DINOMO: An Elastic, Scalable, High-Performance Key-Value Store for Disaggregated Persistent Memory

Sekwon Lee, Soujanya Ponnapalli, Sharad Singhal,
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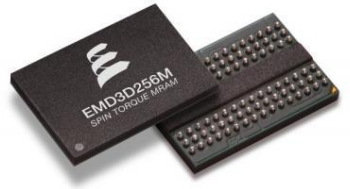
Persistent Memory (PM)

- Byte-addressable, high-performance
- Non-volatile & high-capacity
  - Retain data across power outage
- Cost per GB >>>> HDD or SSD
  - Need to keep utilization high for cost efficiency

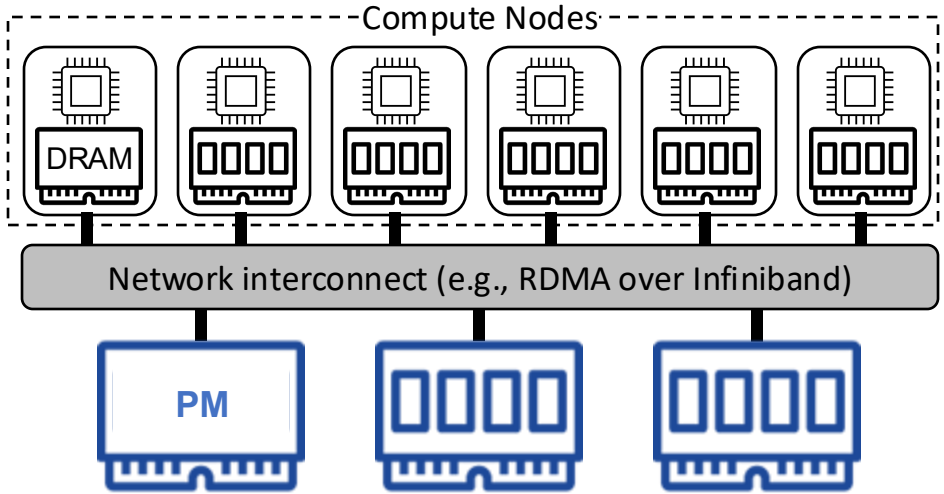
PCM



STT-MRAM

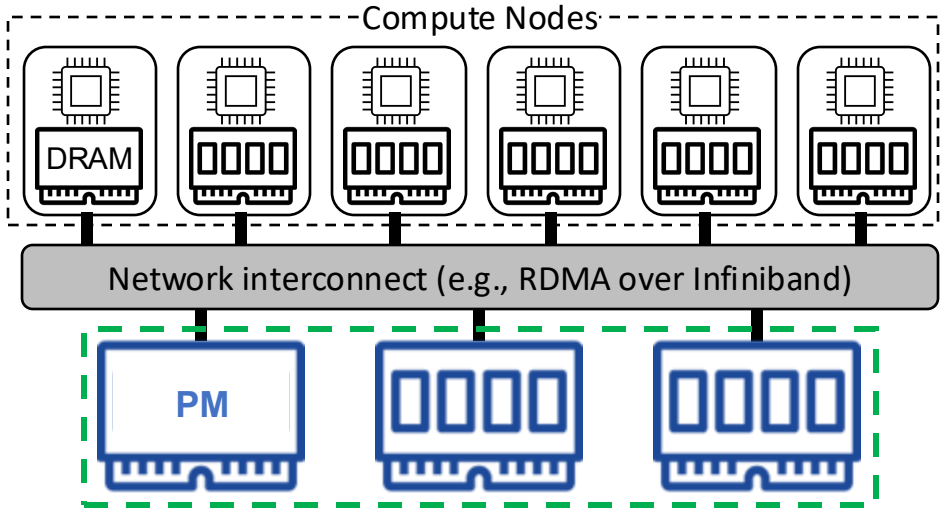
Intel Optane DC PM

Disaggregated Persistent Memory (DPM)



Disaggregated Persistent Memory (DPM)

+ Share PM → Increase utilization, Reduce TCO (Total Cost Ownership)



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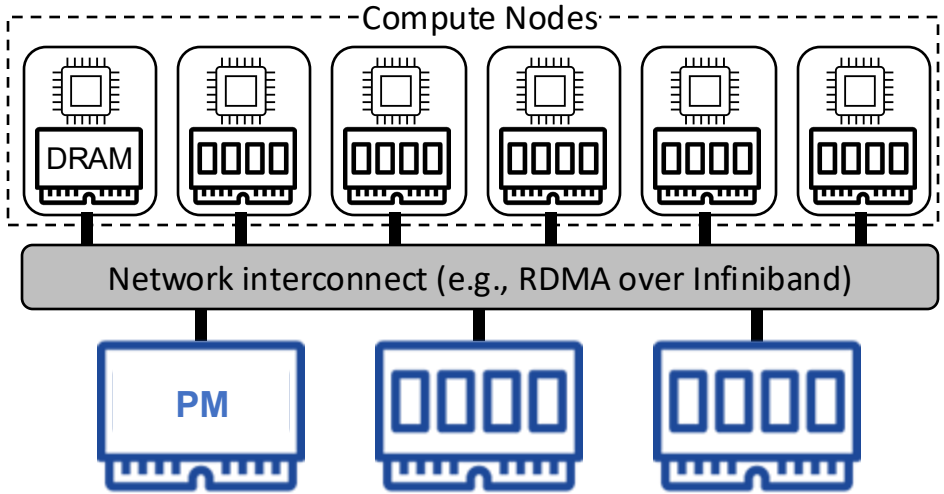
+ Disaggregate PM → Scale resources independently, Separate failure domains



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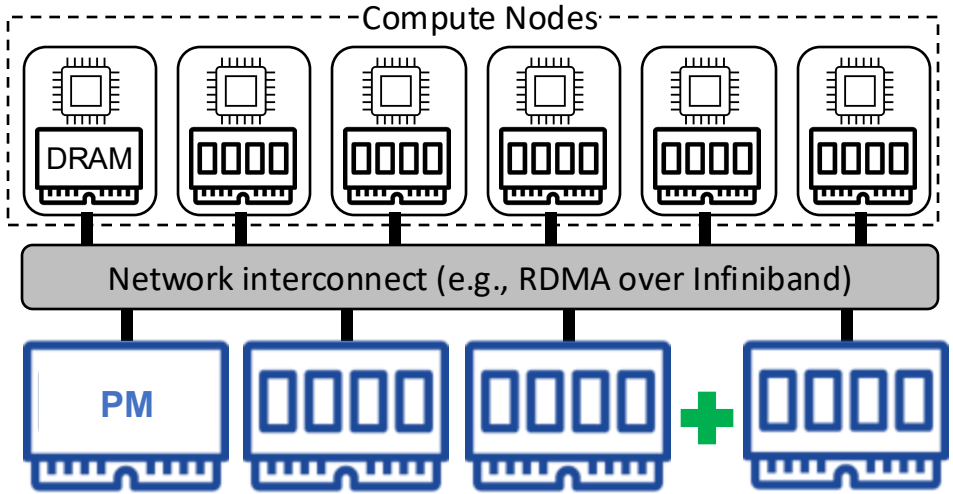

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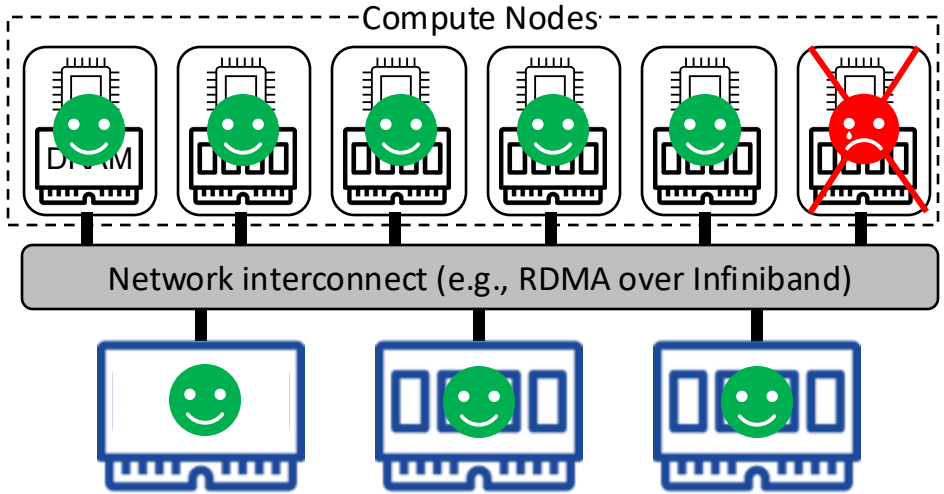
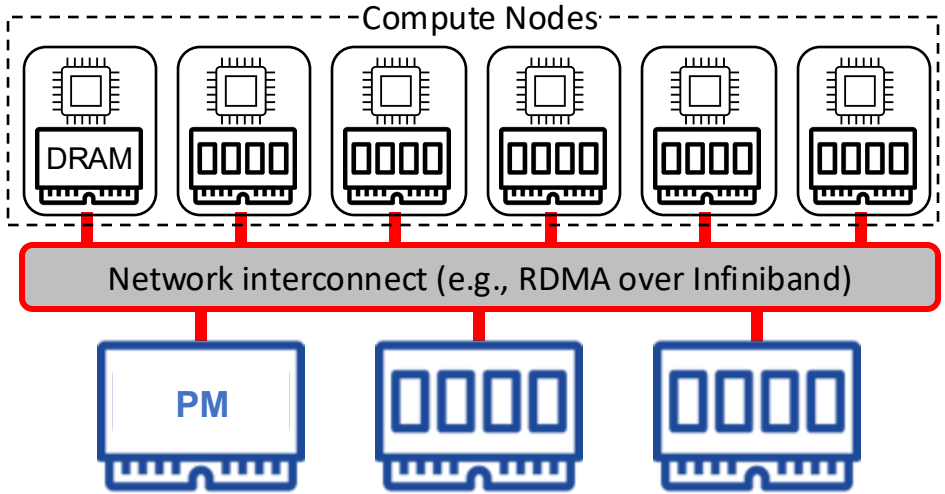


Disaggregated Persistent Memory (DPM)

+ Share PM → Increase utilization, Reduce TCO (Total Cost Ownership)
+ Disaggregate PM → Scale resources independently, Separate failure domains
– Access PM over network (1 - 4µs) >> local PM latency (300 - 400ns)



Key-Value Store (KVS) for DPM

High common-case performance
despite high-network costs

Scalability
with the increase in provisioned resources

Fast reconfiguration
in response to dynamics (e.g., node addition/failure)

Key-Value Store (KVS) for DPM

Challenge: easy to sacrifice one of the three goals to achieve the others

No DPM KVSs providing all the three goals simultaneously

in response to dynamics (e.g., node addition/failure)

DINOMO

First DPM KVS achieving high performance, scalability, and fast reconfiguration simultaneously

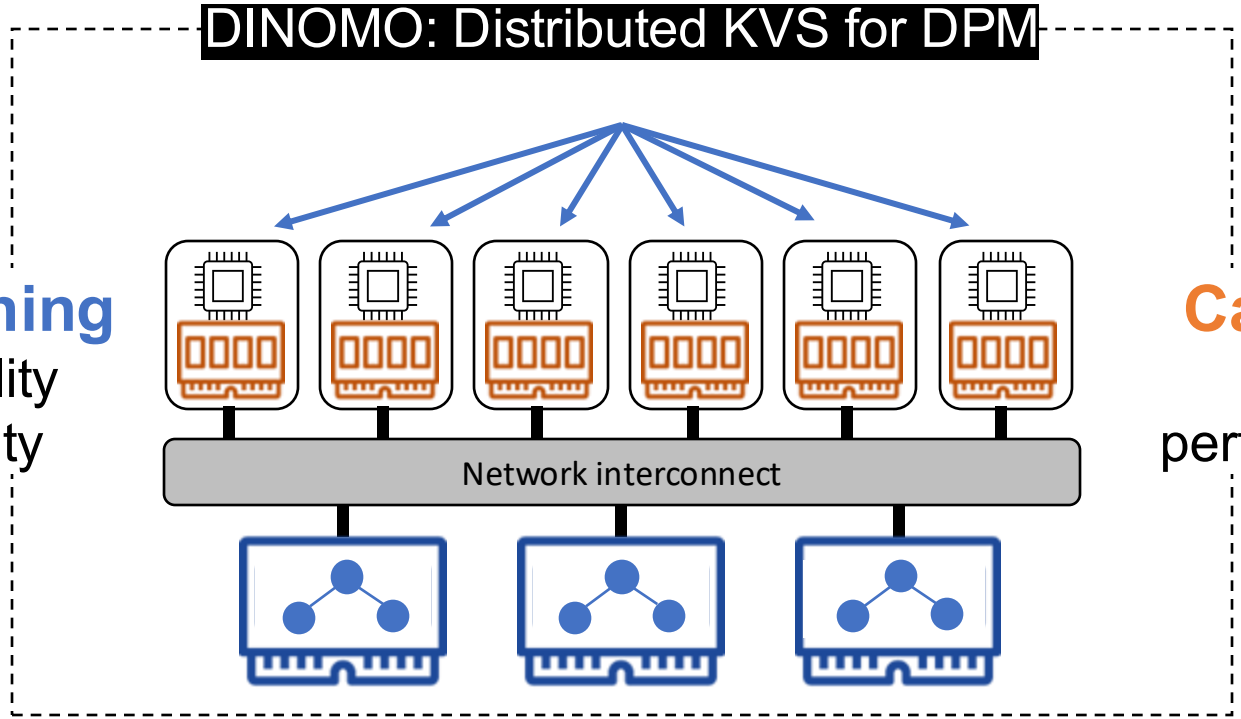
Adapt techniques (e.g., **partitioning**, **caching**, **replication**) from storage research community for DPM

Full end-to-end implementations including KVS data plane, control plane, and client

Better performance up-to **10x** at scale and elasticity

https://github.com/utsaslab/dinomo

Outline



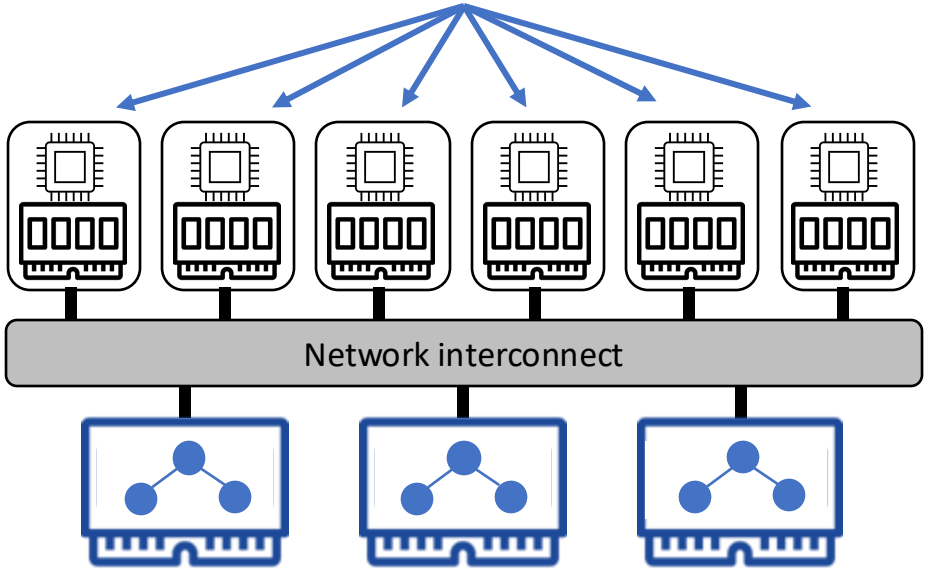
Partitioning
Scalability
Elasticity

Caching
High performance

Outline

DINOMO: Distributed KVS for DPM

Ownership partitioning
Scalability
Elasticity



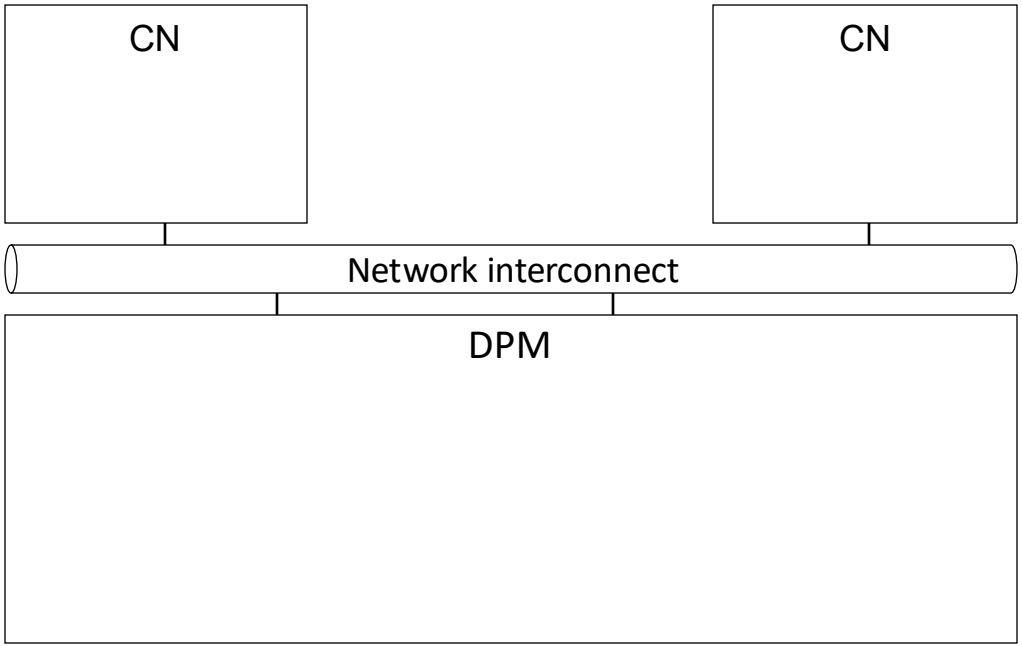
Caching
High performance

System architectures for DPM

- What to share or partition?

Goals \ KVSs	?	Shared everything	Shared nothing
High performance	✓	X	✓
Scalability	✓	X	✓
Lightweight reconfiguration	✓	✓	X

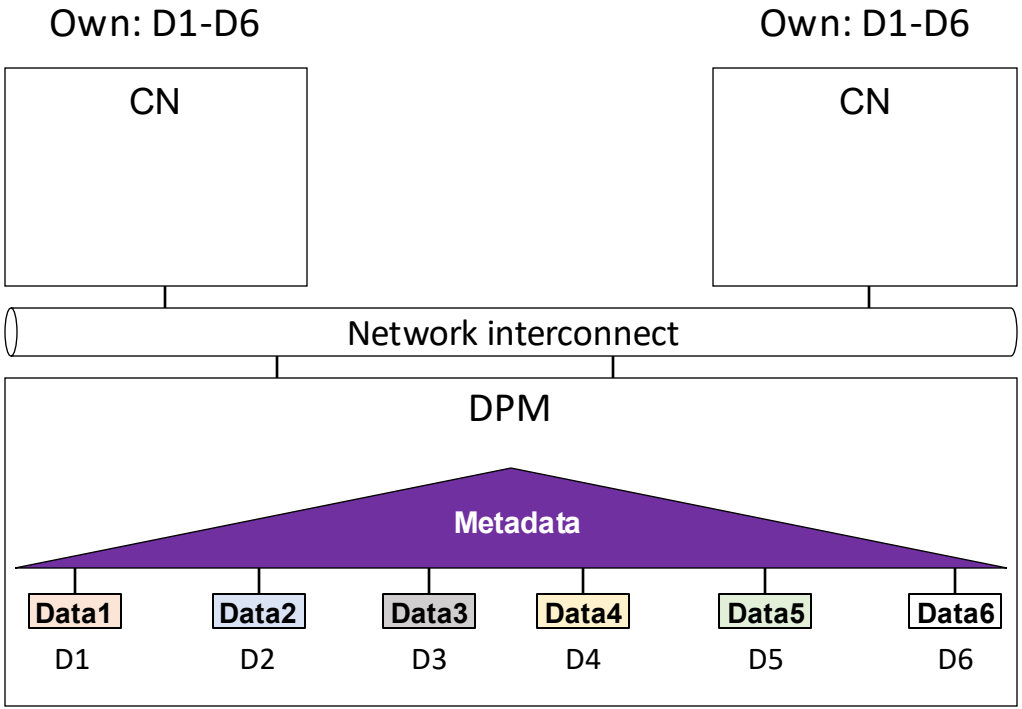
Shared everything



Shared data, metadata, ownership

- Data: key-value pairs
- Metadata: index structures
- Ownership: access permission

Shared everything



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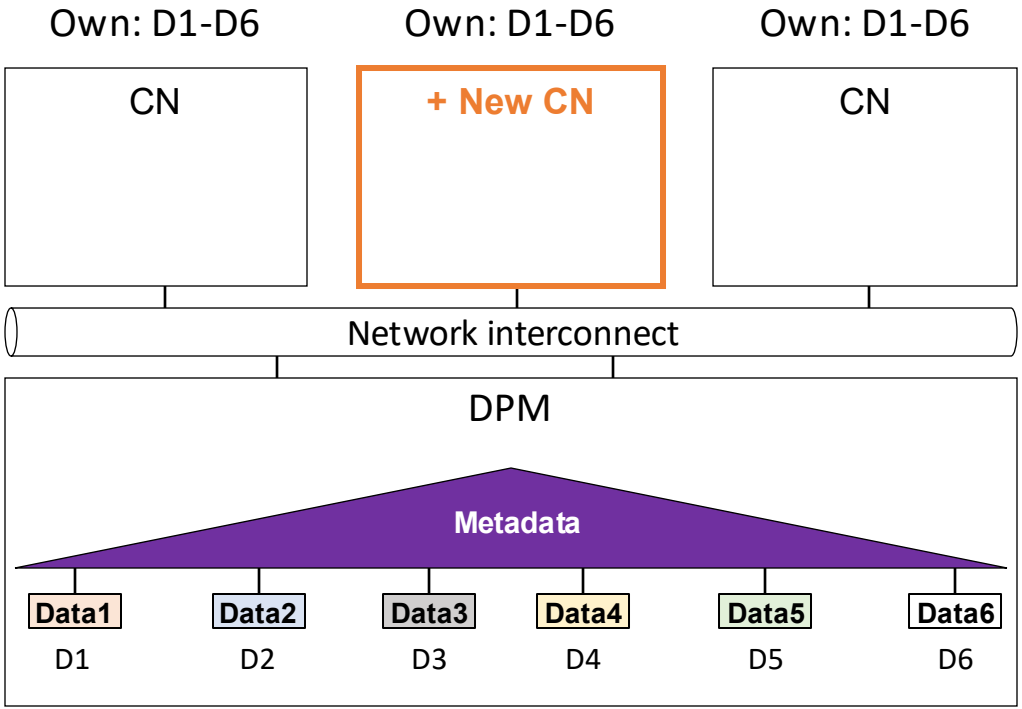
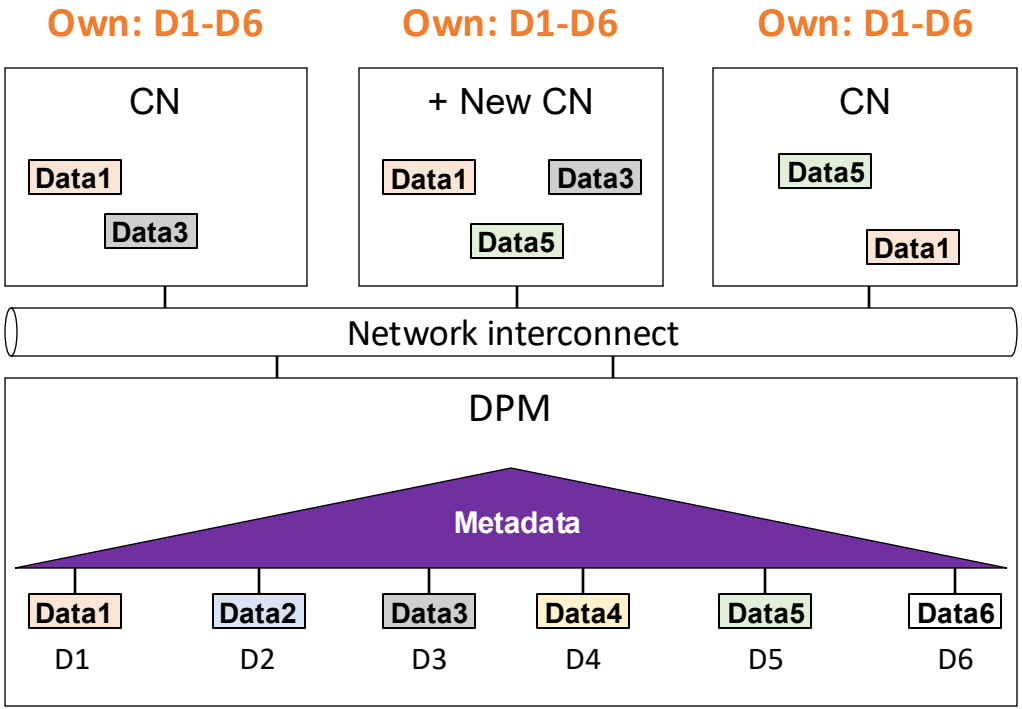


Shared data, metadata, ownership

Fast reconfiguration without data reorganization

Shared everything



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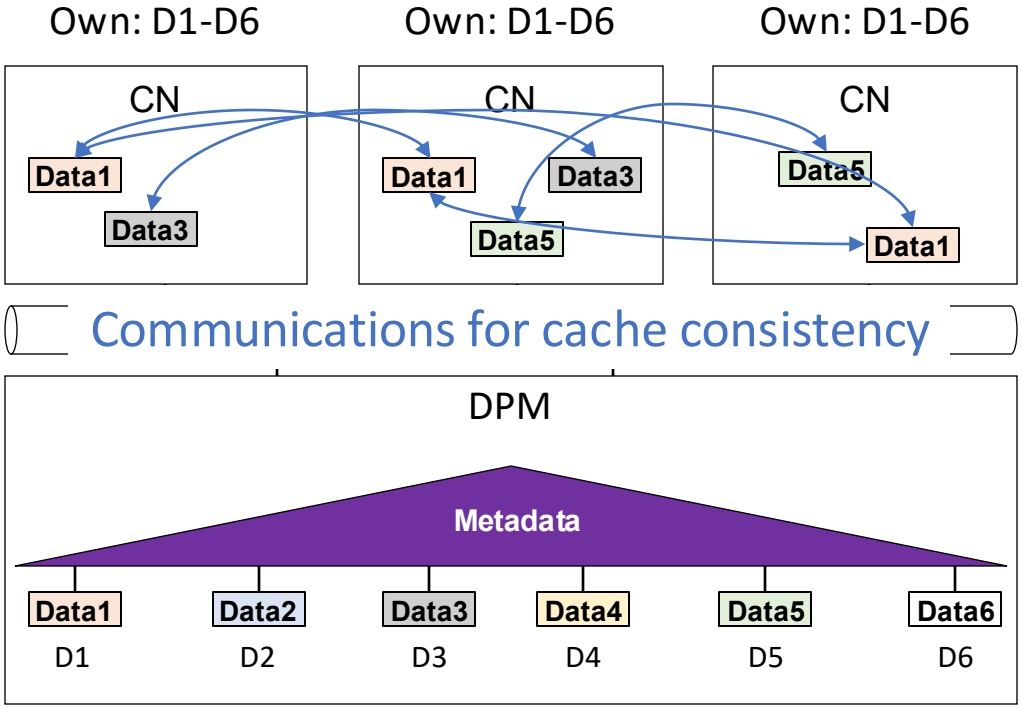
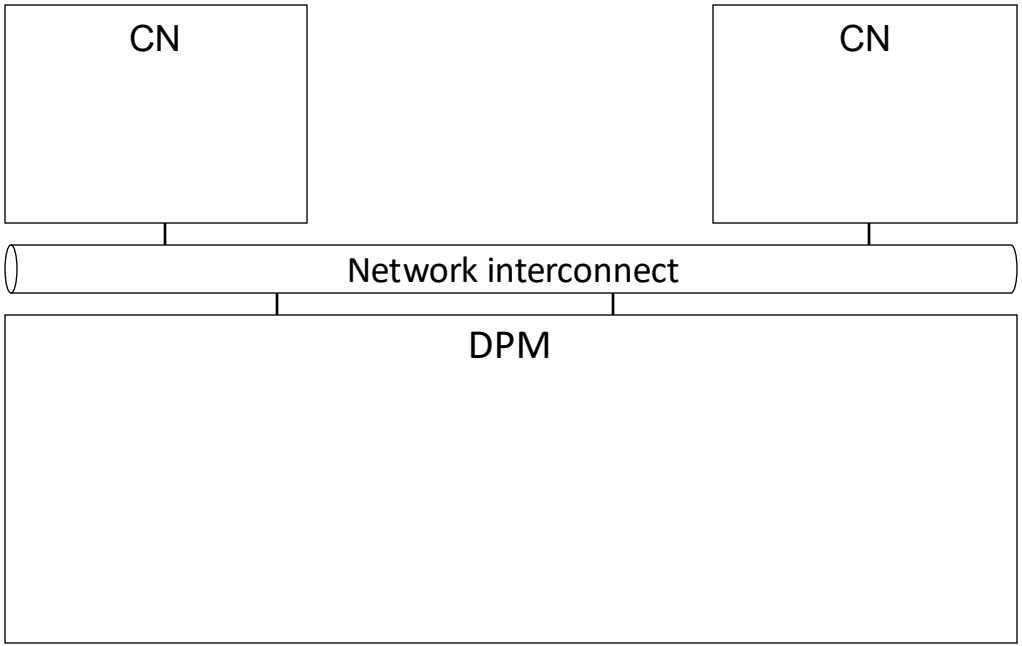


Shared data, metadata, ownership

Fast reconfiguration without data reorganization

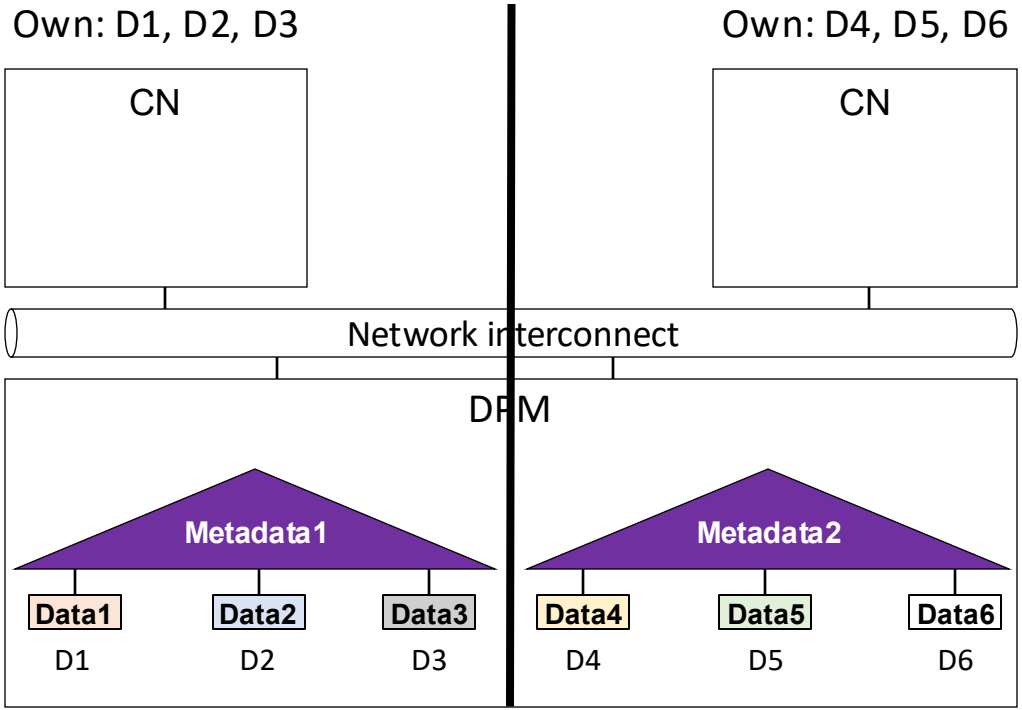
Low performance/scalability due to consistency overheads

Shared nothing



Partitioned data, metadata, ownership

Shared nothing



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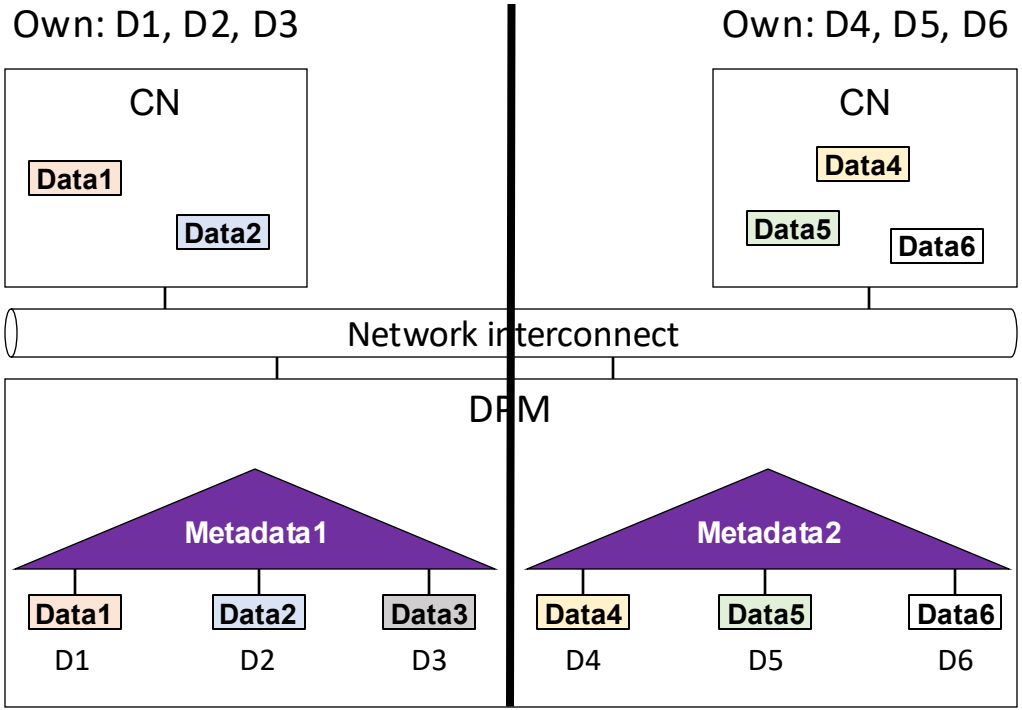

Partitioned data, metadata, ownership

High performance/scalability without consistency overheads

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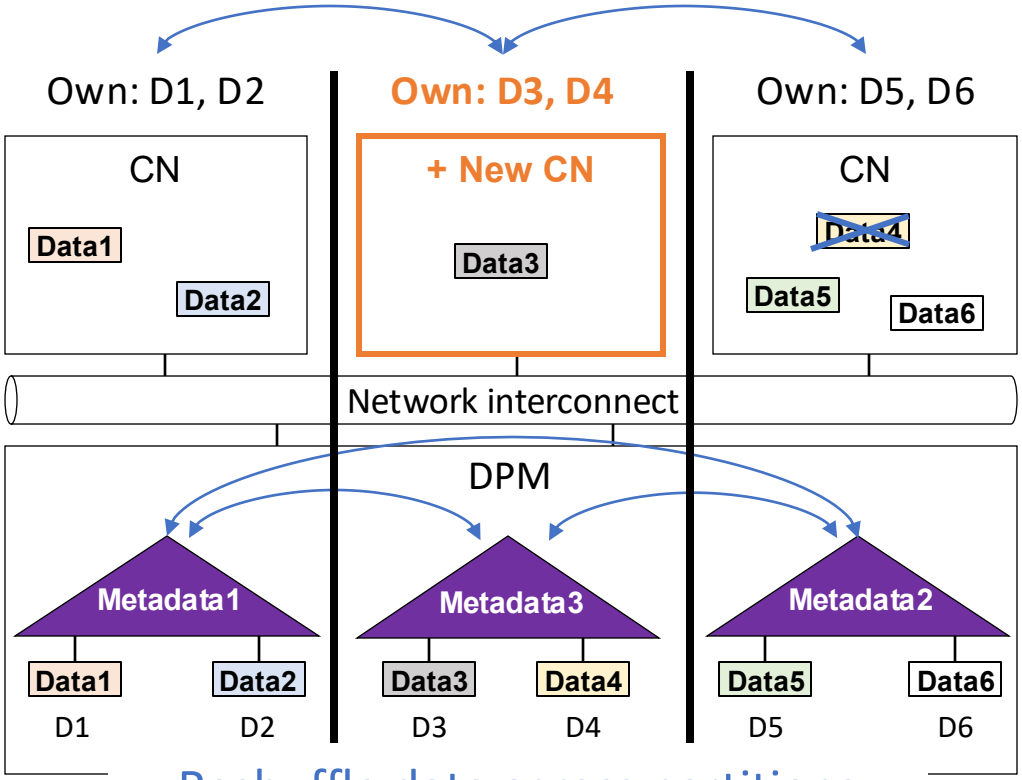


Reshuffle data across partitions

Partitioned data, metadata, ownership

High performance/scalability without consistency overheads

Slow reconfiguration due to expensive data reorganization

System architectures for DPM

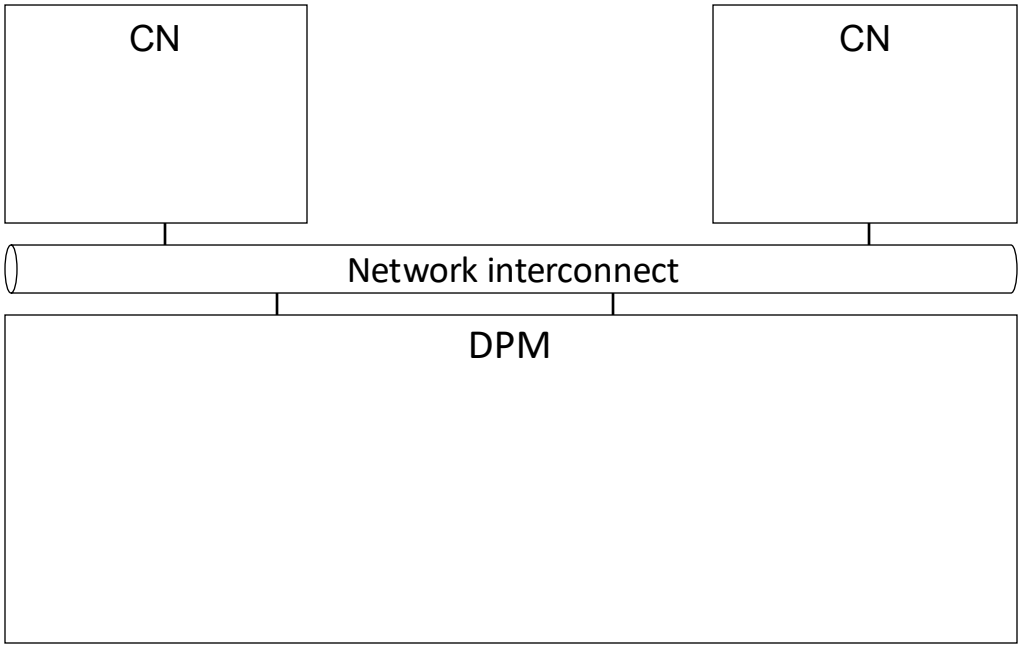
- What to share or partition?

Goals \ KVSs	Ownership partitioning	Shared everything	Shared nothing
High performance	✓	X	✓
Scalability	✓	X	✓
Lightweight reconfiguration	✓	✓	X

Approach: Partition ownership across compute nodes while sharing data through DPM

Insight: Data and ownership can be an independent consideration owing to disaggregation

Ownership Partitioning



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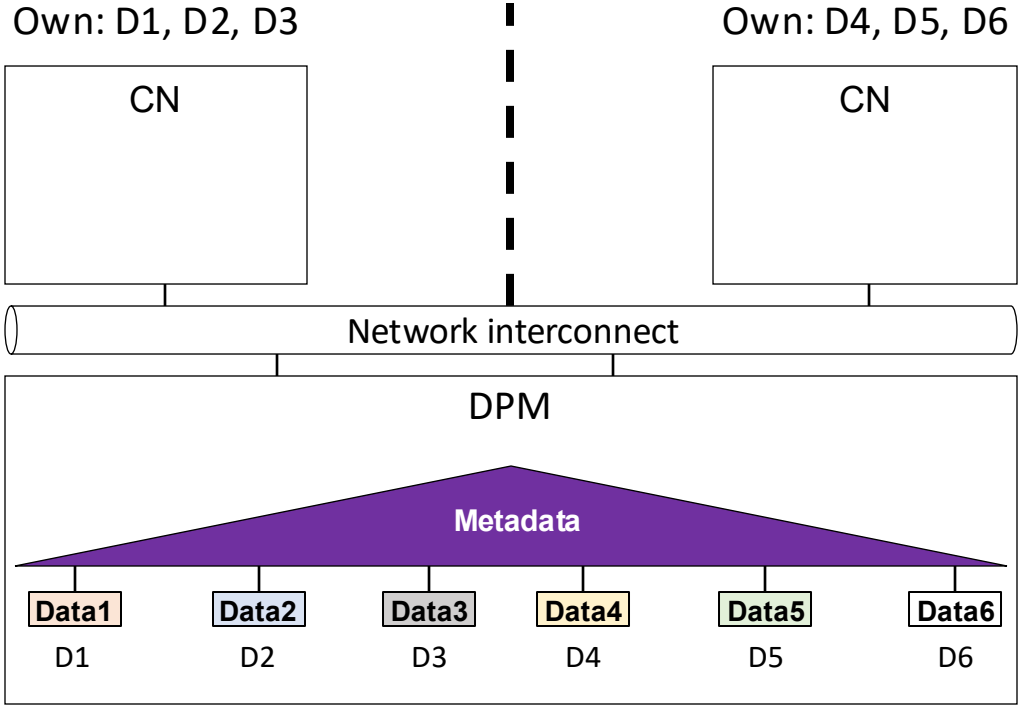

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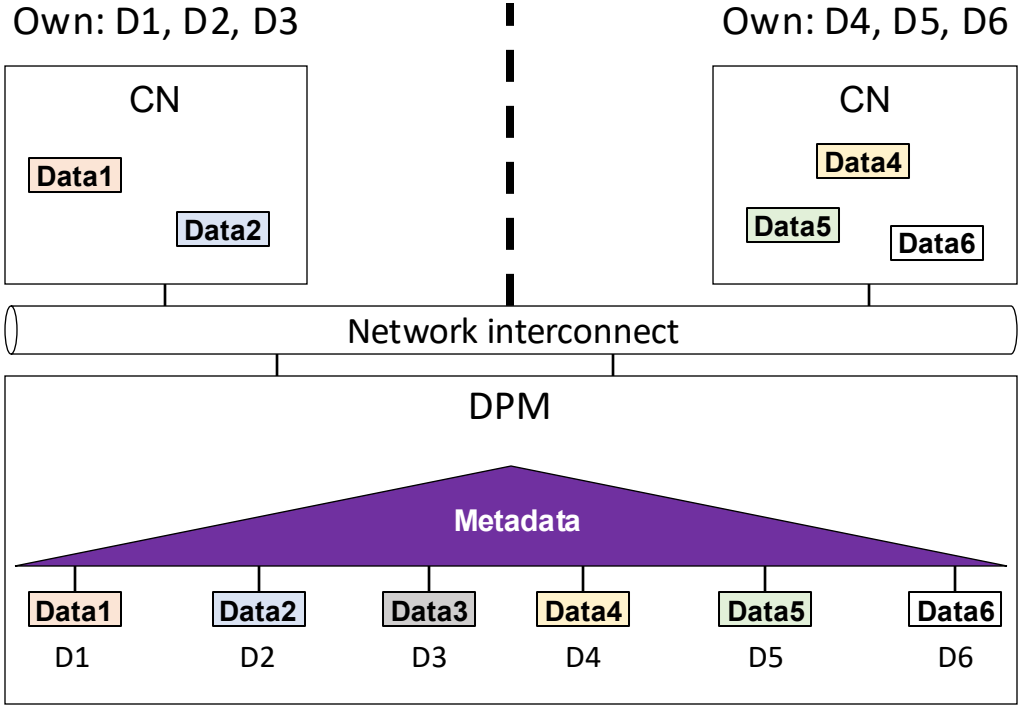

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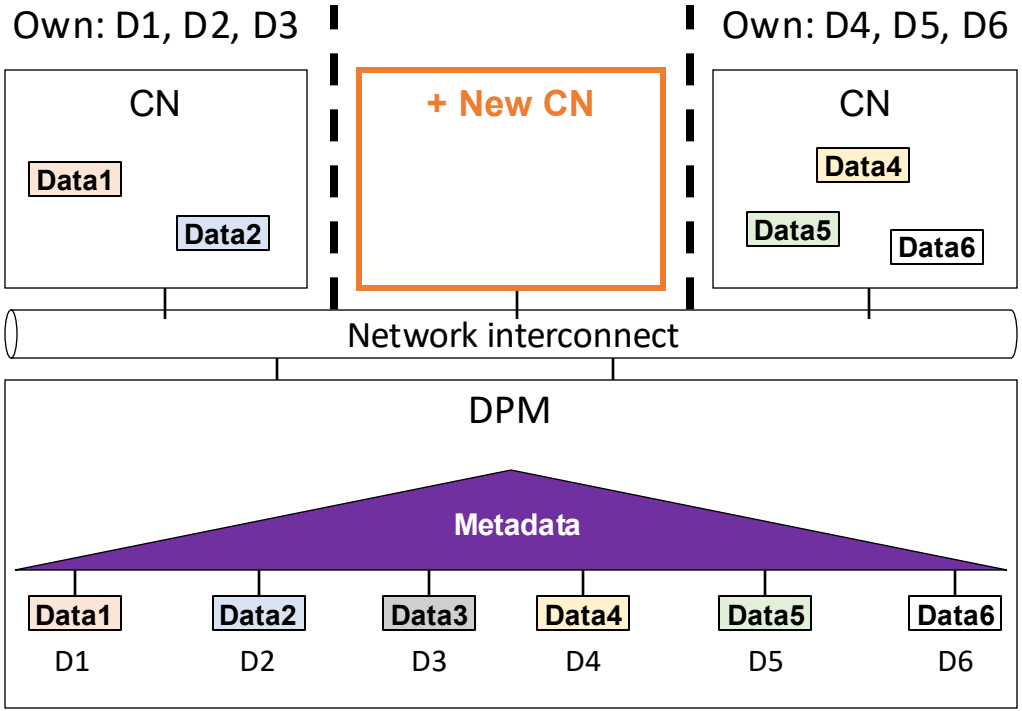

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High performance/scalability without consistency overheads

Fast reconfiguration without data reorganization

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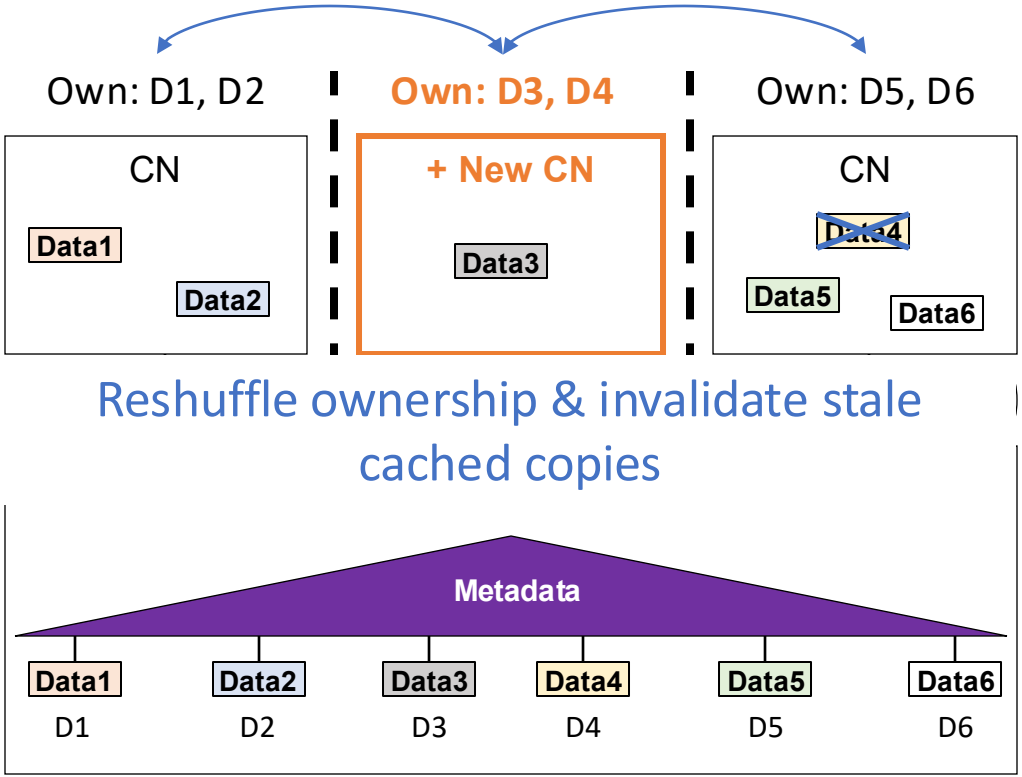

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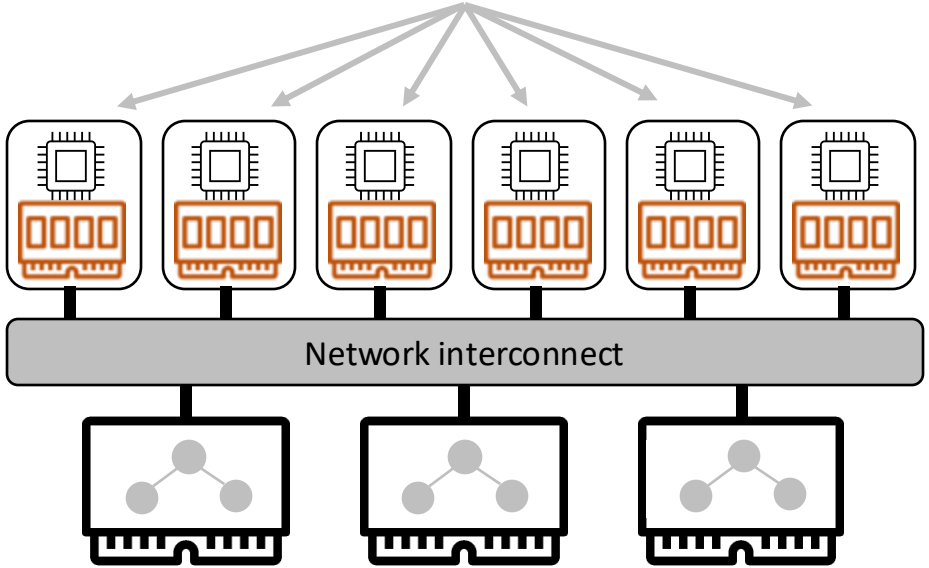
Outline

DINOMO: Distributed KVS for DPM

Ownership partitioning
Scalability
Elasticity



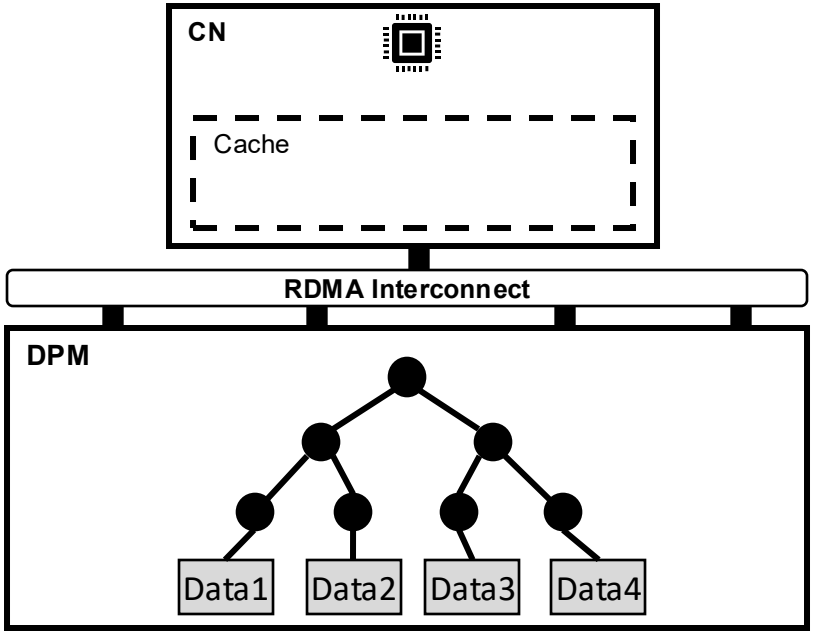
Disaggregated adaptive cache
High performance

Caching for DPM

- Number of network round trips significantly impacts on overall system performance
- Cache data or metadata into the memory of compute nodes to reduce round trips to DPM
  - Important to minimize cache misses

Static caching strategies

- Value
  - Entire copy of data in DPM
- Shortcut
  - Remote pointer to data in DPM



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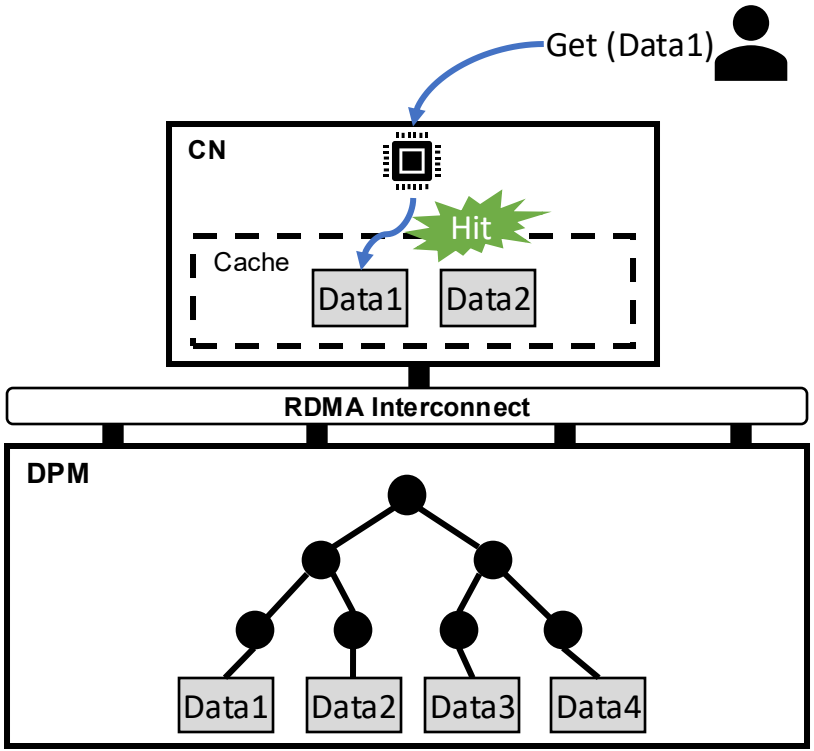

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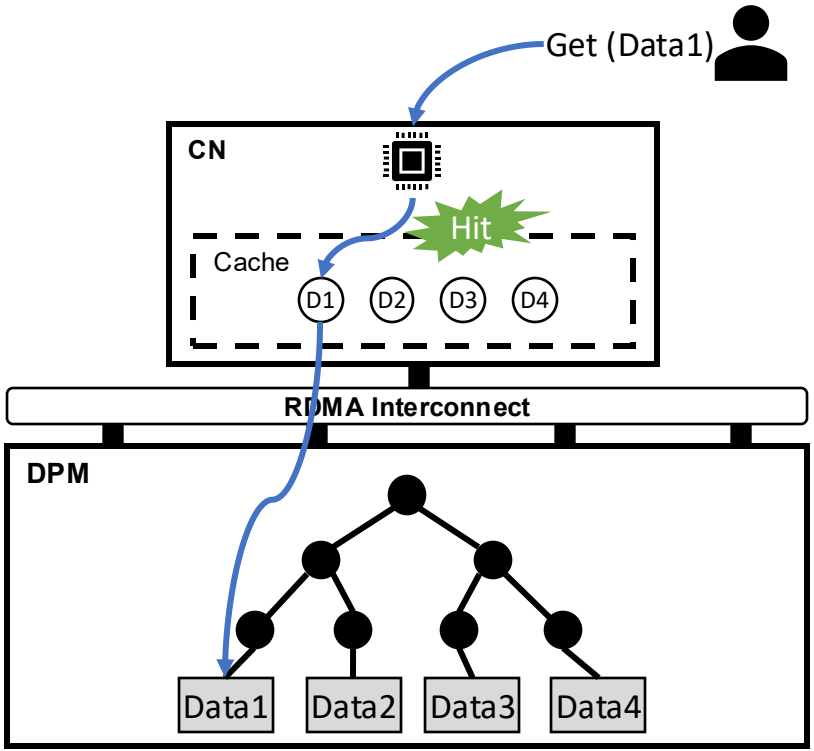

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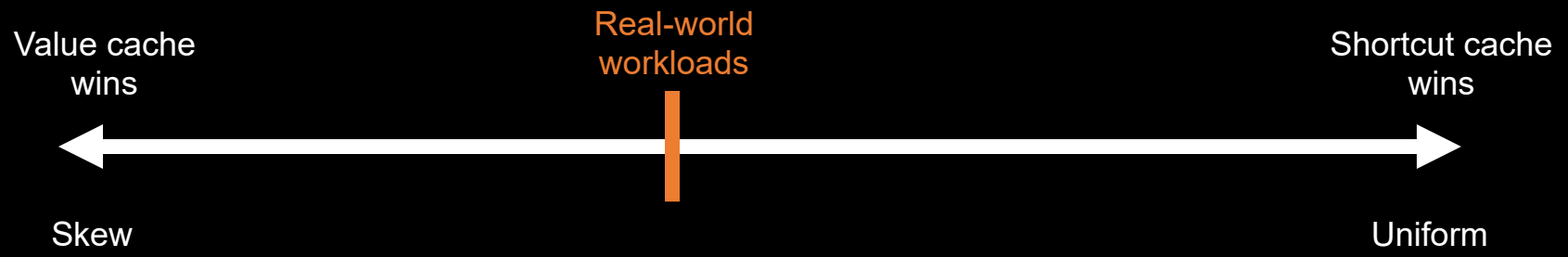


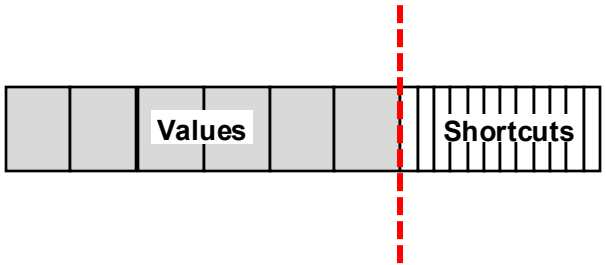
Is it better to cache a few values without overheads on hits, or a larger number of shortcuts with fixed hit overheads?

Answer: Efficient ratio depends on workload patterns and available memory space

We need an **adaptive policy** changing ratio between values and shortcuts!

Disaggregated Adaptive Caching

- Adaptive policy
  - Change the boundary via demotion and promotion



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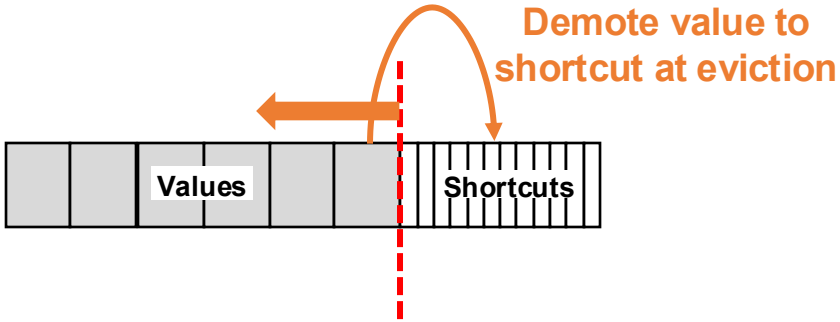

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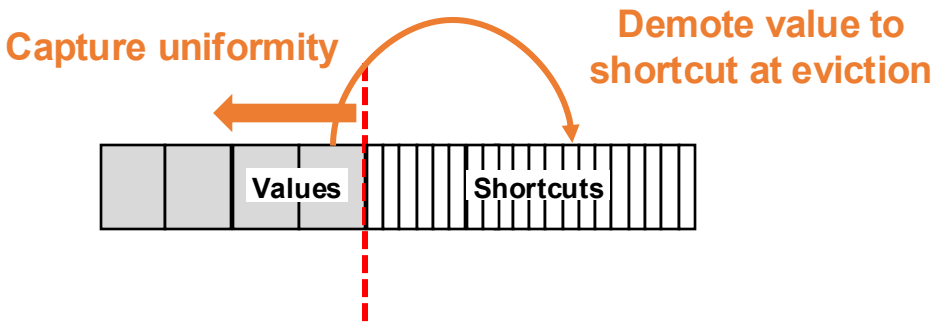

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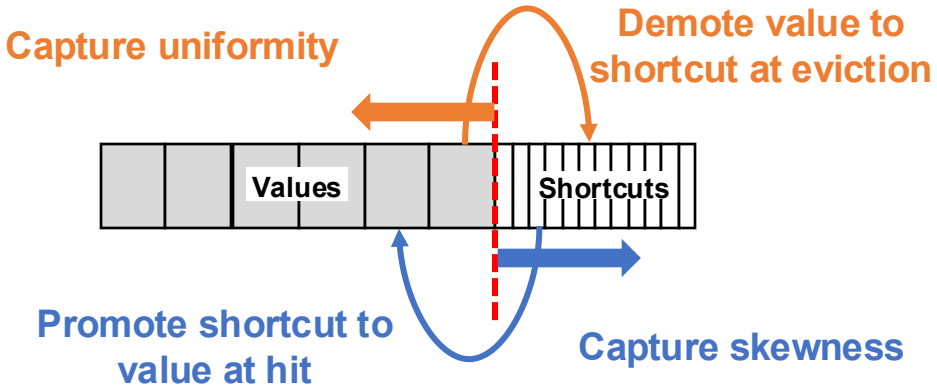
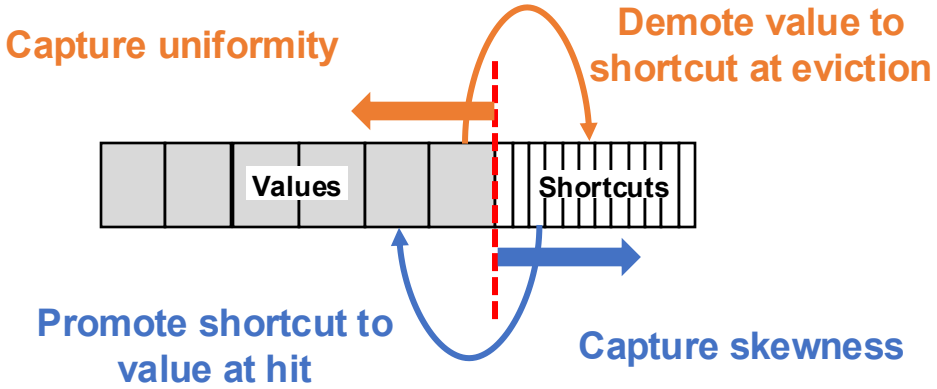


Disaggregated Adaptive Caching

- Adaptive policy
  - Change the boundary via demotion and promotion
  - Promotion policy considering sizes, hit costs, and miss costs
    - *Hit benefit from the promoted shortcut > Miss costs from evicted shortcuts*



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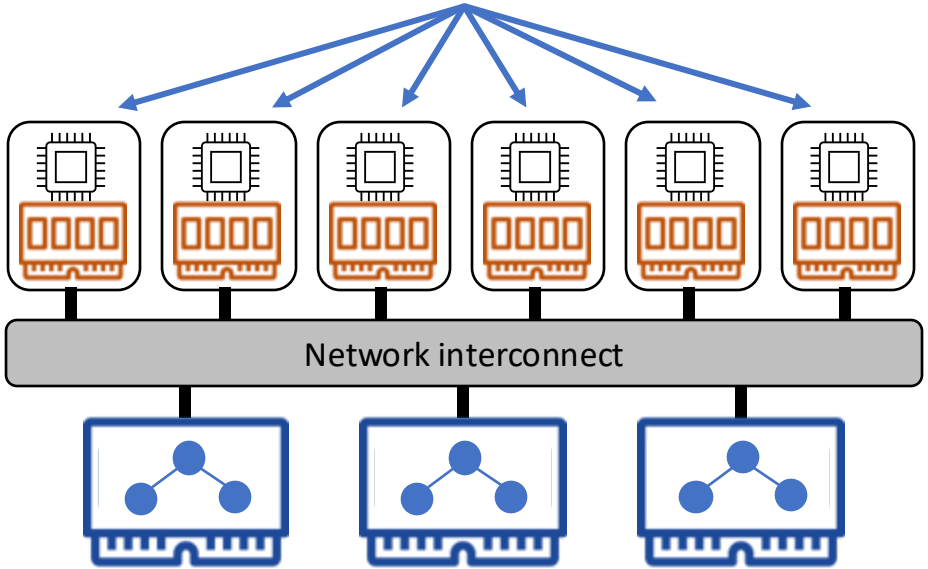

Ownership partitioning
Scalability
Elasticity

Disaggregated adaptive cache
High performance

Evaluation

- How does DINOMO fare against the state-of-the-art in terms of performance and scalability?

- How elastic and responsive is DINOMO while handling workload dynamics, load imbalance, and node failures?

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  - DINOMO scales performance with # of CNs
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  - DINOMO scales performance with # of CNs
  - DINOMO performs up-to 10x better than the state of the art
- How elastic and responsive is DINOMO while handling workload dynamics, load imbalance, and node failures?
  - DINOMO is much more responsive than shared-nothing counterparts, but comparable to shared everything

DINOMO 

- First KVS for DPM achieving high performance, scalability, and elasticity simultaneously
- Use a novel combination of techniques, ownership partitioning and disaggregated adaptive cache
- Experimentally show DINOMO can scale performance and efficiently react to reconfigurations
- Try our KVS: https://github.com/utsaslab/dinomo

Backup

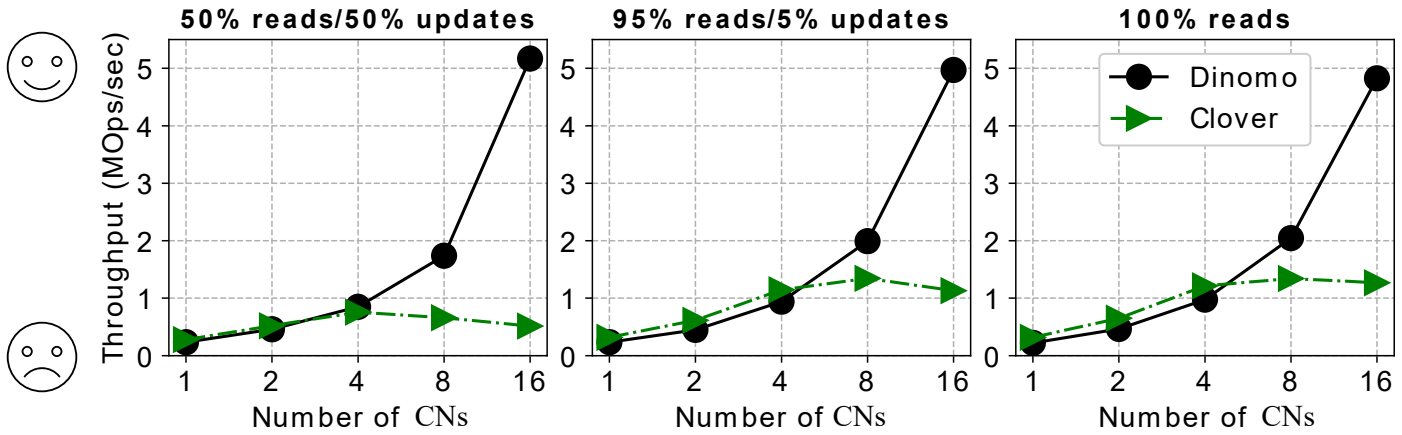
Evaluation setup

- System configuration
  - DPM: 4 threads, 110GB of DRAM to emulate PM
  - 16 CNs: 8 threads, 1GB of DRAM for caching (≈1% of the DPM)
  - Connected via 56Gbps ConnectX-3 RNICs
- Baseline
  - Performance/scalability: Clover (shared everything, shortcut-only cache)
  - Elasticity: DINOMO-N (Disaggregated adaptive caching, but partition data/metadata)
- Workload
  - YCSB workloads with 8B keys and 1KB values

Evaluation

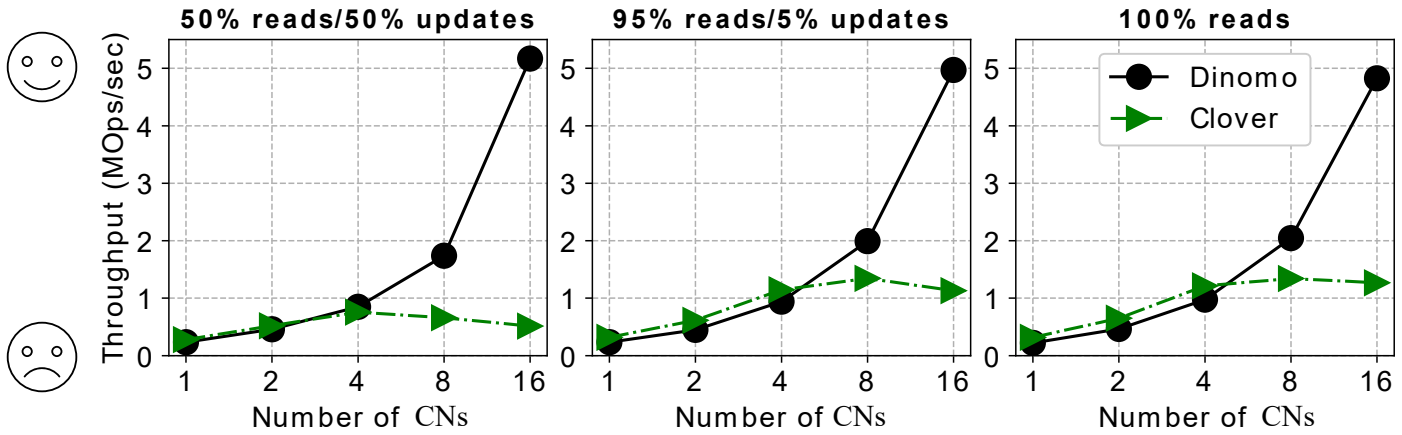
- How does DINOMO fare against the state-of-the-art in terms of performance and scalability?
- How elastic and responsive is DINOMO while handling changes in workloads?

Performance and Scalability



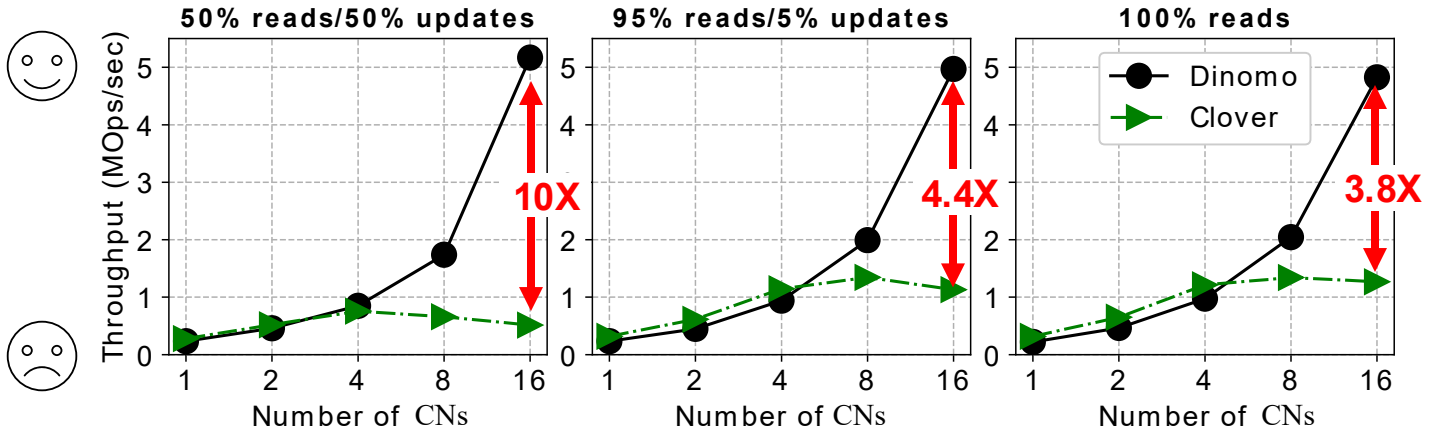
Performance and Scalability

- DINOMO scales to 16 CNs, but Clover does not beyond 4 CNs



Performance and Scalability

- DINOMO scales to 16 CNs, but Clover does not beyond 4 CNs
- With 16 CNs, DINOMO outperforms Clover upto 10x



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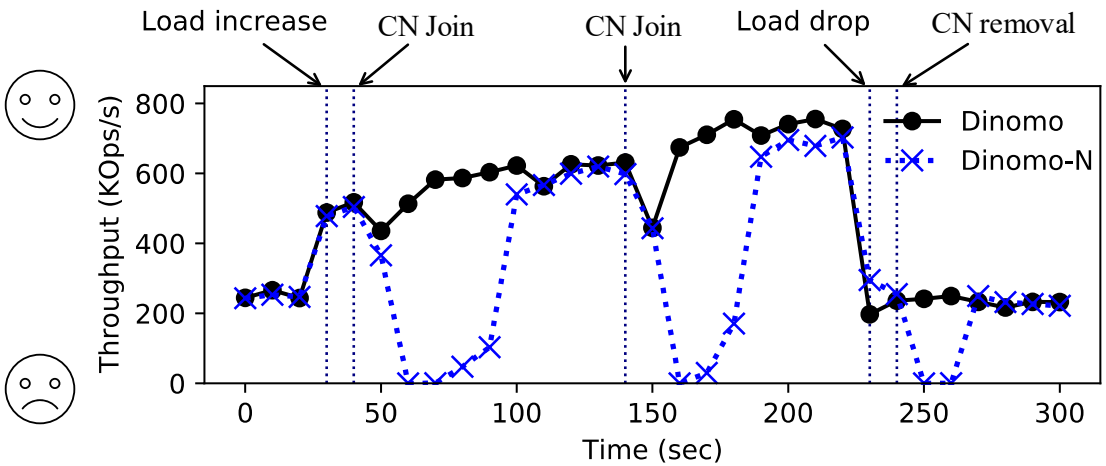
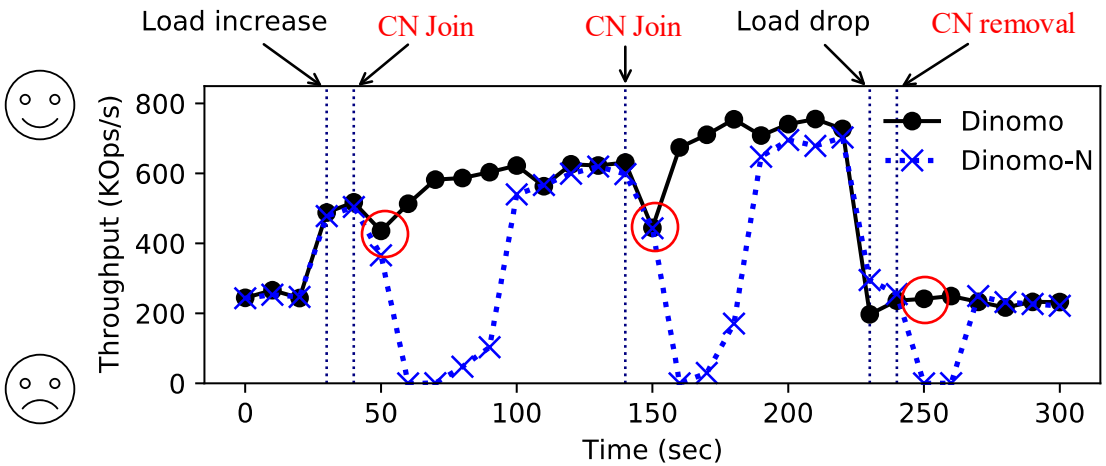
Elasticity


Load increase
CN Join
CN Join
Load drop
CN removal
Throughput (KOps/s)
800
600
400
200
0
0
50
100
150
200
250
300
Time (sec)
Dinomo
Dinomo-N

Elasticity

- DINOMO: Brief throughput dips when adding/removing CNs



Elasticity

- DINOMO: Brief throughput dips when adding/removing CNs
- DINOMO-N: Throughput dips for 20-40 seconds due to expensive data reorganization