Patronus: High-Performance and Protective Remote Memory

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Tsinghua University

Remote Memory

Remote memory architecture

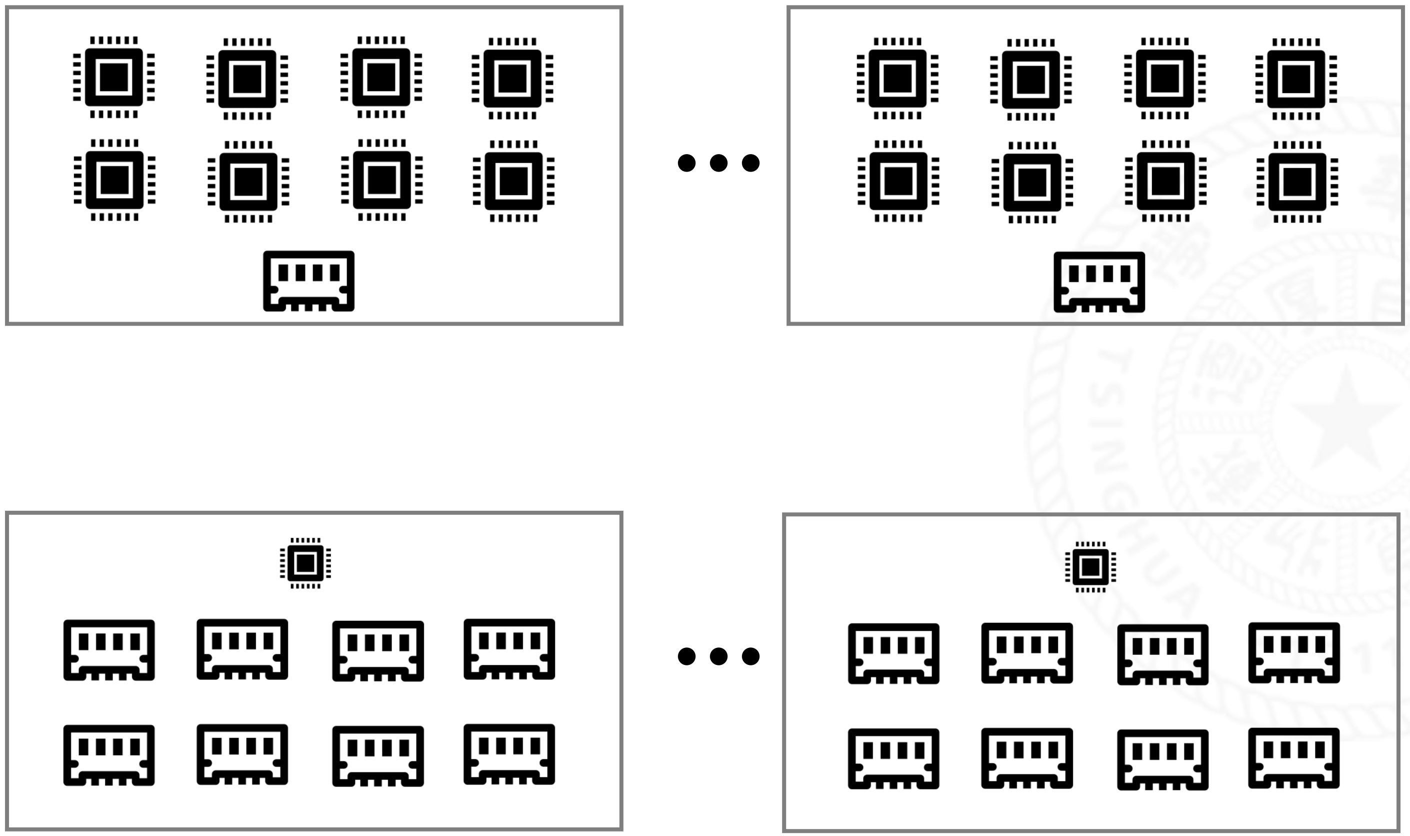
❖ Physically separate CPU and memory into network-attached components

many CPU cores,
small local DRAM

Compute Nodes
(CNs)

large DRAM,
several wimpy cores

Memory Nodes
(MNs)



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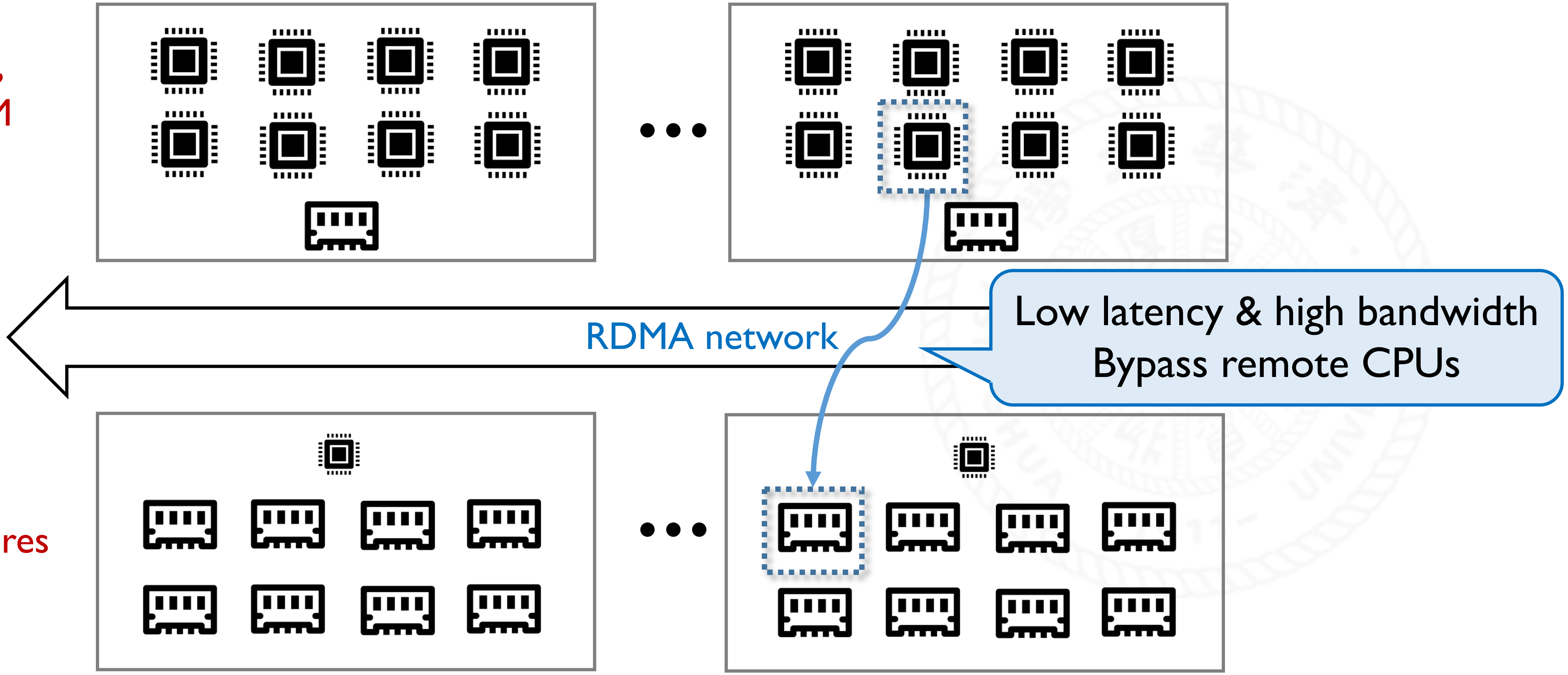

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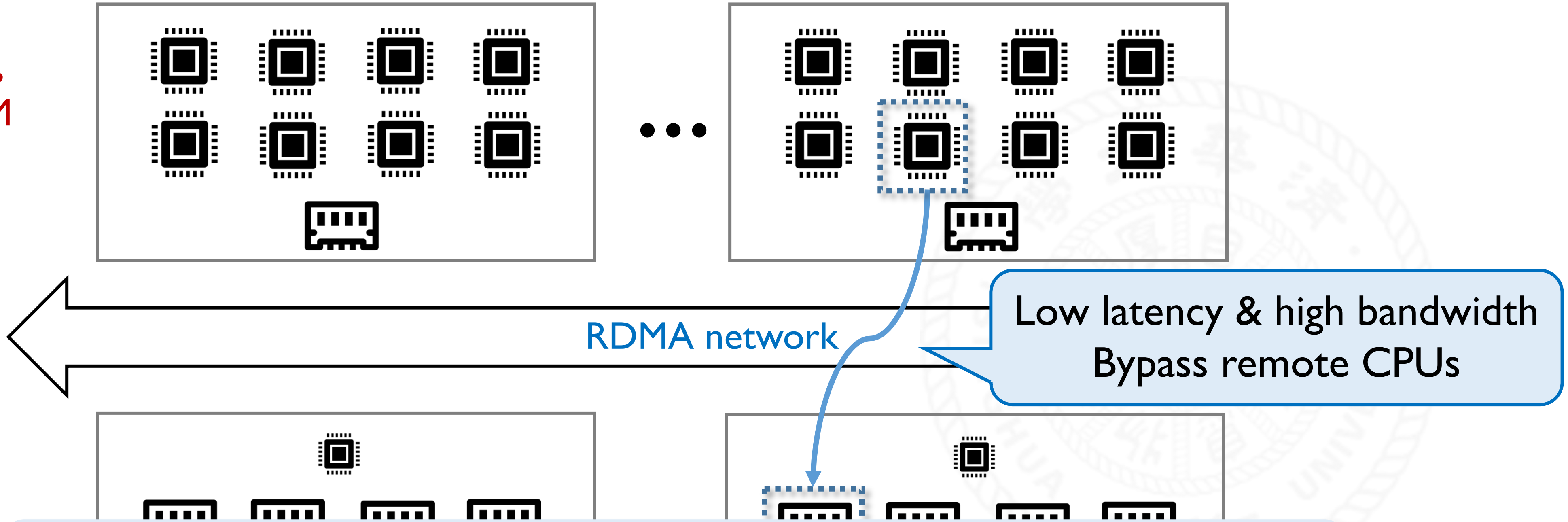

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Memory Nodes
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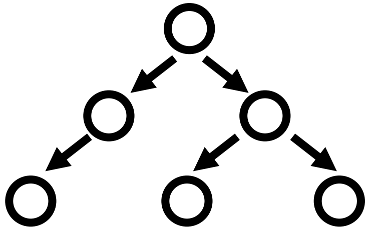
RDMA-enabled remote memory is widely deployed
to improve memory utilization

Remote Memory

Many efforts to make remote memory practical on multiple fronts



efficient remote indexes

[ATC'21,SIGMOD'22,HotOS'19]

easy-to-use

programming models

[OSDI'20,ATC'18,SoCC'17]

popular applications

and more

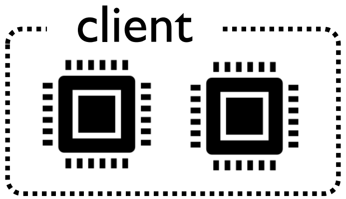
[FAST22, OSDI'18, ATC'15]

However, protection for remote memory is not explored

Necessity: Protection for Remote Memory

Unprotected RM fails to avoid application anomalies

Example 1 **buggy/malicious clients**
(access illegal address)



(out-of-bound)

`write(0x00-0xff)`

corrupt data!

(unregulated)

`read(0x00-0xff)`

privacy breaches!

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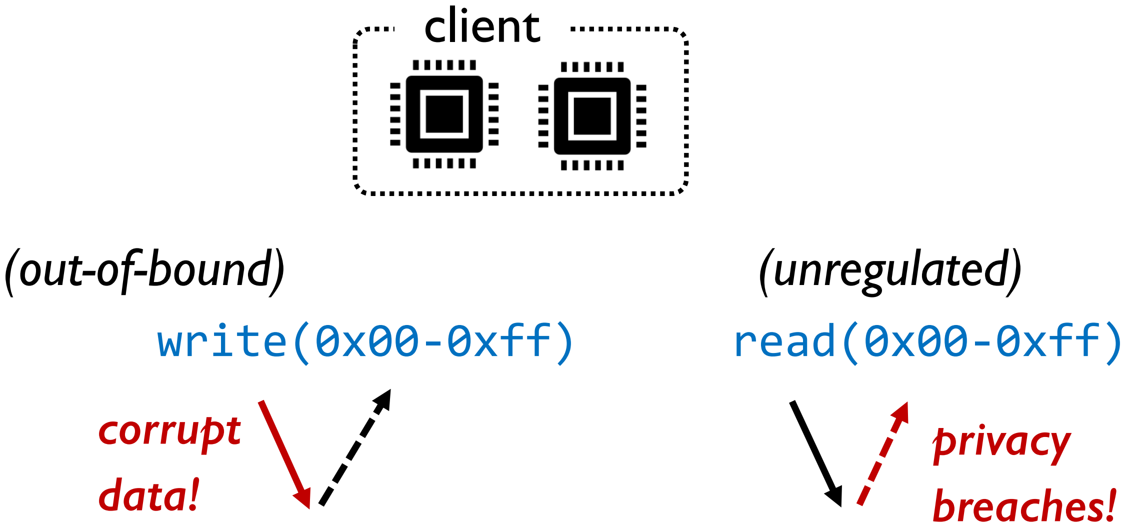
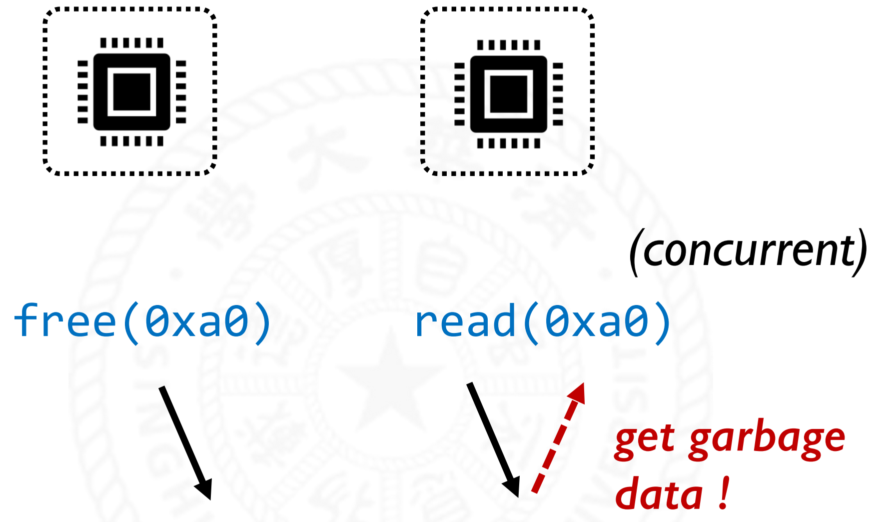


Example II memory management race
(access at illegal time)



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Unprotected RM fails to avoid application anomalies

Example I buggy/malicious clients
(access illegal address)

client

(out-of-bound)
`write(0x00-0xff)`
corrupt data!

(unregulated)
`read(0x00-0xff)`
privacy breaches!

Example II memory management race
(access at illegal time)

`free(0xa0)`

(concurrent)
`read(0xa0)`
get garbage data !

RM protection is necessary
especially for workloads with shared access patterns

Difficulty: Protection + Performance (I)

It is difficult to achieve high-performance protection on the common path

- Reason 1: CPUs are weak on memory nodes
- Reason 2: Existing protection mechanisms are expensive

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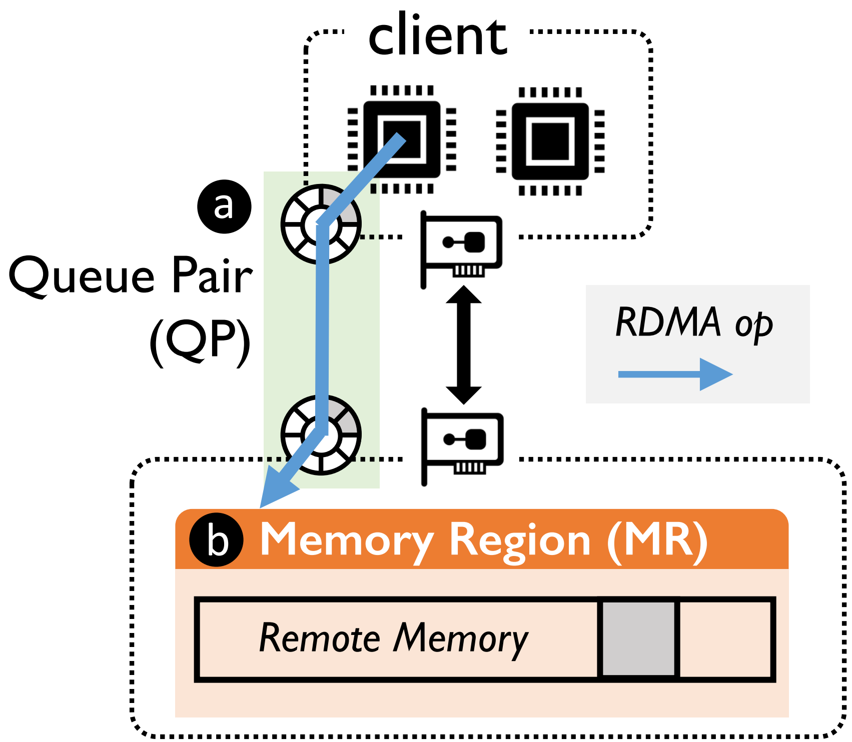

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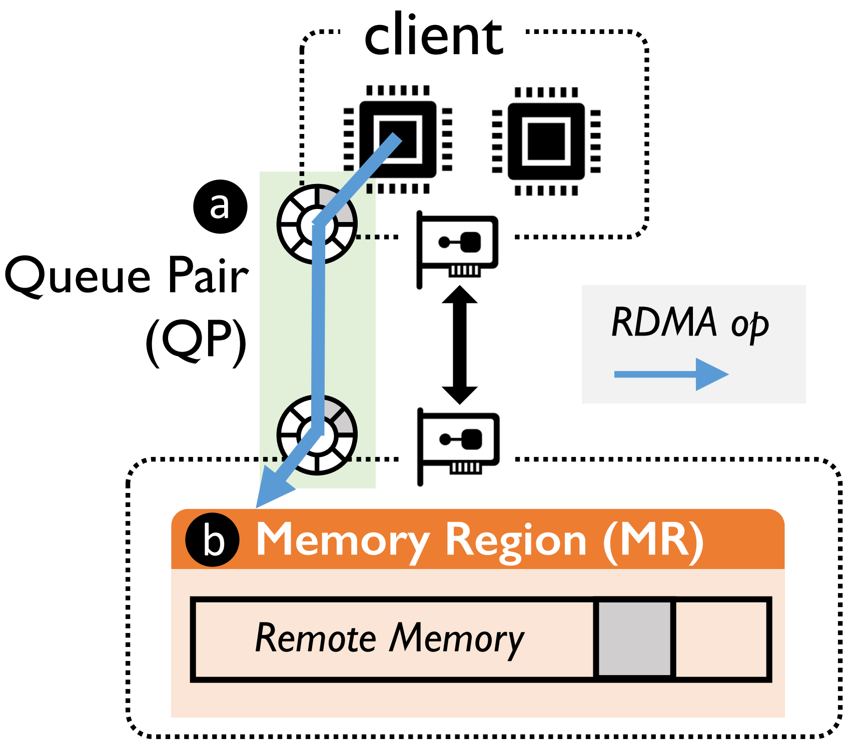

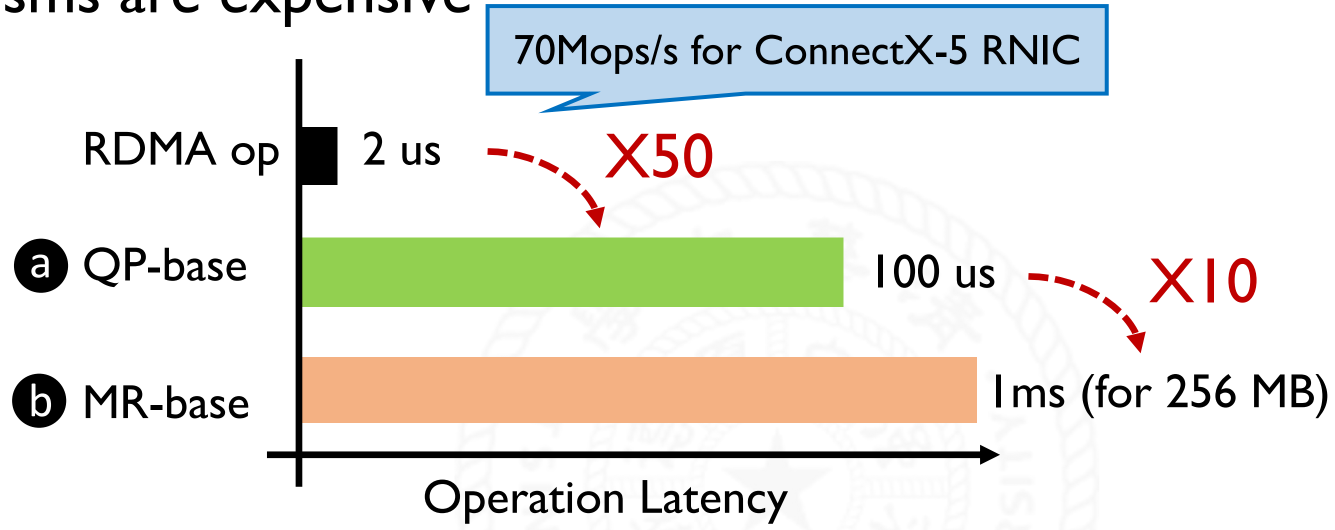

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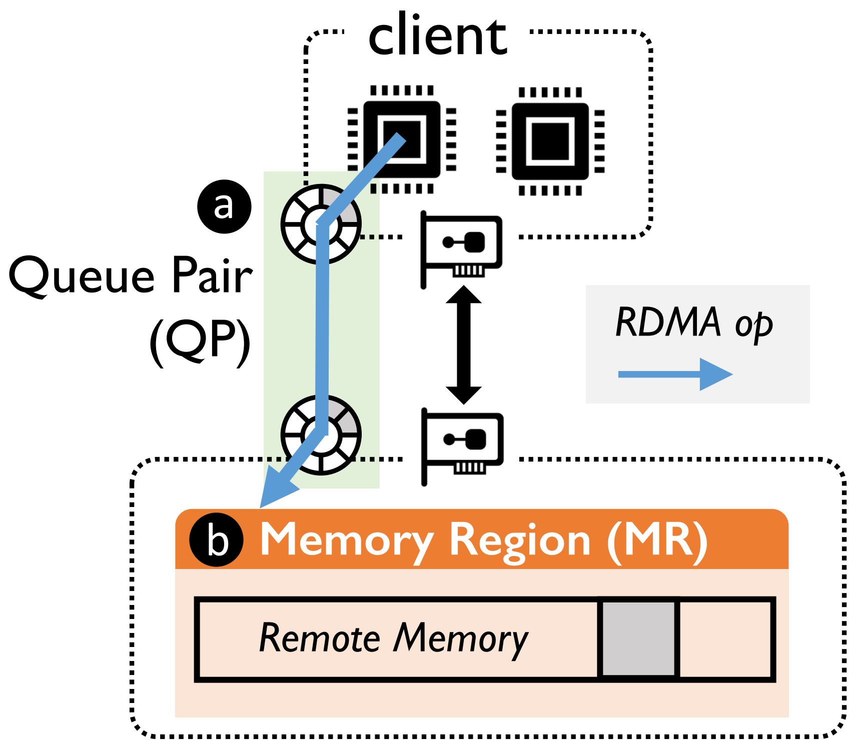
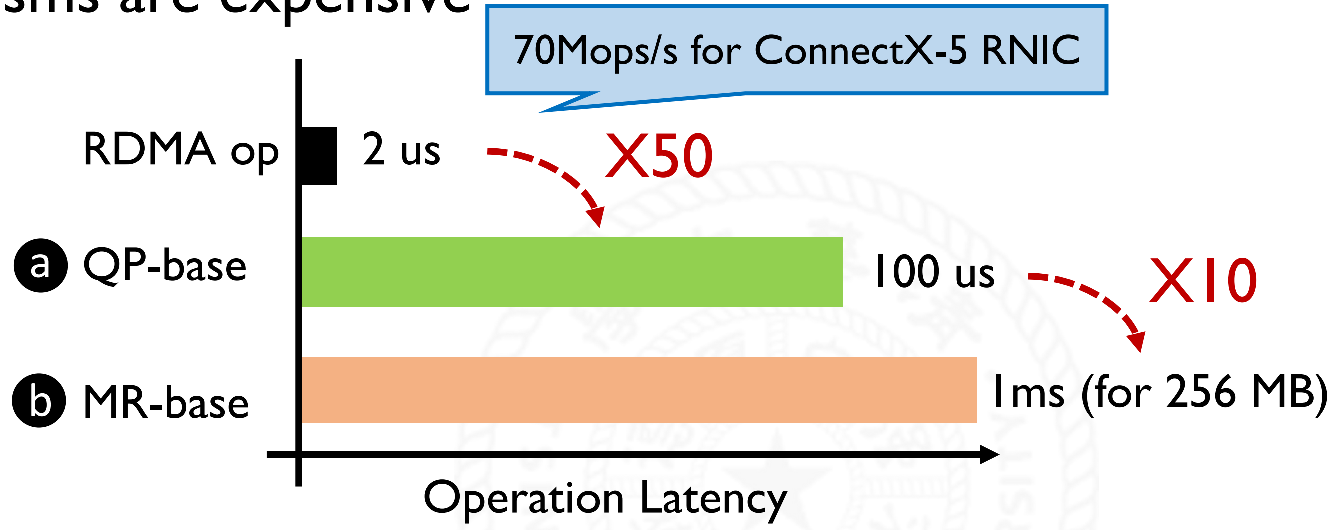




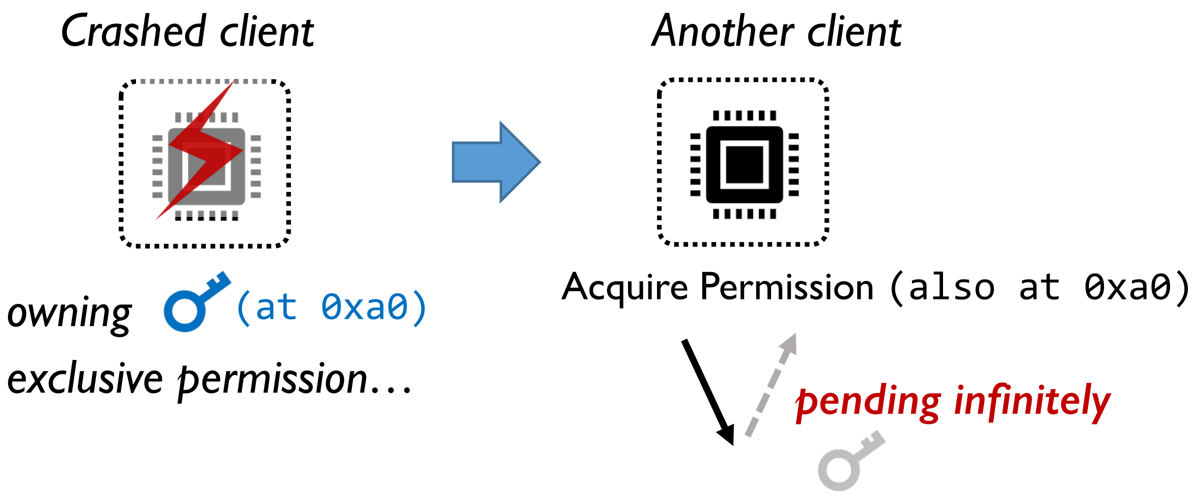
Existing mechanisms are <u>50X-500X slower</u> than RDMA data path.

EXAMPLE Existing applications (FaRM [NSDI'14], Octopus [ATC'17]) have to use 2GB coarse-grained MR, leaving RM no protection.

Difficulty: Protection + Robustness (II)

It is difficult to remain robust on the failure path:

Exception I Client failures



Client failures impact system progress

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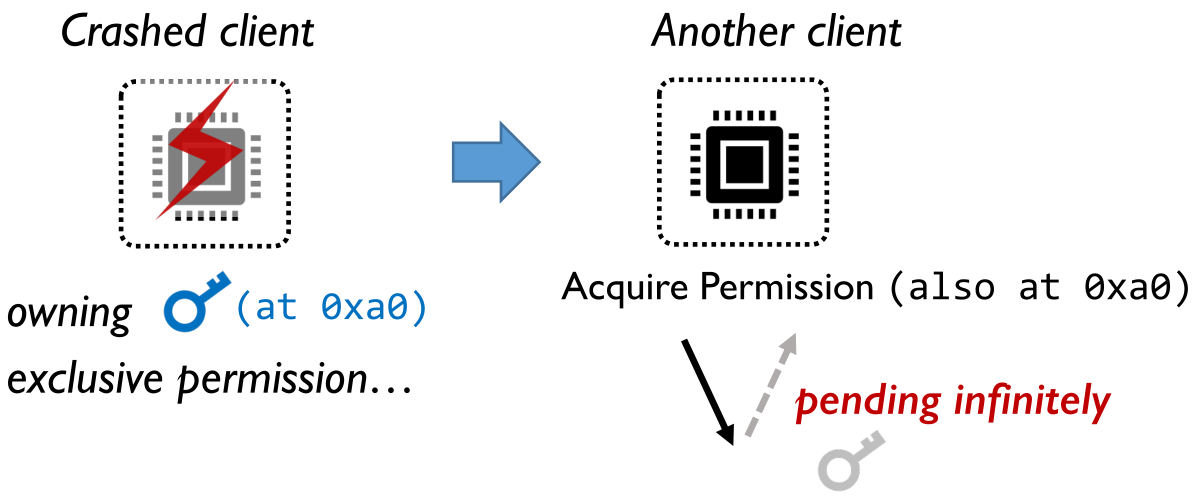

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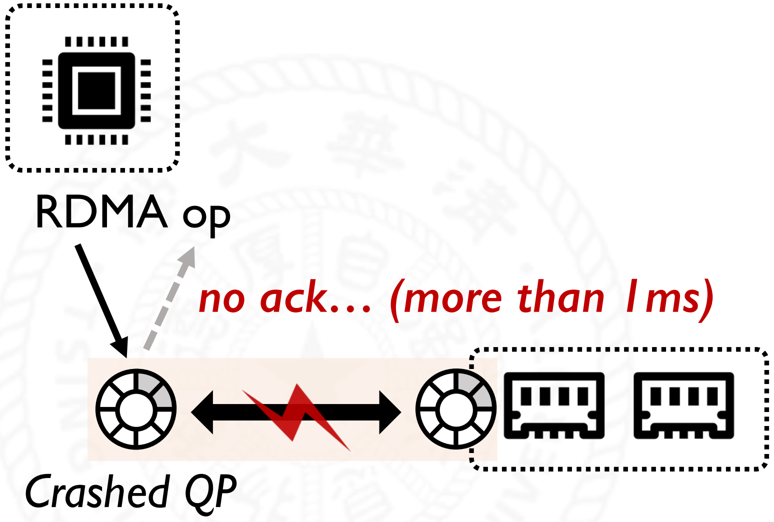

QP failures interrupt application execution

Goal - Protective System

- RM systems are performance-critical → Fast protection management on par with data path
- Client failures impact system progress → React fast to client failures
- QP failures interrupt application execution → Retain performance under QP failures

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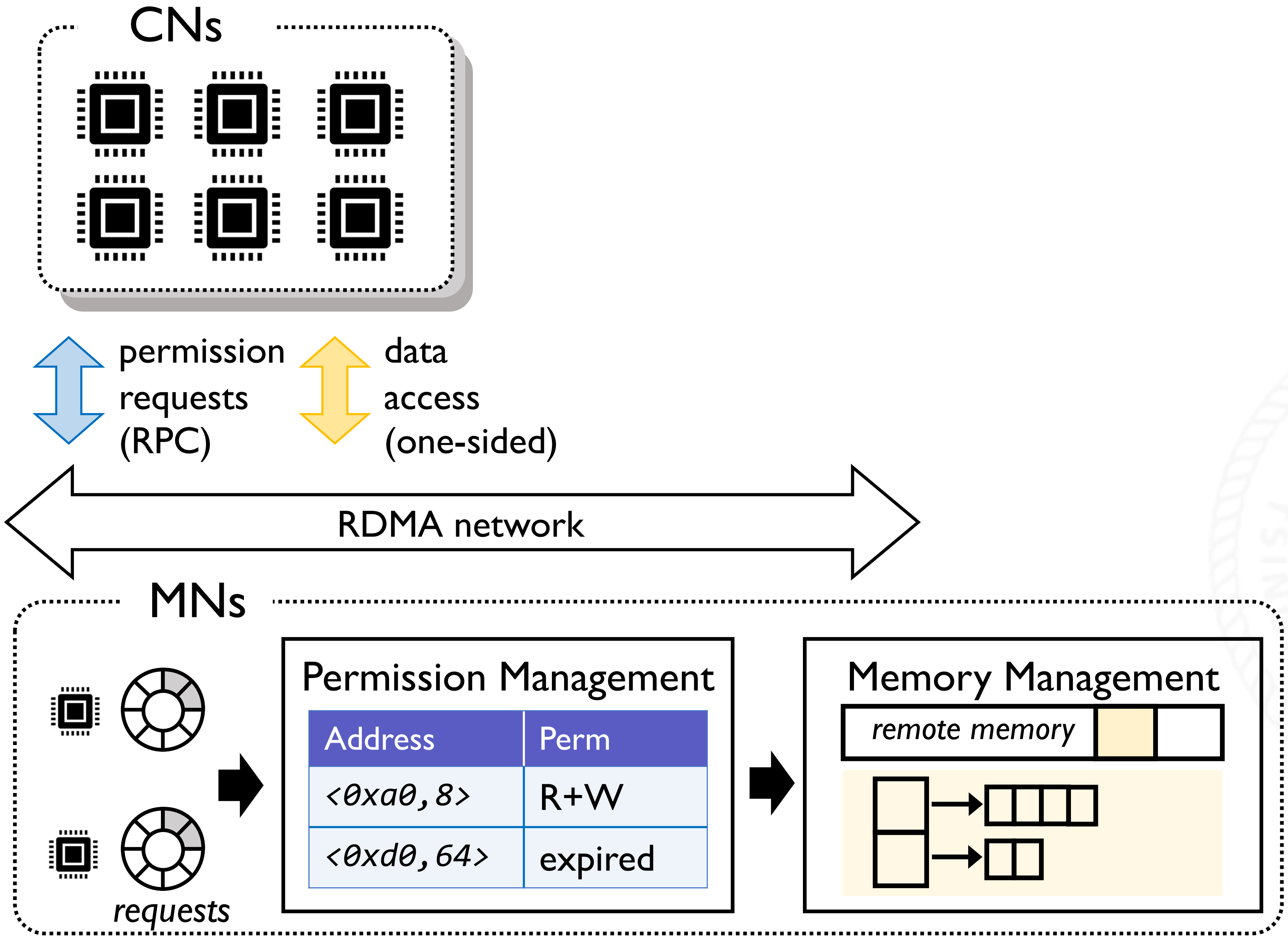
Patronus: a protective RM system that is
high-performance and robust under all situations

Outline

- ❖ Background & Motivation
- ❖ Patronus – High-Performance Protective Remote Memory
- ❖ Results
- ❖ Conclusion

Patronus Overview



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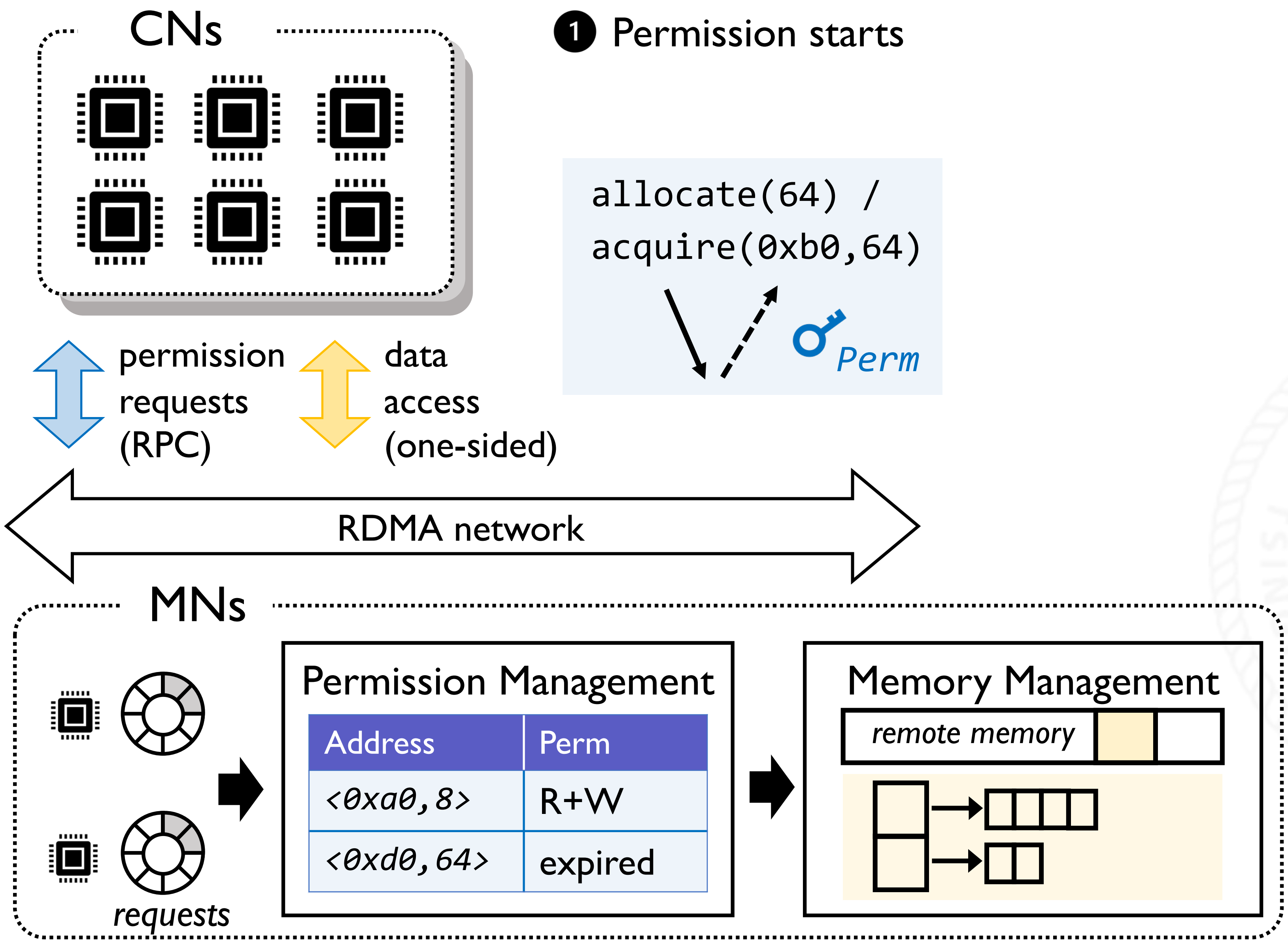

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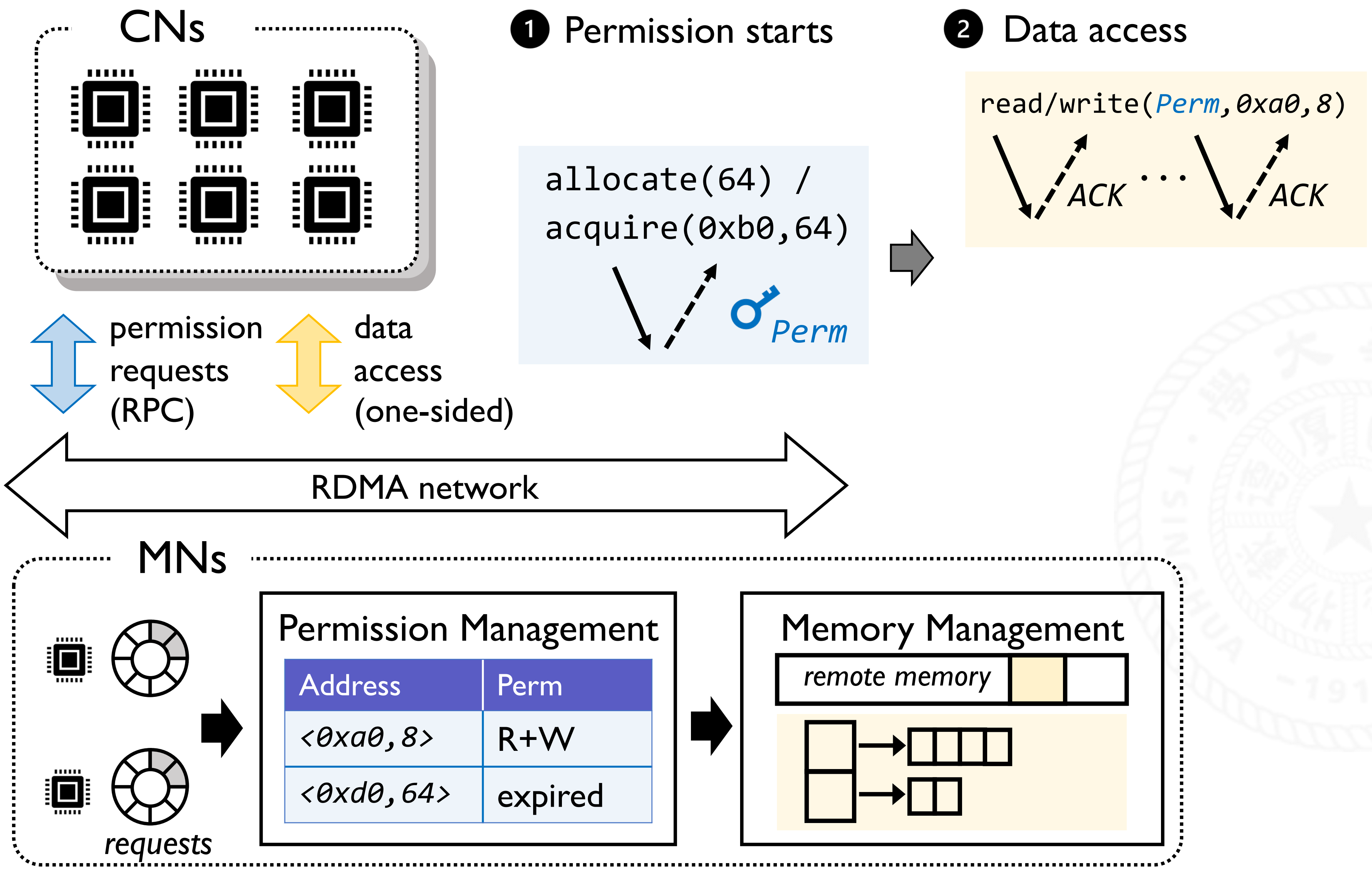

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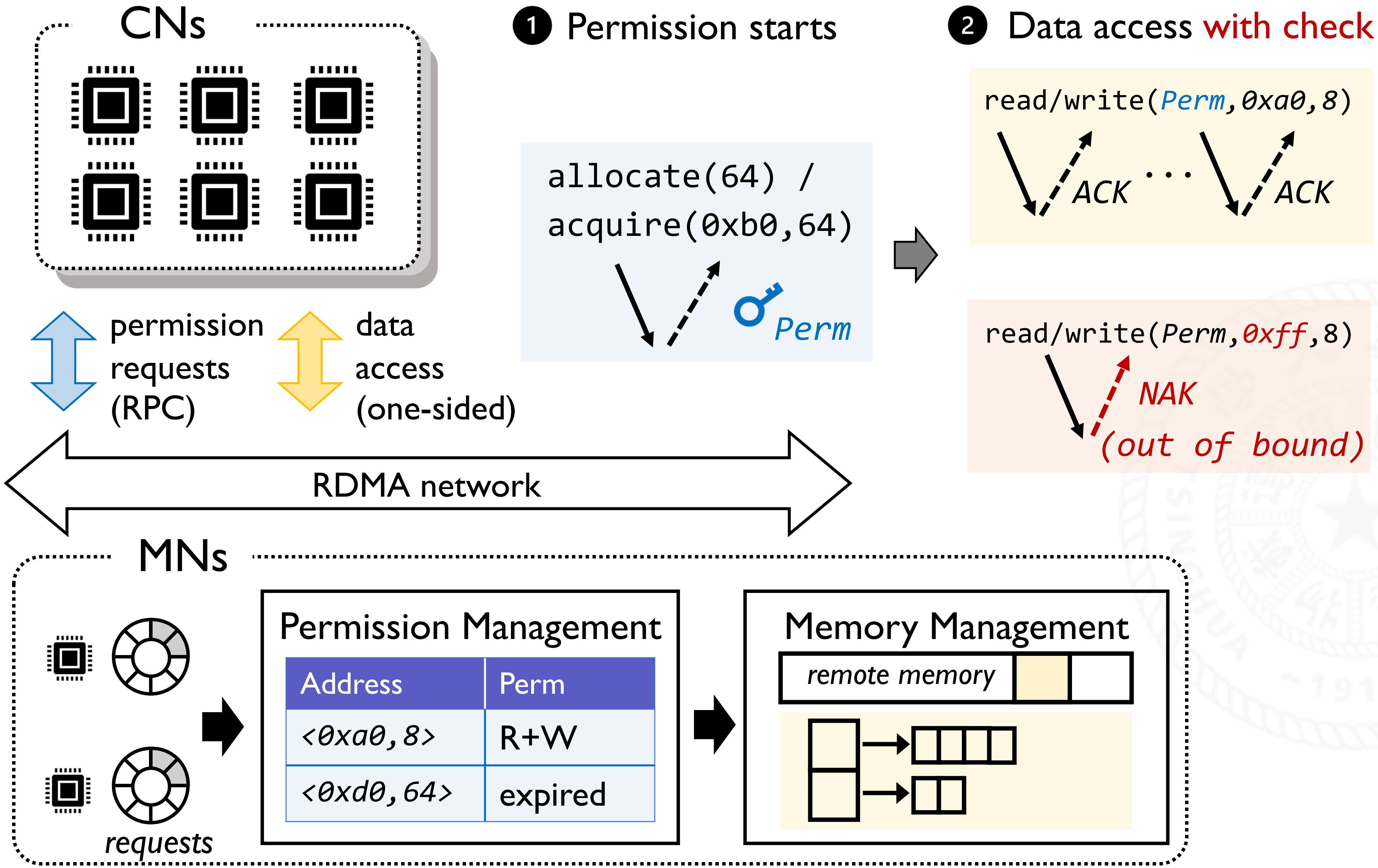

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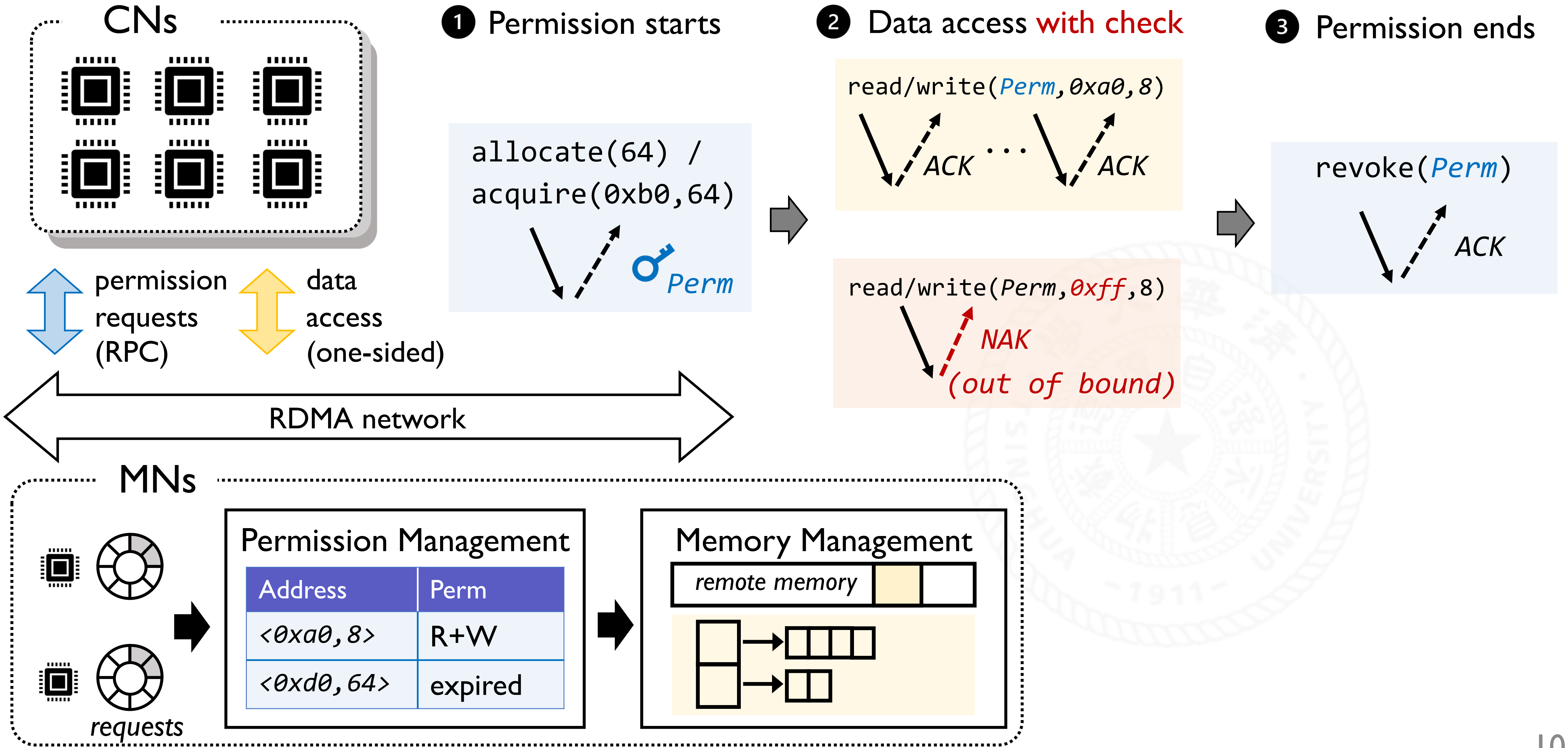

Opportunity – Memory Window (MW)

Memory Window: an advanced & light-weight protection mechanism

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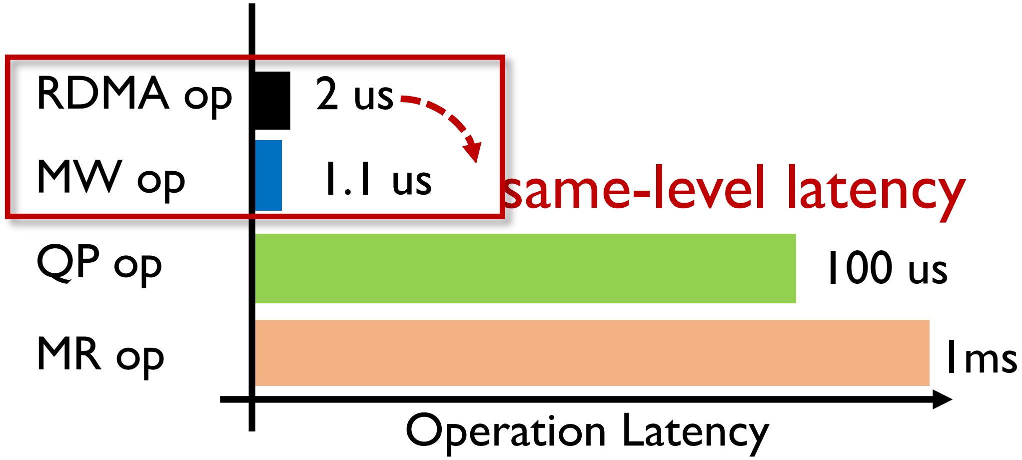

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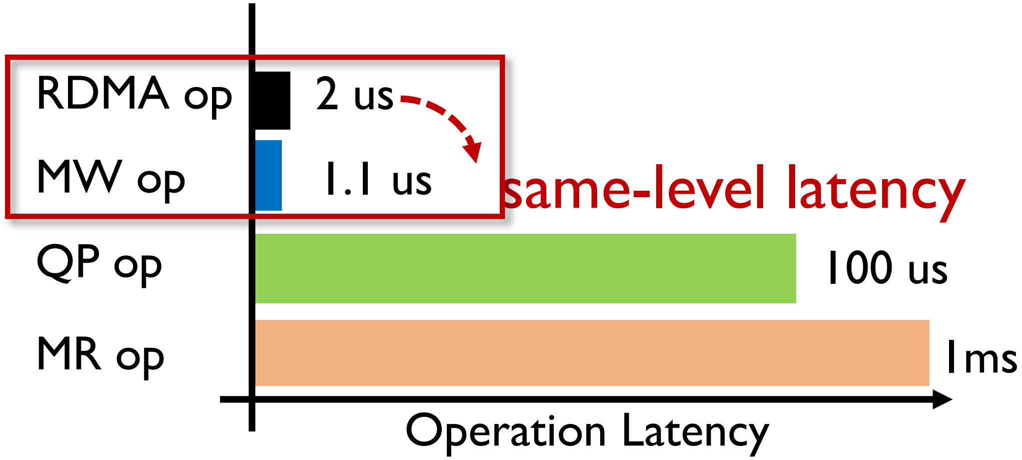

Action	MW	Effect
Permission starts	`bind`	-> 🔑
Permission ends	`unbind`	✗🔑
(rebind = unbind + bind)		

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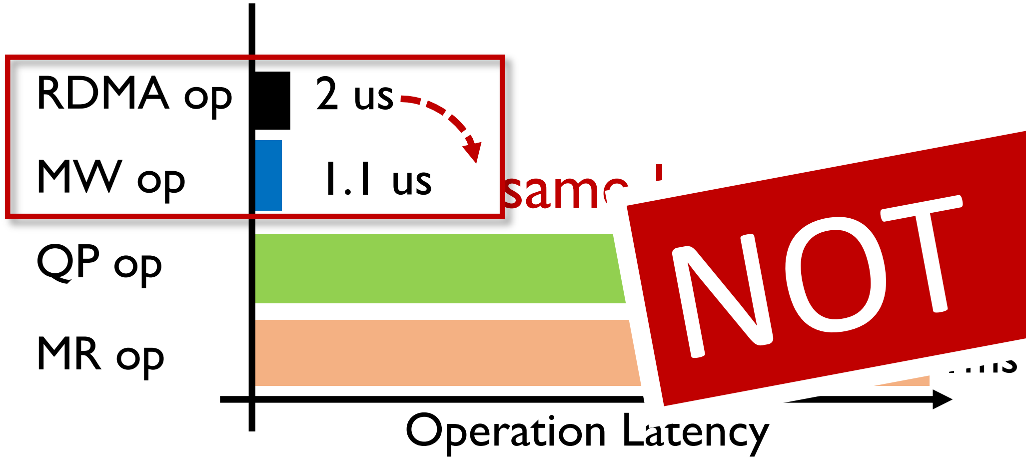

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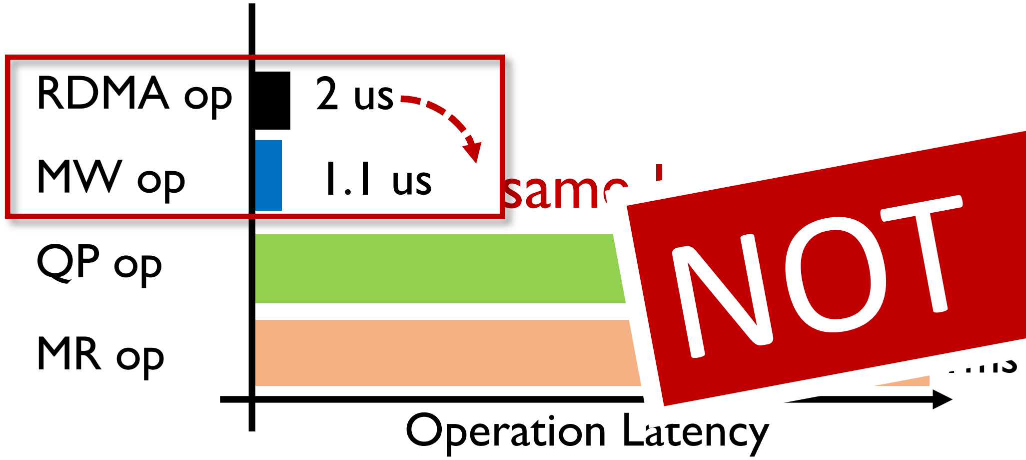

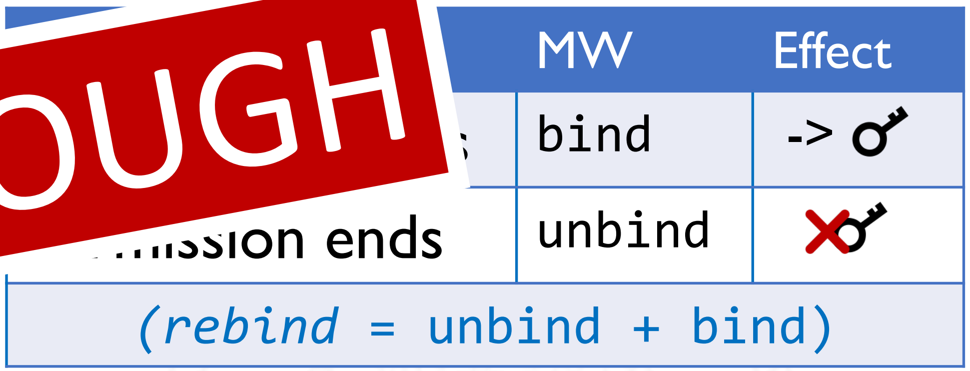

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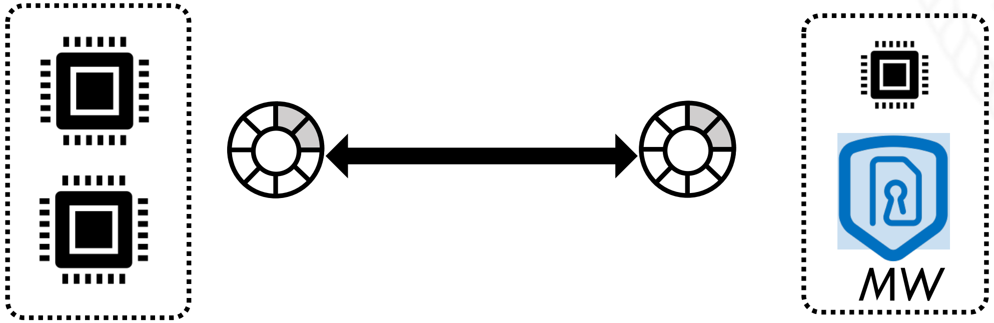

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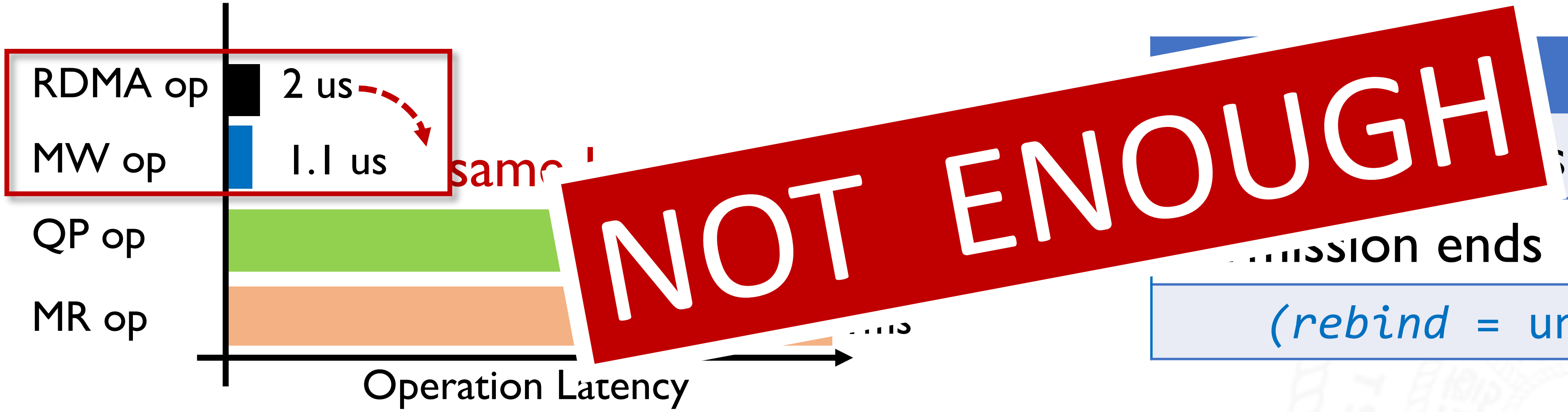

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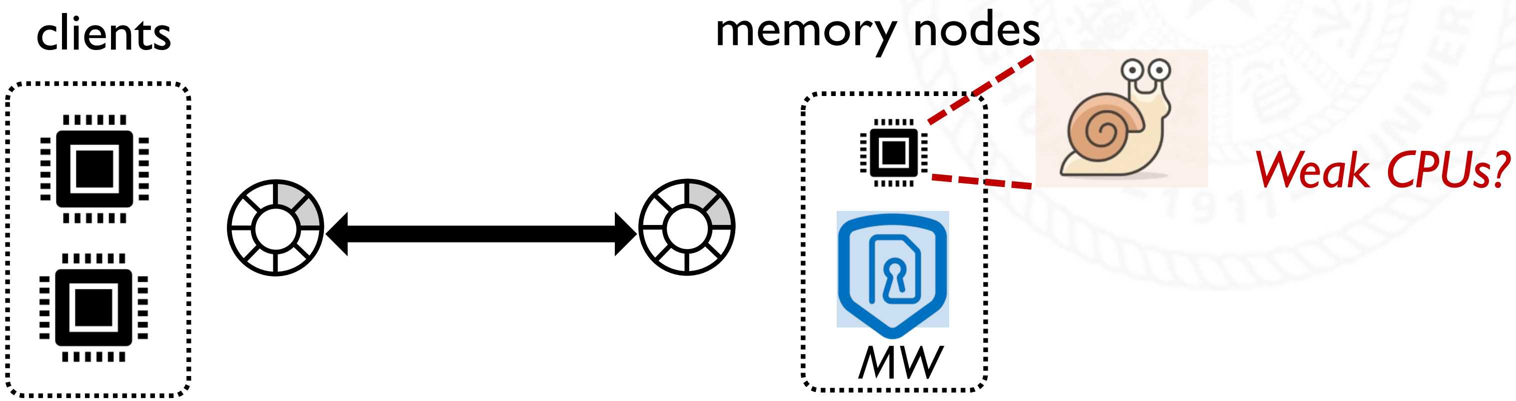

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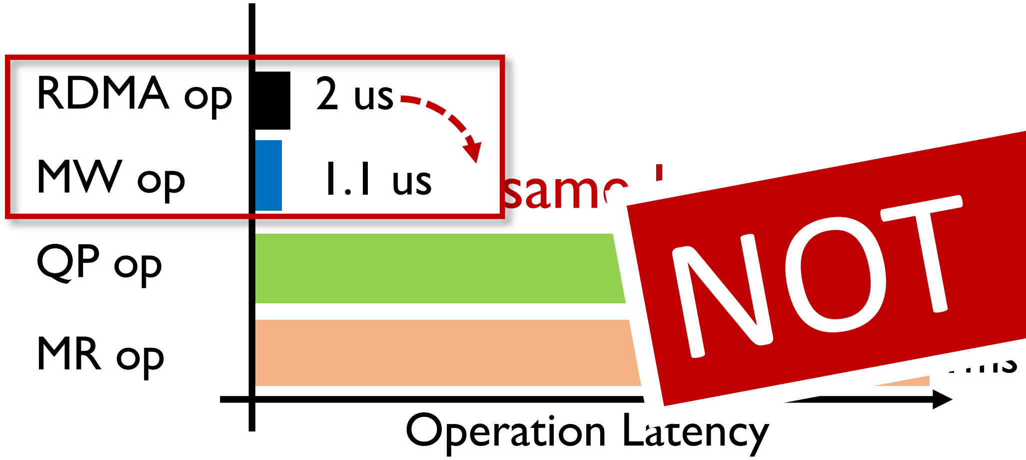

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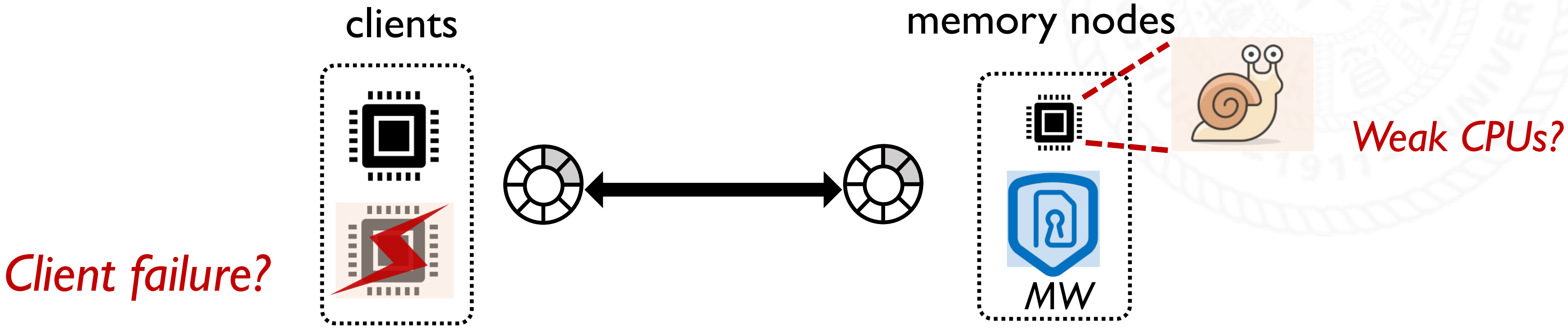

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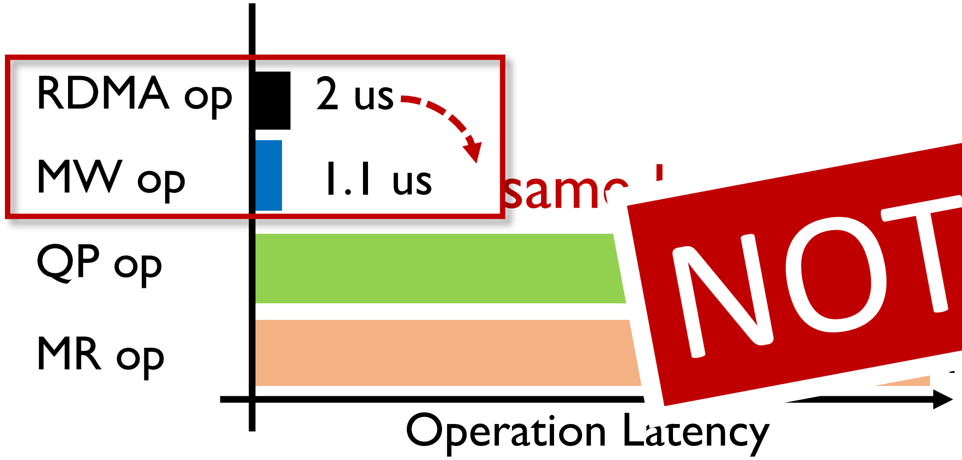

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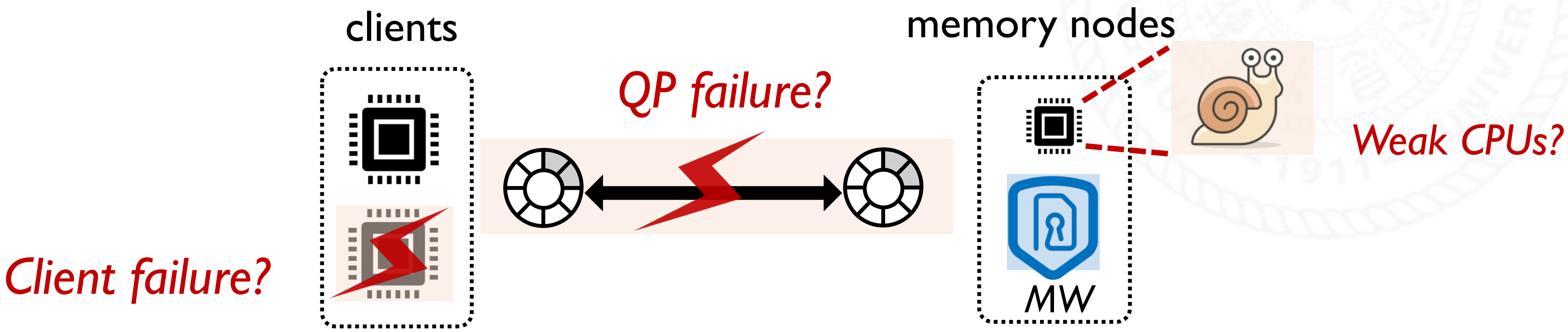
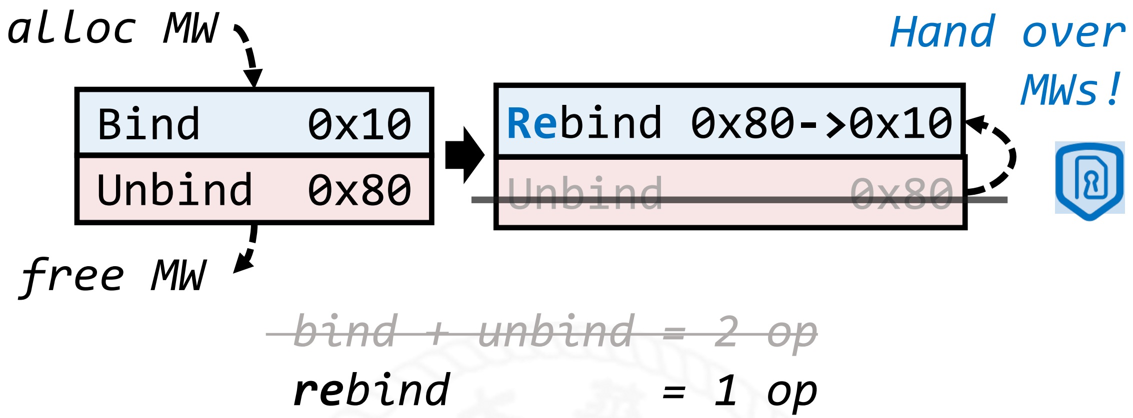


Technique (1) – MW Operation Reduction

❖ MW handover

- Observation: binding and unbinding ops co-exist
- *Bind* op + *unbind* op => *rebind* op
- Hand over MWs between requests
- Result: reduce *half* of MW ops



Same semantics can be achieved with fewer operations

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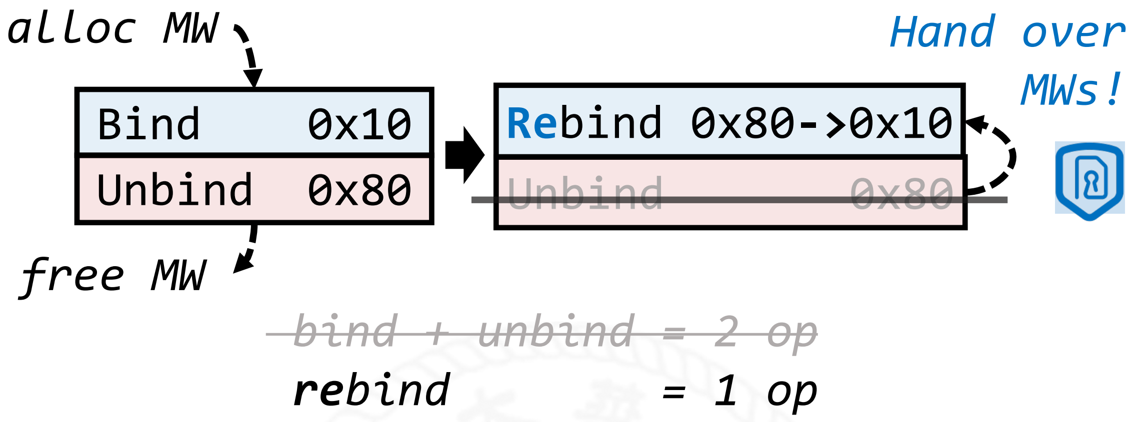
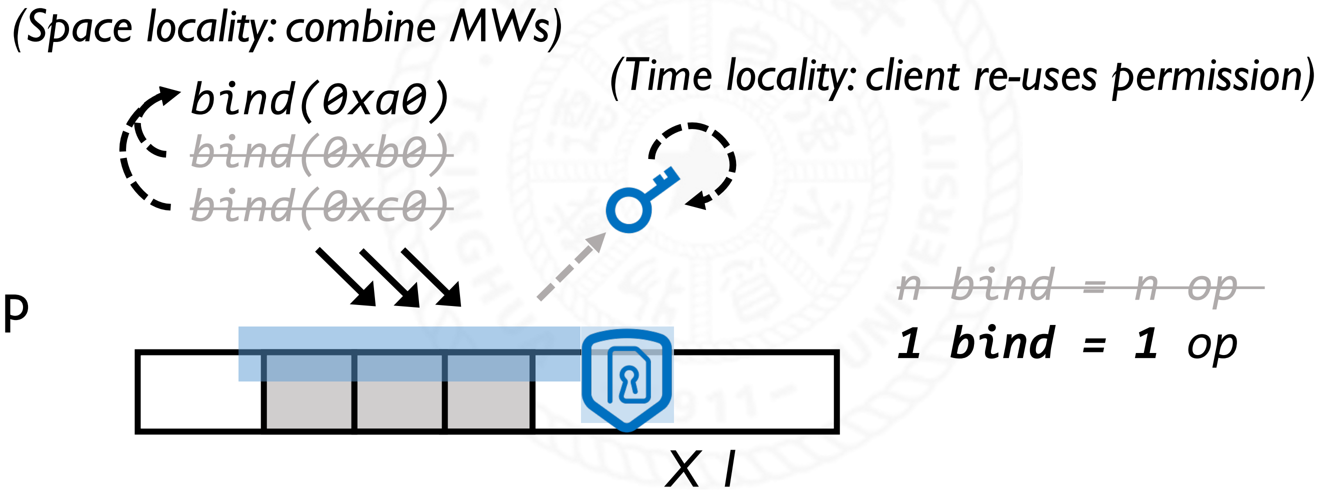


- Exploit locality
  - Observation: space and time locality
  - Multiple *bind* ops (w/ locality) => one *bind* op
  - Result: reduce binding MW ops



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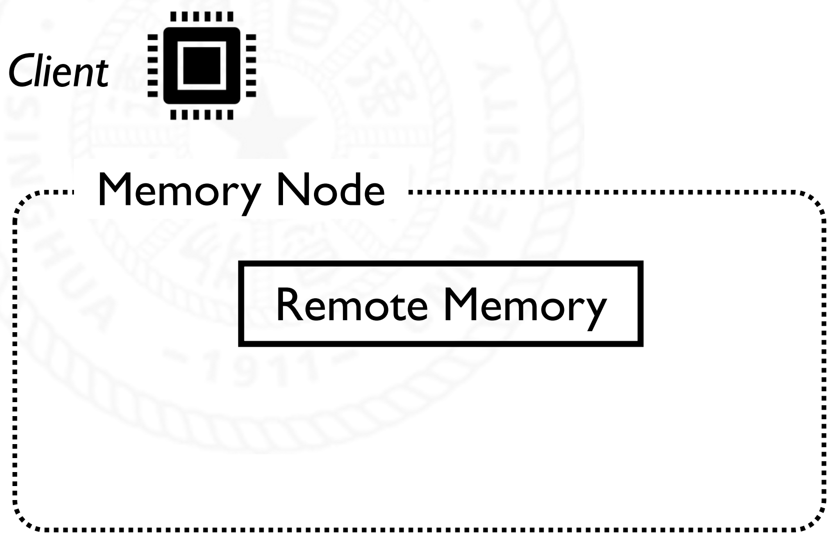
Use *leases* to handle client failures



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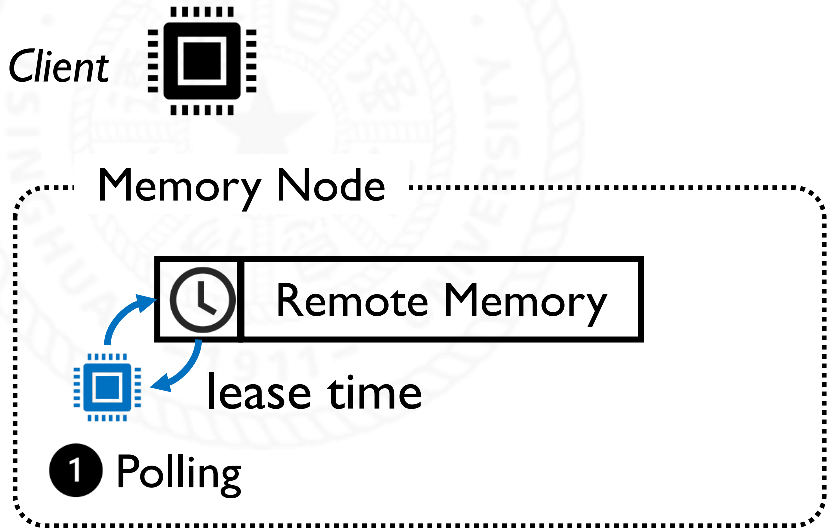

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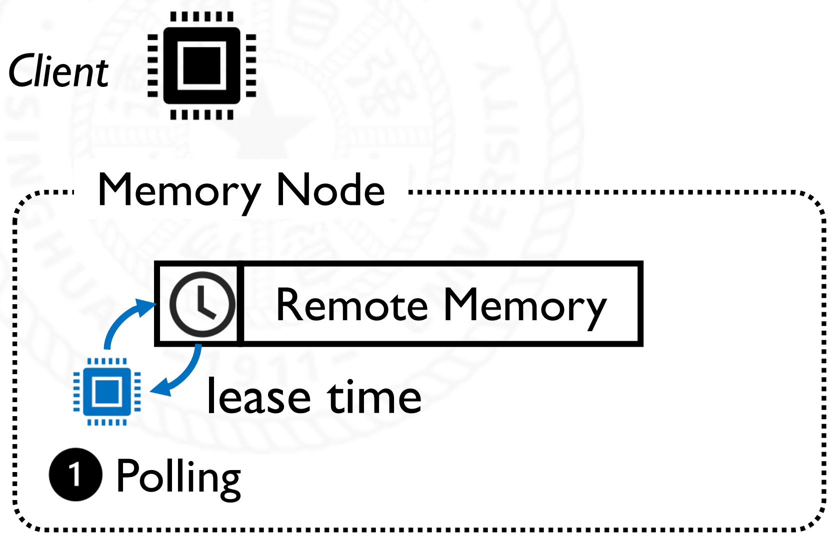
Offloads lease extension overhead to compute nodes



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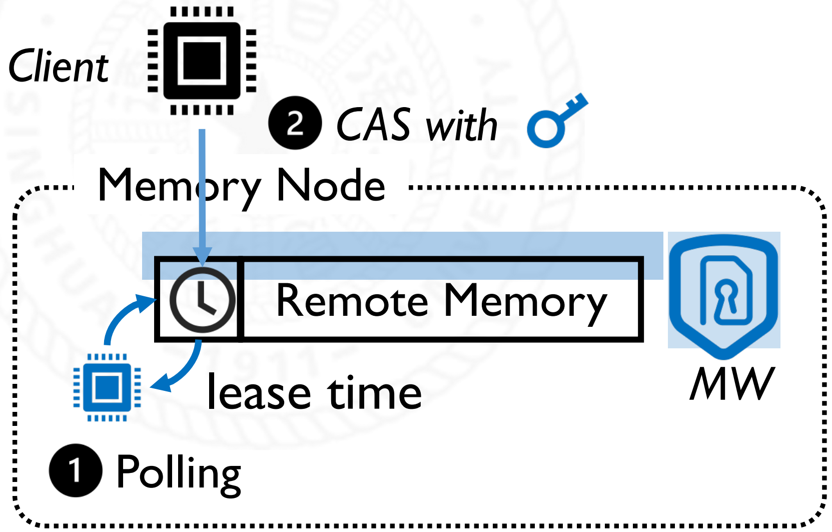
Client-collaborated lease extension

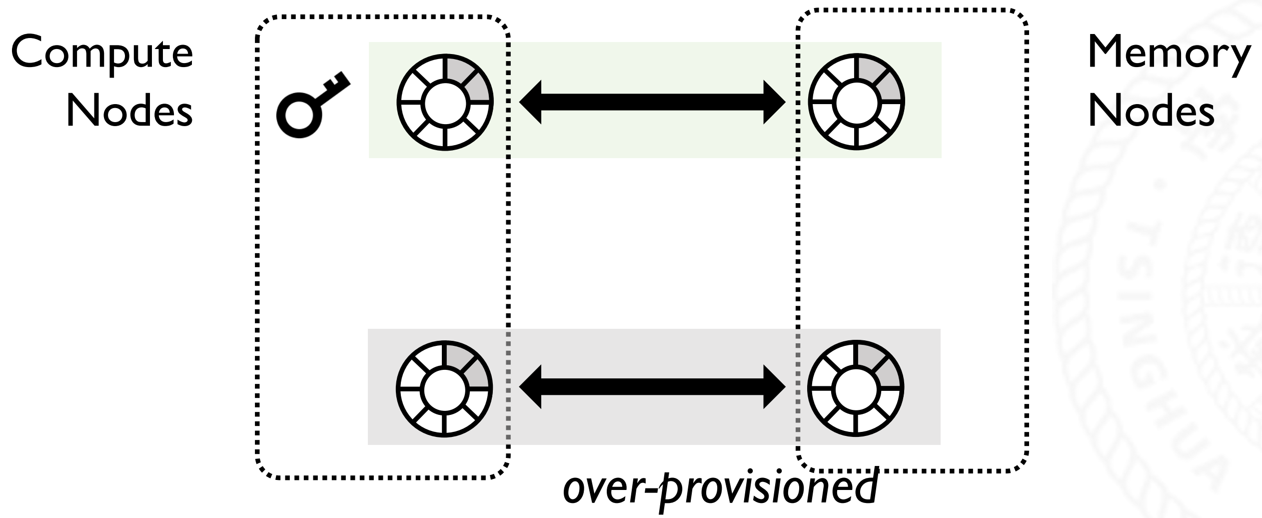
- Enabler: MWs are byte-granularity to expose variables
- Expose the `lease_time` variable ( ) to clients
- Clients extend permission via RDMA_CAS (2)
- Result: Extension only costs one in-bound RDMA op



Technique (3) – Over-Provisioning for QP failures

Over-provision QPs to hide interruption from QP failures

❖ On QP failures: promote a healthy QP as substitution



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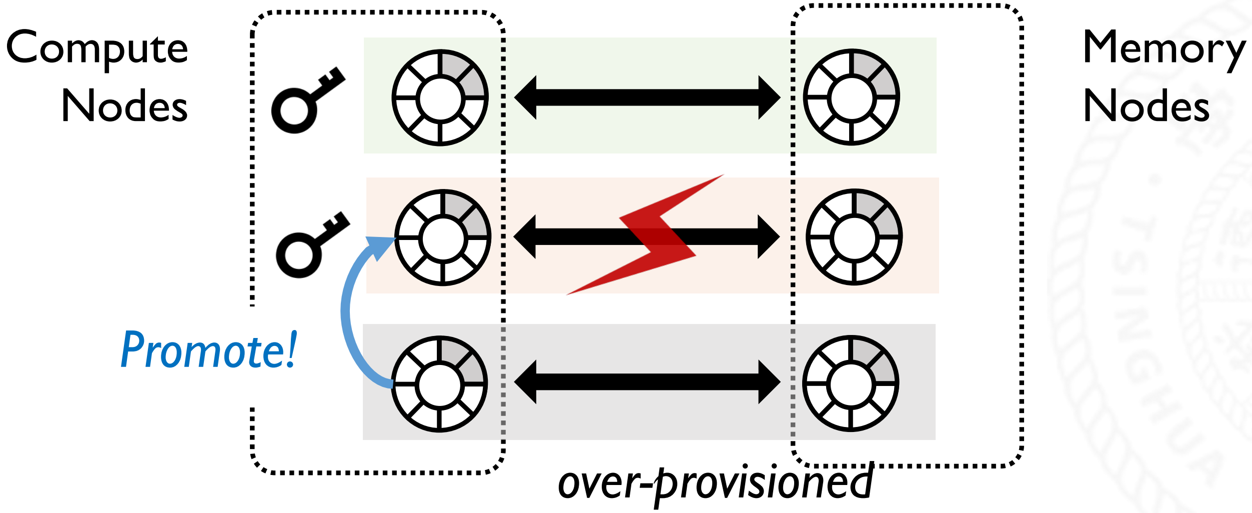

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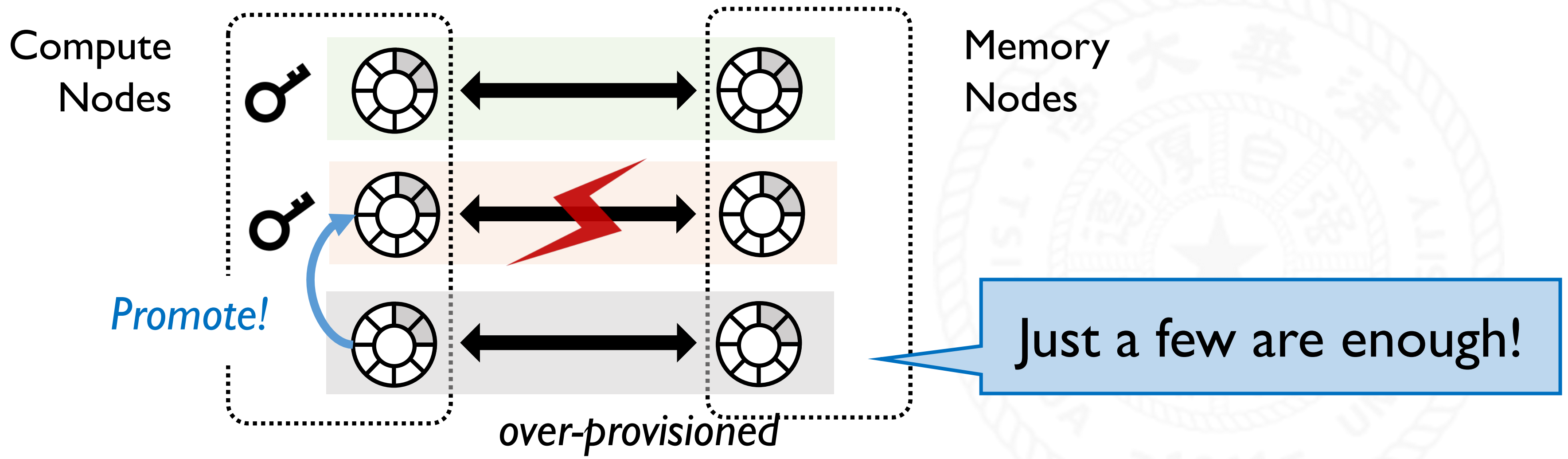

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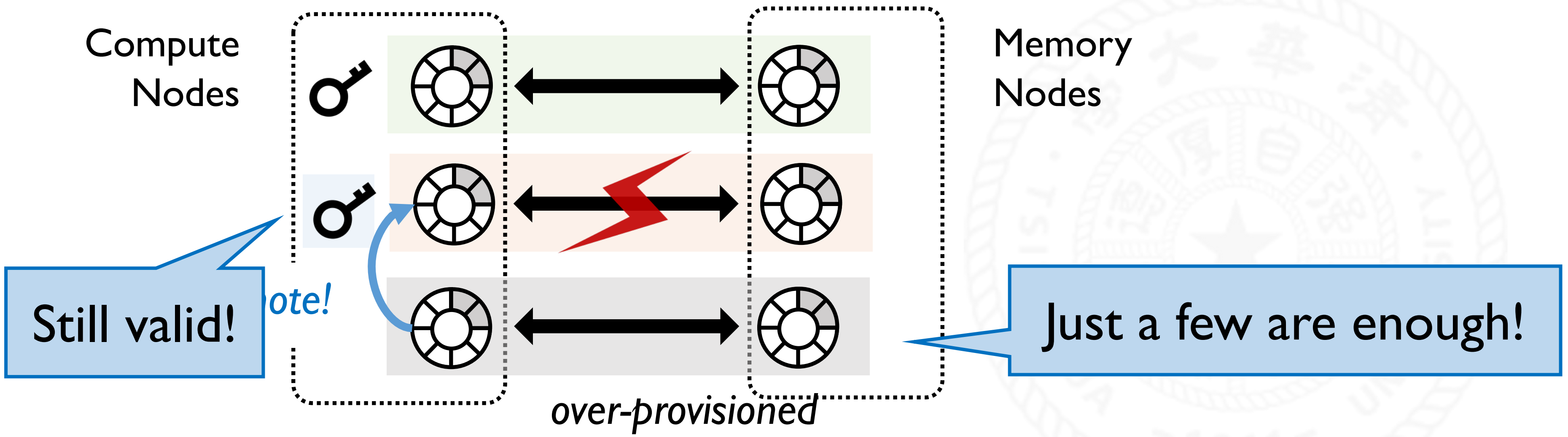

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Over-provision QPs to hide interruption from QP failures

- ❖ On QP failures: promote a healthy QP as substitution
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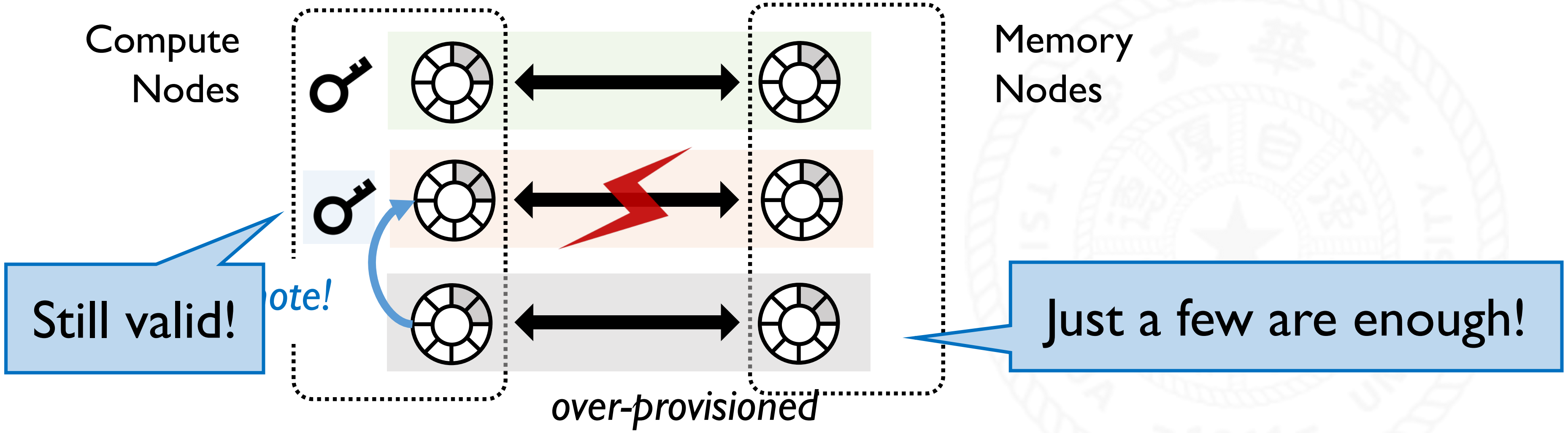
- ❖ Result: low downtime under QP failures



Over-provisioning improves robustness

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Experimental Setup

Hardware Platform

CPU	Xeon Gold 6240M CPUs, **32** cores per node
DRAM	186GB DDR4
NIC	Mellanox MT27800 ConnectX-5 Family

Cluster

- 3 Compute node (no cache)
- 1 Memory node (<= 4 CPU cores)

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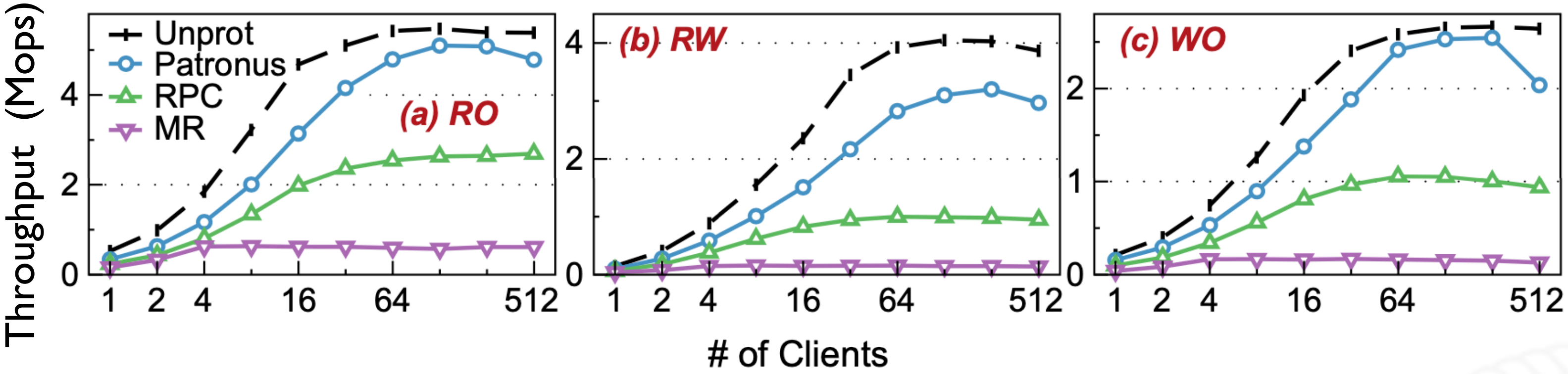
Evaluated Cases

- Common path: 2 one-sided data structures and 2 function-as-a-service workloads.
- Exception path: client failures and QP failures.

Evaluation (1): Overall Performance

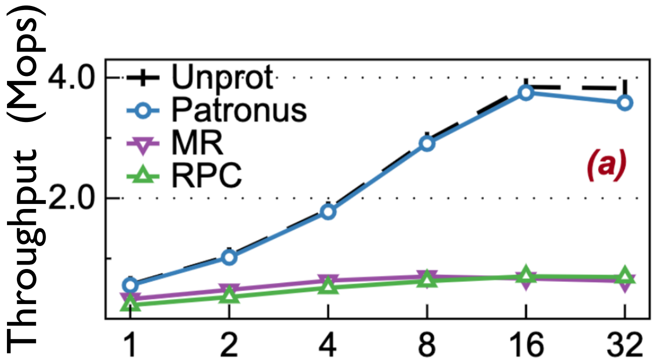
RACE Hashing

Zipfian 0.99
KV = 4KB



- Vanilla unprotected impl
- Use Patronus for permission
- Use MR for permission
- Use RPC in data path

Concurrent Queue



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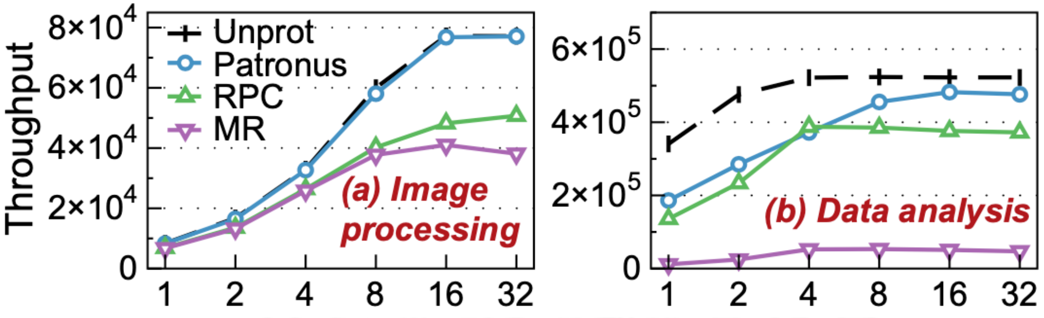

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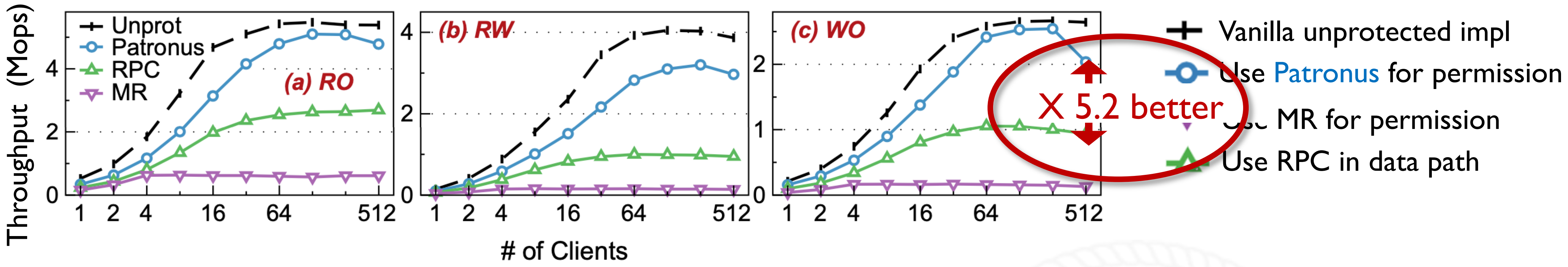

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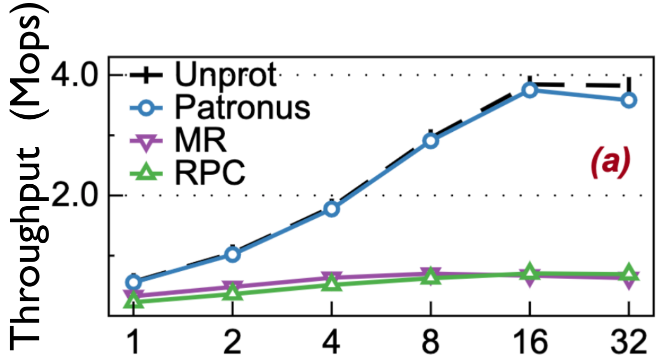

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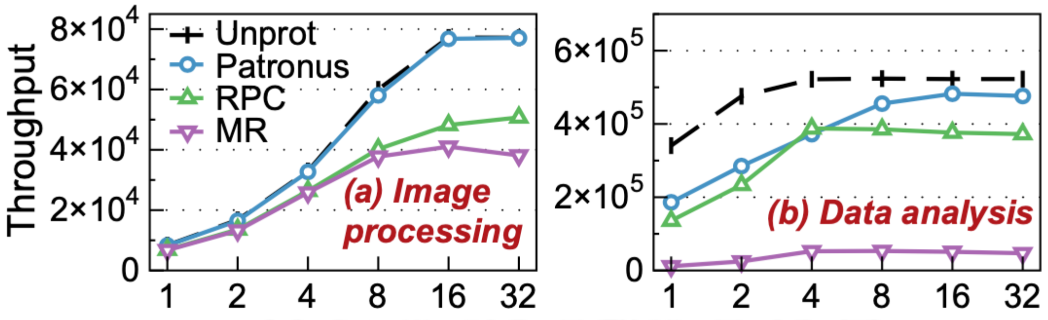

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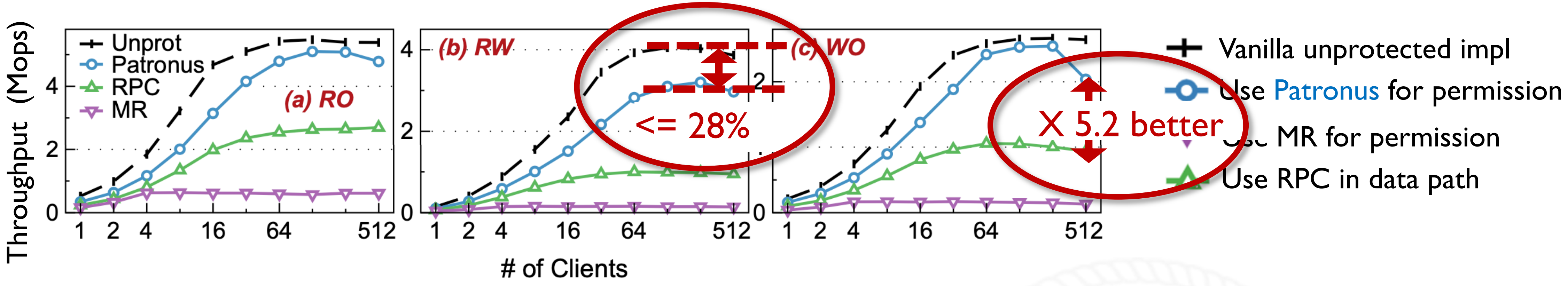
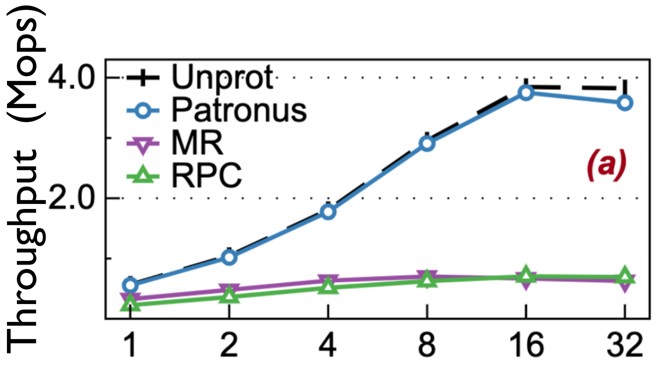
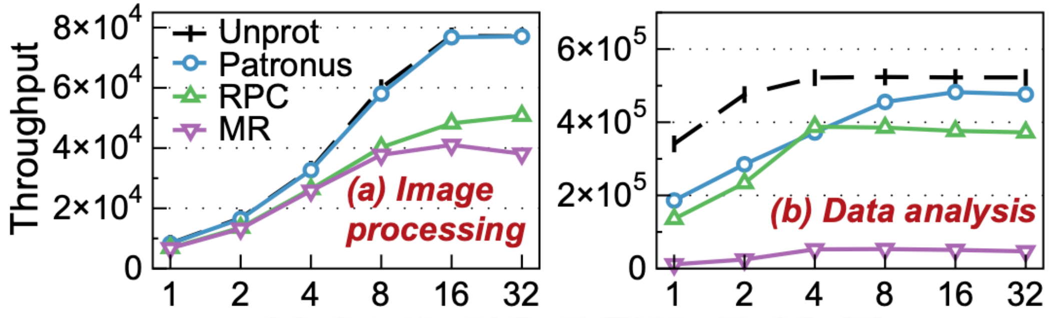
Zipfian 0.99
KV = 4KB



Concurrent Queue



Function as a Service

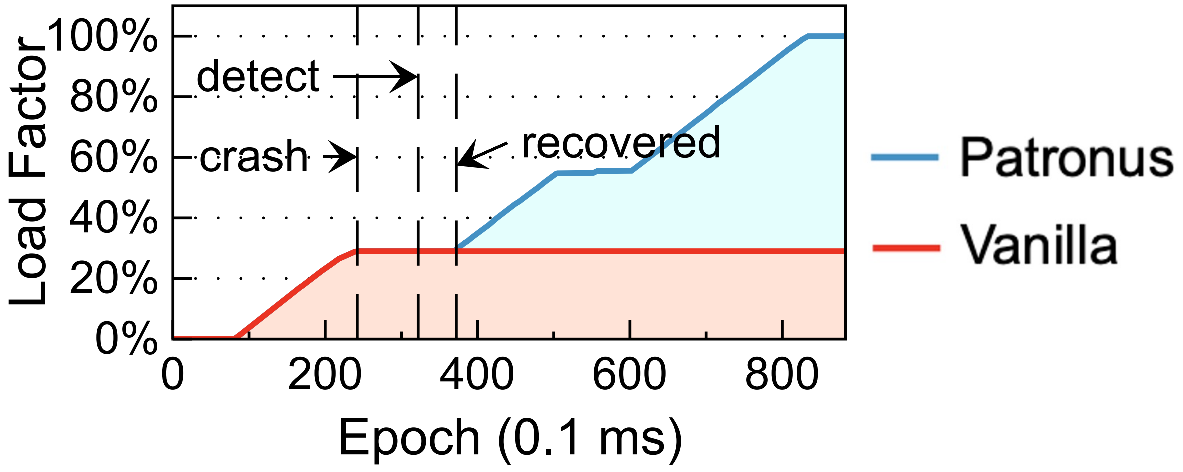


Patronus performs up to X5.2 better than the competitors and has <= 28% overhead than vanilla implementation

Evaluation (2): Failure Handling

Handling client failures

- Vanilla: not handling client failures
- Patronus: resumes progress after 80 epochs.



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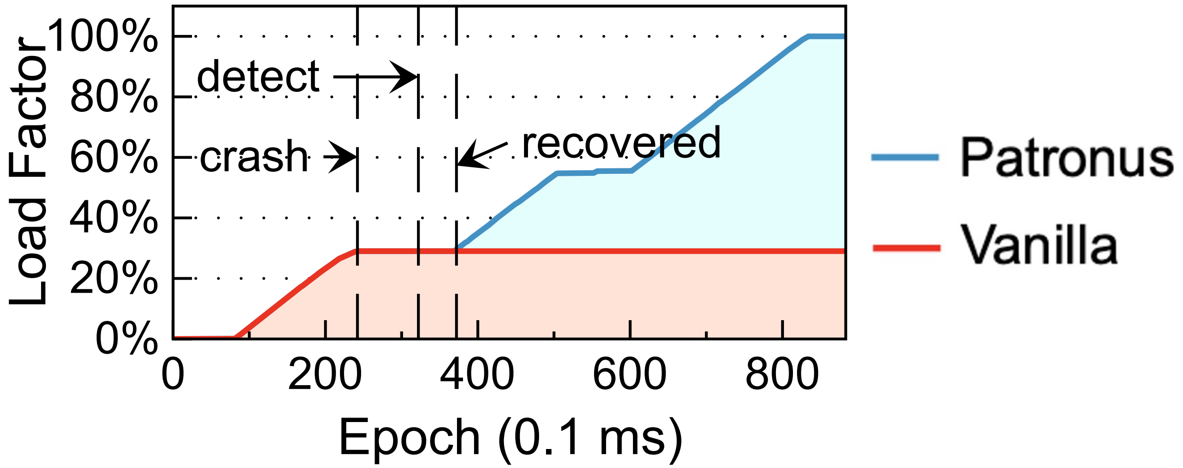

Handling QP failures

- Trigger out-of-bound access manually

Category	Vanilla	Patronus
Promote QP	-	78 us
Notify QP Failure	8 us	-
Recover QP	1004 us	-
Summary	1012 us	78 us (8%)

Patronus is robust to handle client failures and QP failures quickly

Conclusion

- We propose Patronus, a high-performance protective remote memory system for RM protection.
- Three techniques for performance & robustness: MW operations reduction, client-collaborated lease, and QP over-provisioning.
- Patronus takes less than 28% overhead and performs at most x5.2 than the competitors in various real-world workloads.
- More analysis and evaluation results in the paper.

Thanks
Q&A

Patronus – High-Performance and Protective Remote Memory

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