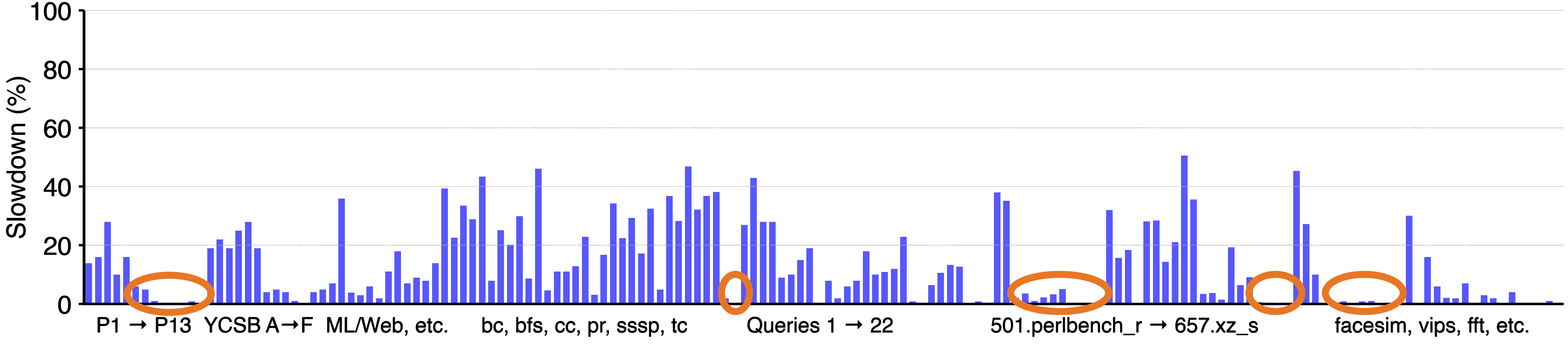

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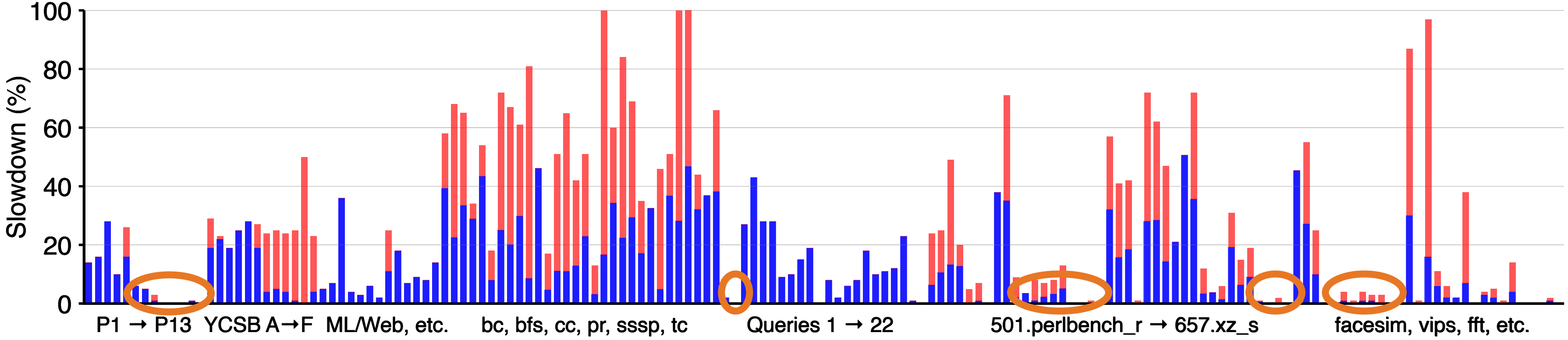
Approximated CXL latencies: 142ns (182%), and 255ns (222%)



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(a) A small fraction of workloads are ***not*** sensitive to CXL latencies

(b) ~60% of the workloads see more than 5% slowdowns

(c) Latency-sensitive workloads see ***bigger*** impact under higher CXL latencies

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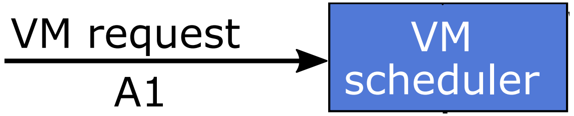
Idea: *Predict the amount of VM memory that can be safely allocated from the pool while satisfying the performance requirement via QoS monitoring.*

Pond: A Full-Stack Memory Pooling System



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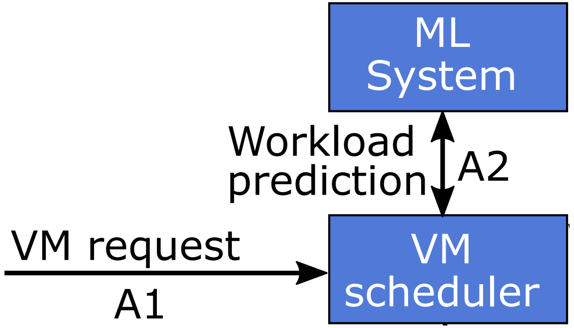

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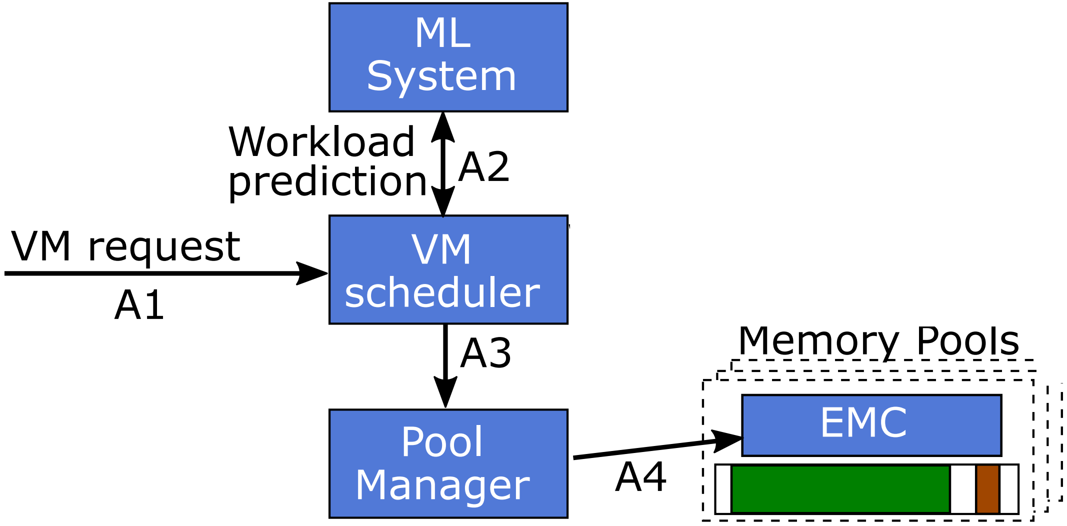

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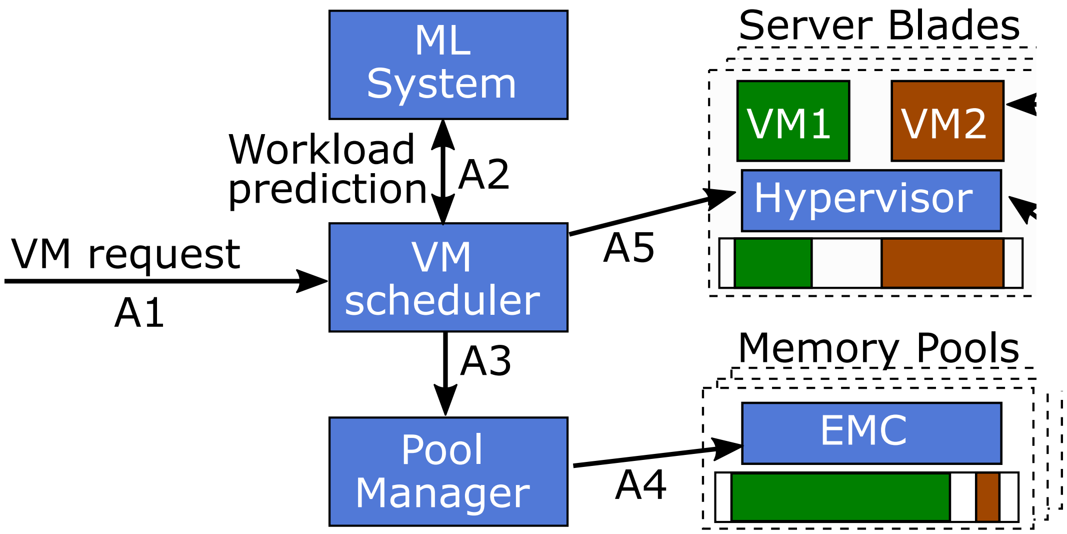

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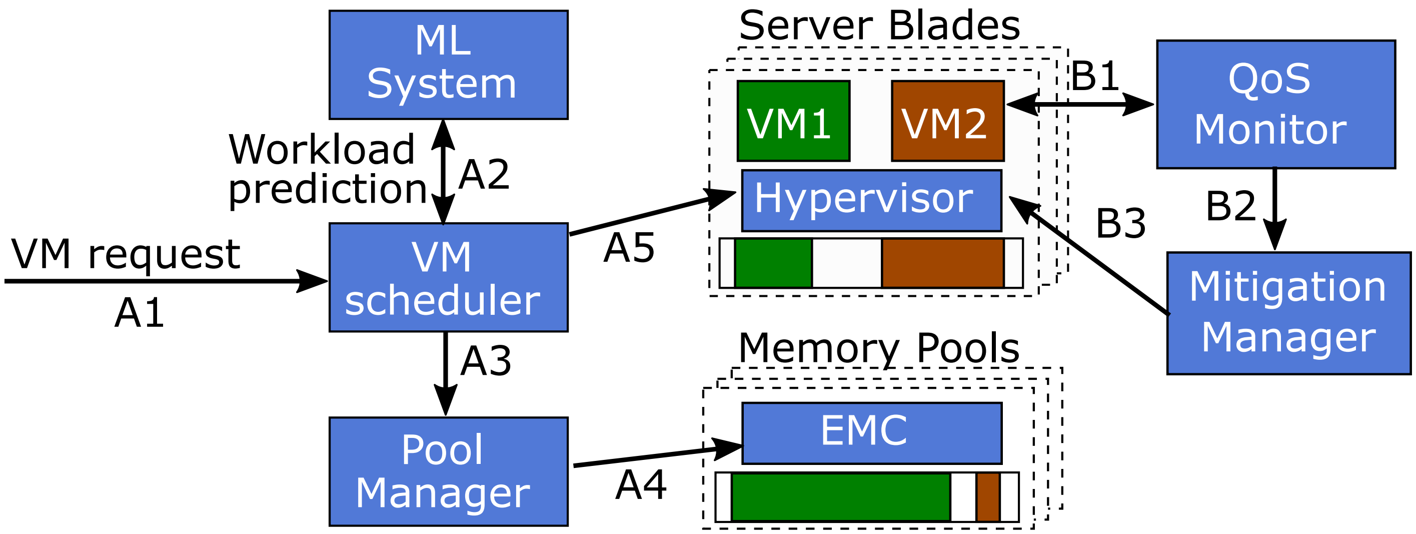

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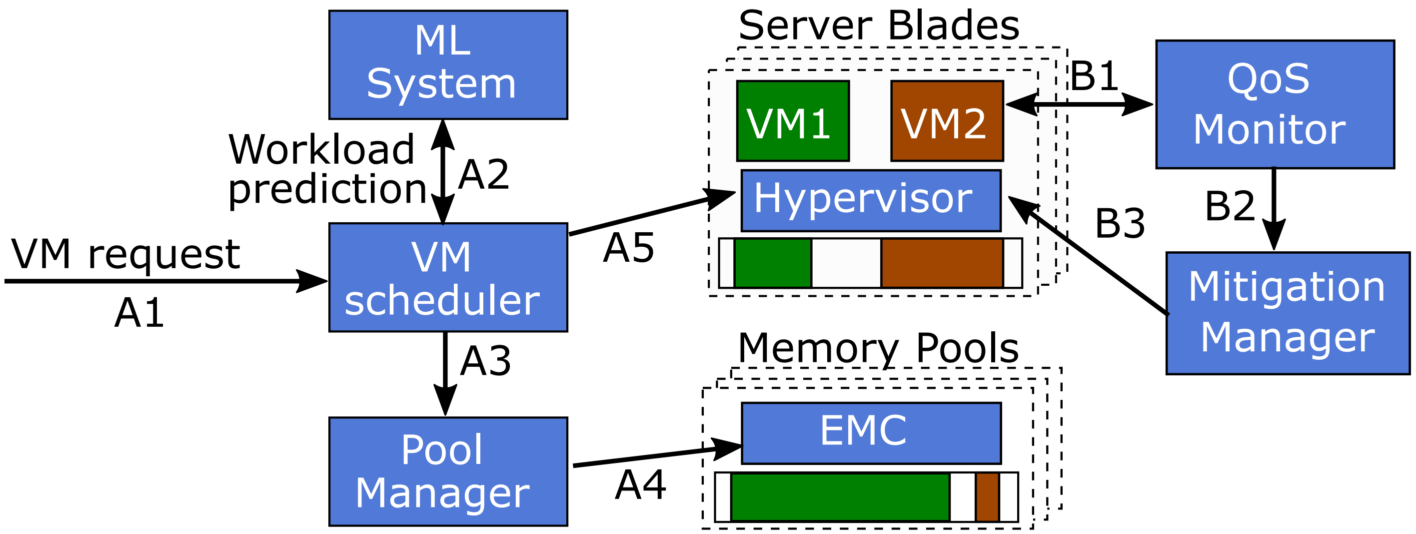

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Hardware, system software, and distributed system layers to manage pooled memory

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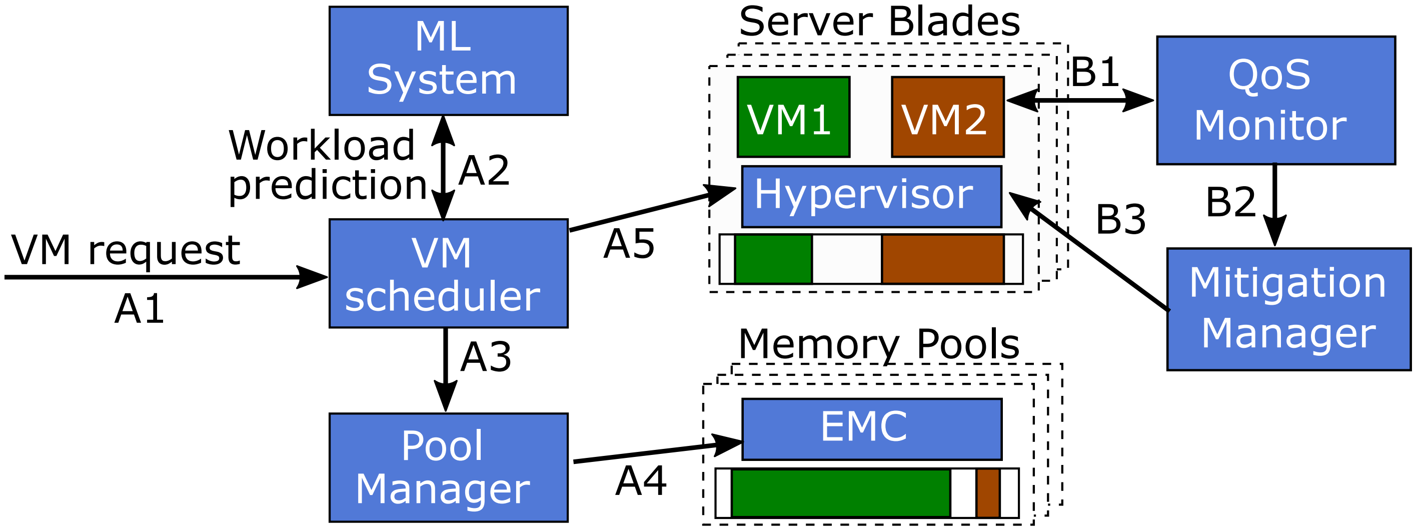
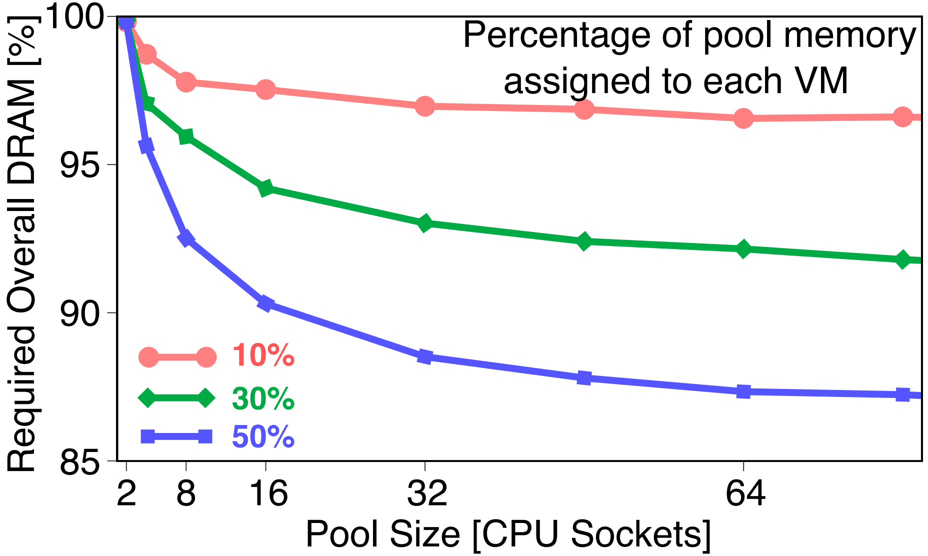


Pond contributions:
Hardware, system software, and distributed system layers to manage pooled memory

Pond benefits:
Reduce DRAM needs by 7% with a small pool → 3.5% reduction in cloud server cost

- Background & Motivation
- Pond Design
  - Overview
  - Memory pool scope
  - zNUMA
  - Prediction-assisted VM memory allocation
- Evaluation
- Conclusion

Pond Small Low Latency Pool



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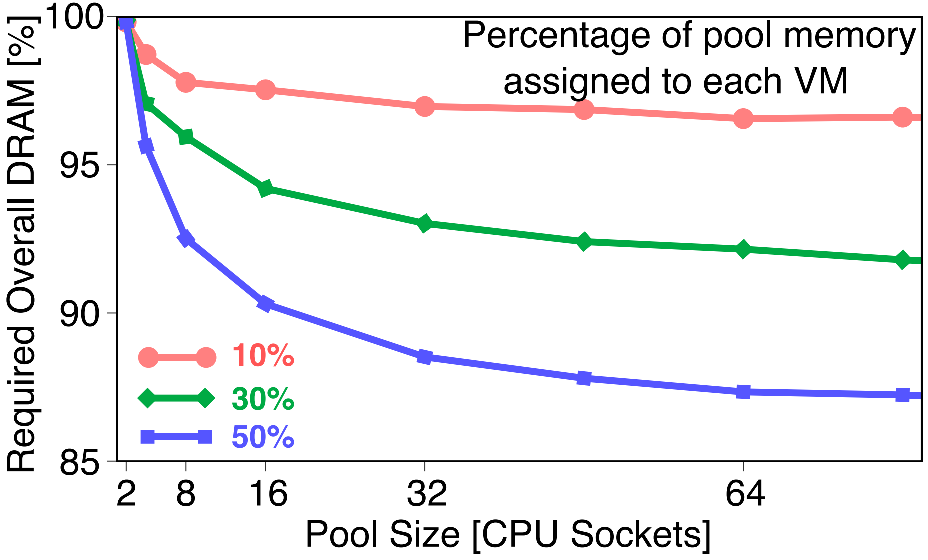
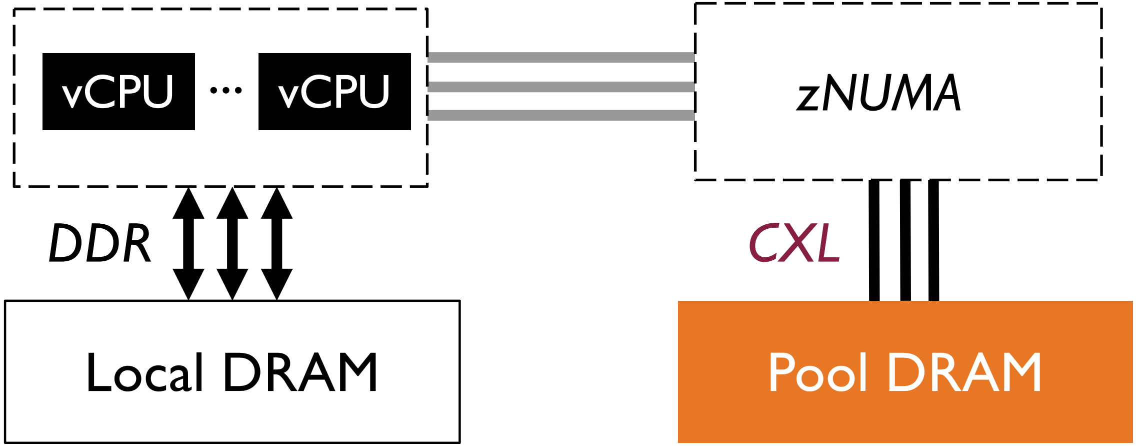


Small pools are effective!

While larger pools get diminishing returns.

CXL Memory as a zNUMA Node to the VMs

- ❑ *Zero-core NUMA (zNUMA)*



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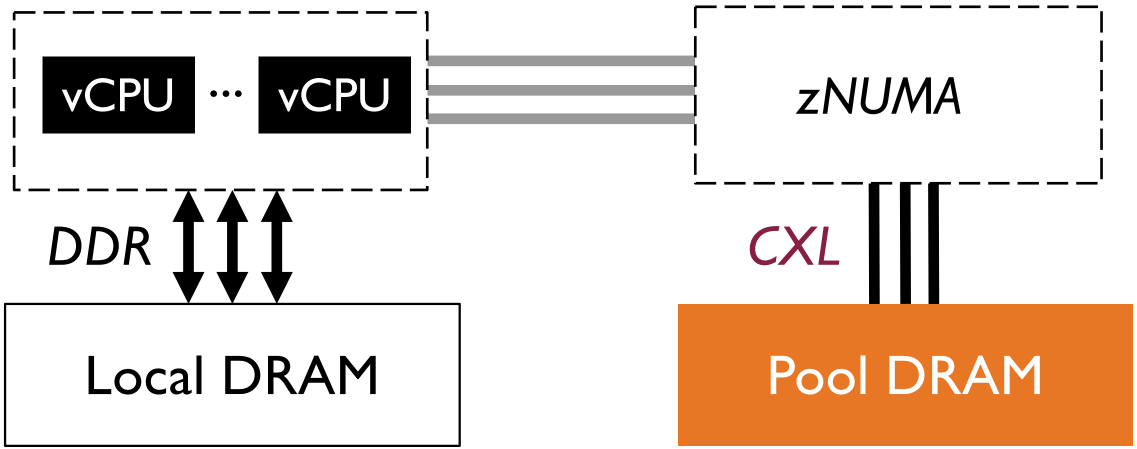

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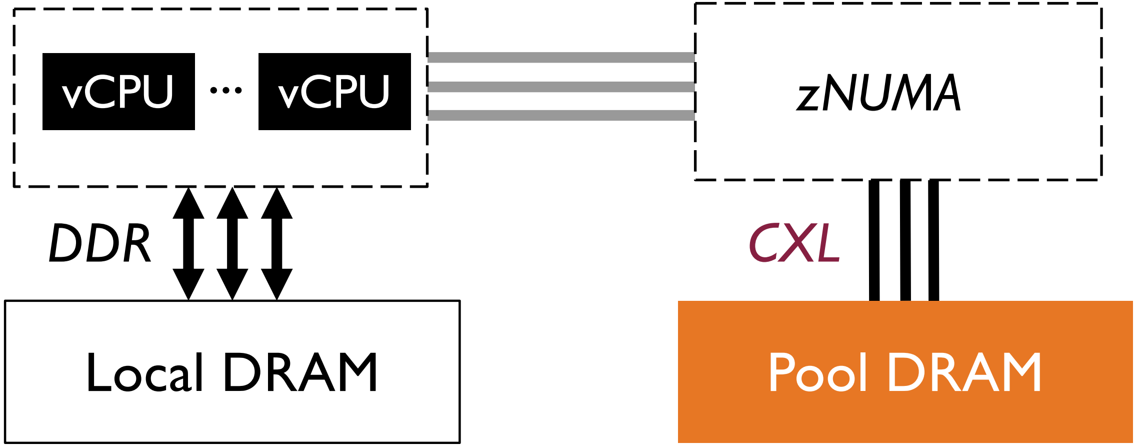
- No spilling under correct predictions



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Entire pool/CXL DRAM

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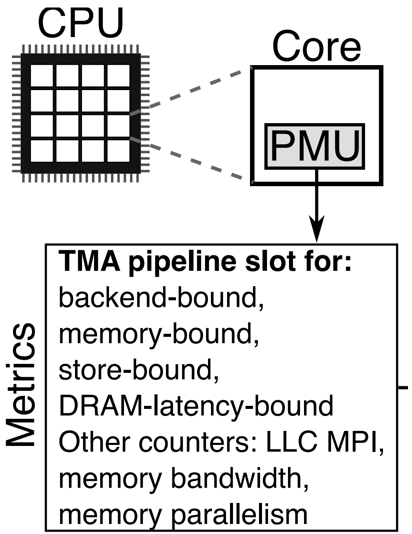
zNUMA: Pool DRAM = Untouched

Latency Sensitivity Prediction

Features from opaque VMs
➔ existing HW counters



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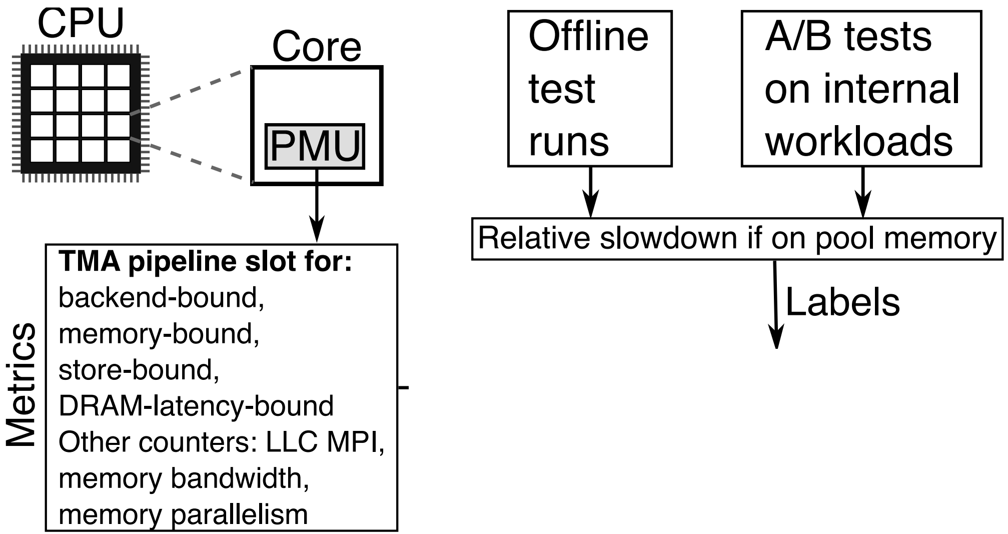

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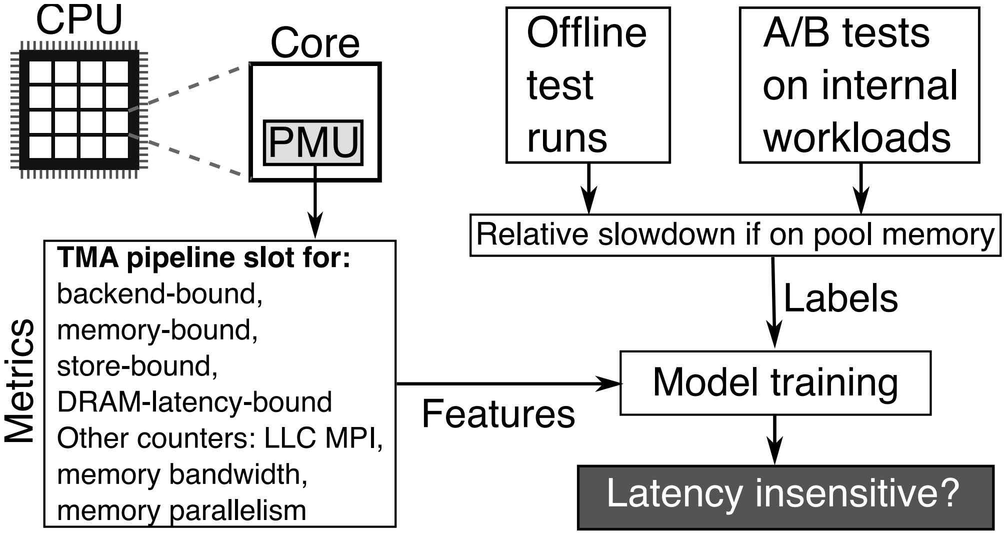
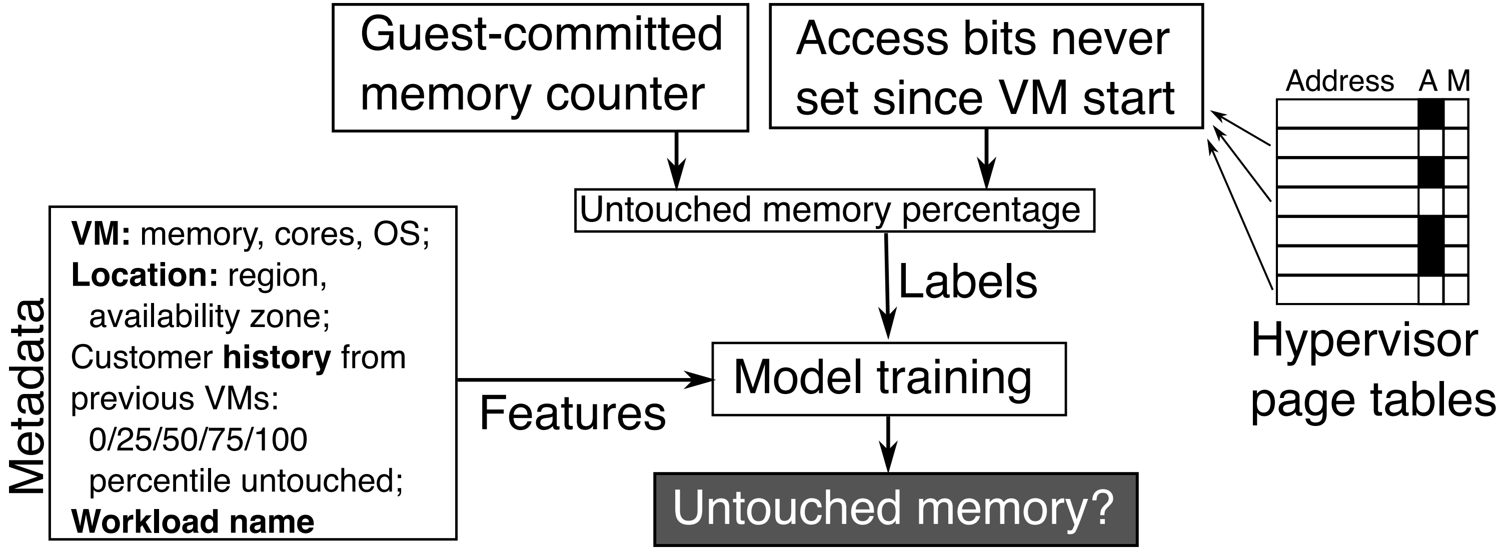
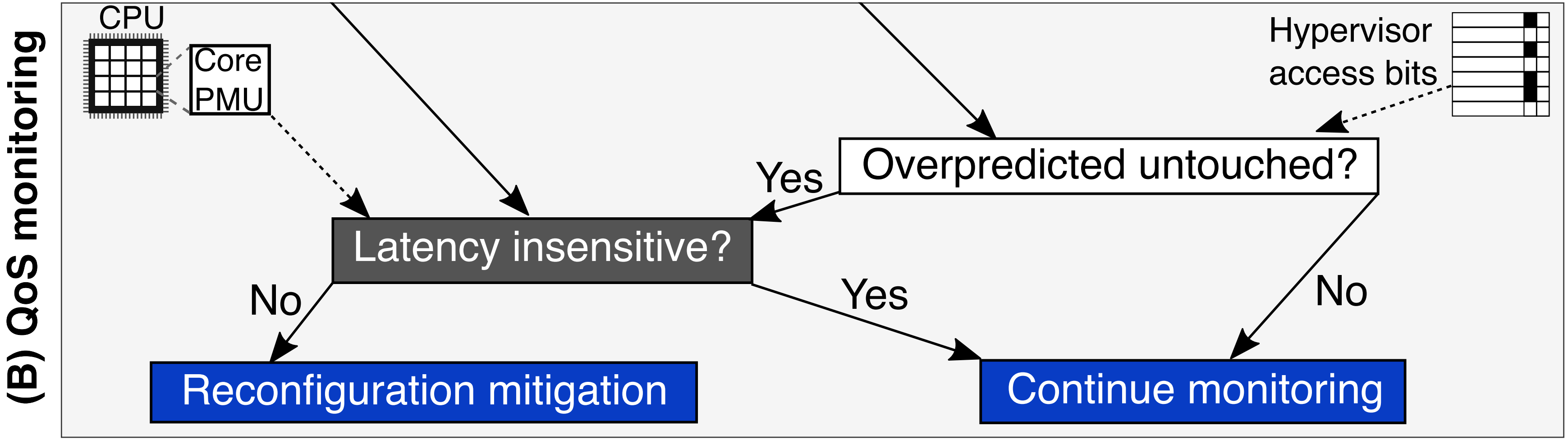


Untouched Memory Prediction



Prediction target: the amount of untouched memory (GB)

Misprediction Handling



zNUMA Effectiveness

Workloads	zNUMA traffic
Video	0.25%
Database	0.06%
KV store	0.11%
Analytics	0.38%

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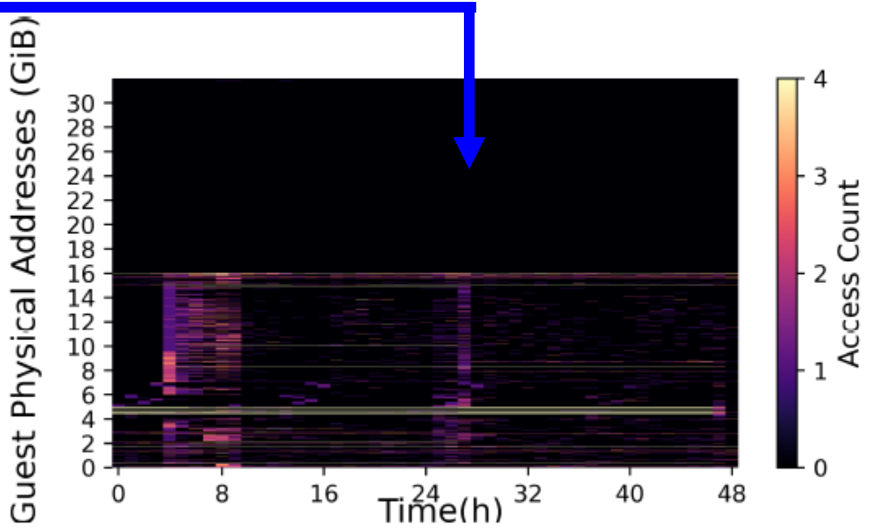
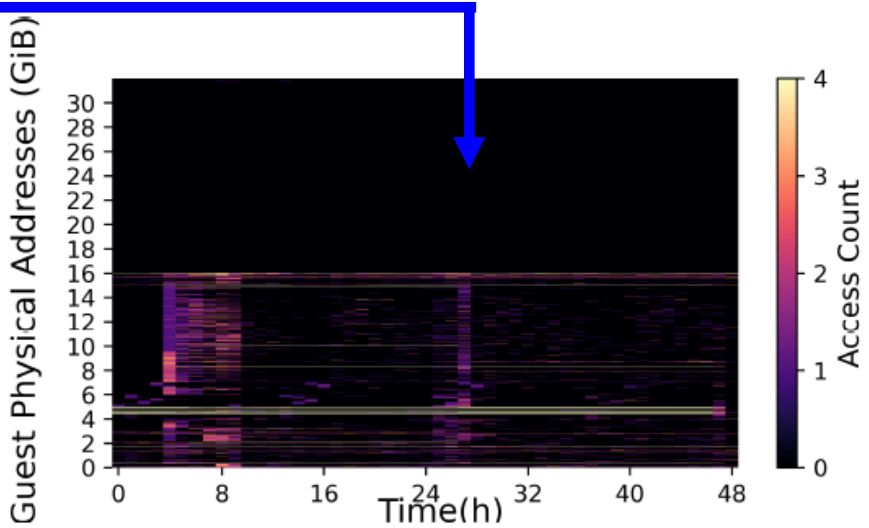


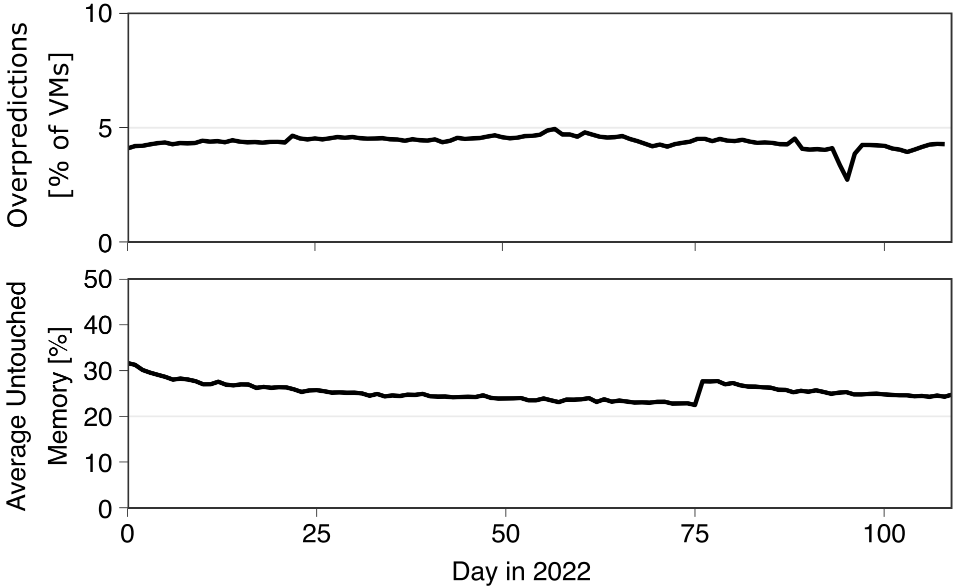
zNUMA Effectiveness

Workloads	zNUMA traffic
Video	0.25%
Database	0.06%
KV store	0.11%
Analytics	0.38%



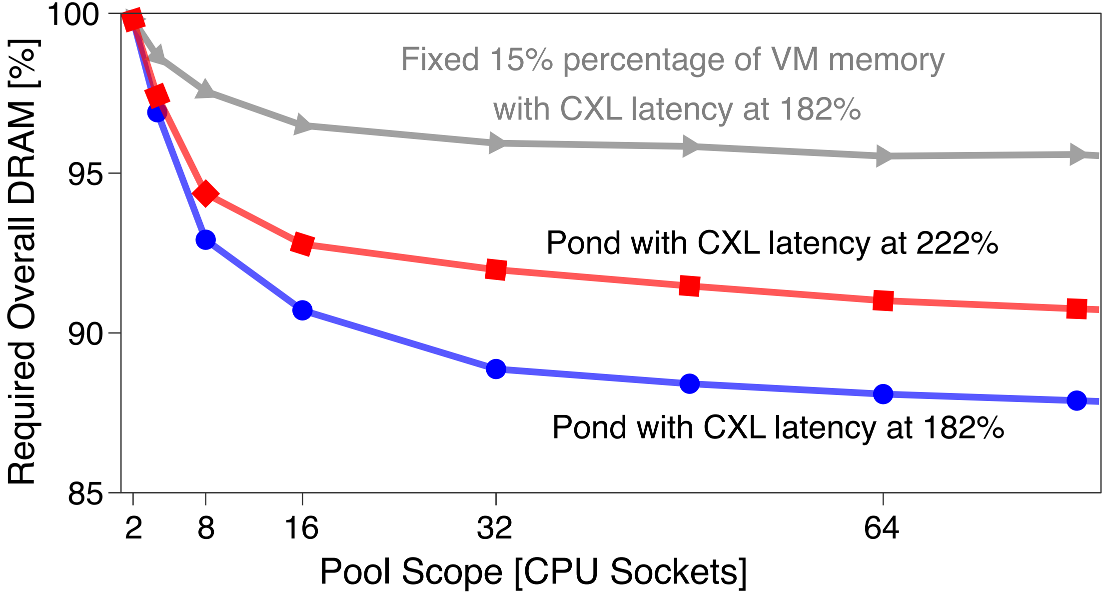
zNUMA is effective for correct predictions

Pond Prediction Model Accuracy



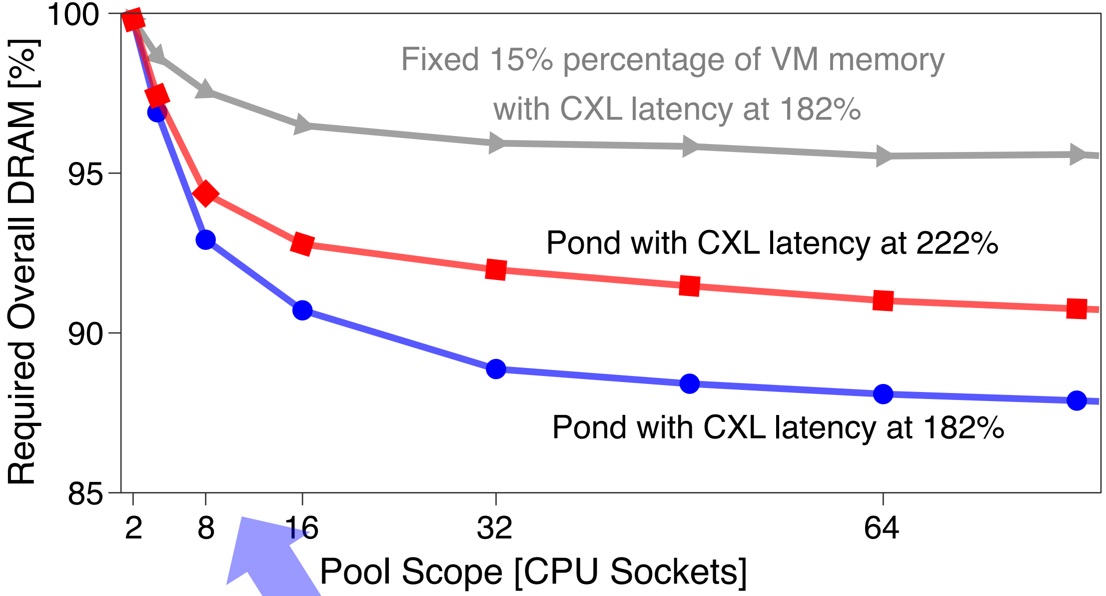
*Pond prediction model identifies **25% of** untouched memory while only overpredicting 4% of VMs*

Pond End-to-end Memory Savings



Configured to target <5% slowdown for 98% of VMs

Pond End-to-end Memory Savings



8-16 socket pool, 7-9% DRAM savings

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More Details in the Paper

- Detailed trace study results and analysis over 100 production clusters
- EMC and pool memory management
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- More evaluation results
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Pond: CXL-Based Memory Pooling Systems for Cloud Platforms

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ABSTRACT

Public cloud providers seek to meet stringent performance requirements and low hardware cost. A key driver of performance and cost is main memory. Memory pooling promises to improve DRAM utilization and thereby reduce costs. However, pooling is challenging under cloud performance requirements. This paper proposes Pond, the first memory pooling system that both meets cloud performance goals and significantly reduces DRAM cost. Pond builds on the Compute Express Link (CXL) standard for load/store access to pool memory and two key insights. First, our analysis of cloud production traces shows that pooling across 8-16 sockets is enough to achieve most of the benefits. This enables a small-pool design with low access latency. Second, it is possible to create machine learning models that can accurately predict how much local and pool memory to allocate to a virtual machine (VM) to resemble same-NUMA-node memory performance. Our evaluation with 158 workloads shows that Pond reduces DRAM costs by 7% with performance within 1-5% of same-NUMA-node VM allocations.

CCS CONCEPTS

• **Computer systems organization** → **Cloud computing**; • **Hardware** → **Emerging architectures**.

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KEYWORDS

Compute Express Link; CXL; memory disaggregation; memory pooling; datacenter; cloud computing.

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1 INTRODUCTION

Motivation. Many public cloud customers deploy their workloads in the form of virtual machines (VMs), for which they get virtualized compute with performance approaching that of a dedicated cloud, but without having to manage their own on-premises datacenter. This creates a major challenge for public cloud providers: achieving excellent performance for opaque VMs (*i.e.*, providers do not know and should not inspect what is running inside the VMs) at a competitive hardware cost.

A key driver of both performance and cost is main memory. The gold standard for memory performance is for accesses to be served by the same NUMA node as the cores that issue them, leading to latencies in tens of nanoseconds. A common approach is to preallocate all VM memory on the same NUMA node as the VM's cores. Preallocating and statically pinning memory also facilitate the use of virtualization accelerators [4], which are enabled by default, for example, on AWS and Azure [12, 14]. At the same time, DRAM has become a major portion of hardware cost due to its poor scaling properties with only nascent alternatives [72]. For example,

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Feasible hardware implementation

Close to local DRAM performance

7-9% DRAM savings by pooling
~25% untouched memory

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Thank you!