Storm: a fast transactional dataplane for remote data structures

Stanko Novakovic   Yizhou Shan   Aasheesh Kolli   Michael Cui
Yiying Zhang   Haggai Eran   Boris Pismenny   Liran Liss   Michael Wei
Dan Tsafrir   Marcos Aguilera

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What is Remote Direct Memory Access (RDMA)?

- Initiate transfer, hardware executes, async. poll for completions

- Infiniband (IB): specialized network stack for RDMA
  - Fully implemented in hardware (PCIe-based adapters) →
  - Also: IB transport on top of IP and lossless Ethernet

- Key benefits:
  1. one-sided access
  2. user-level w/ minimal instr. footprint

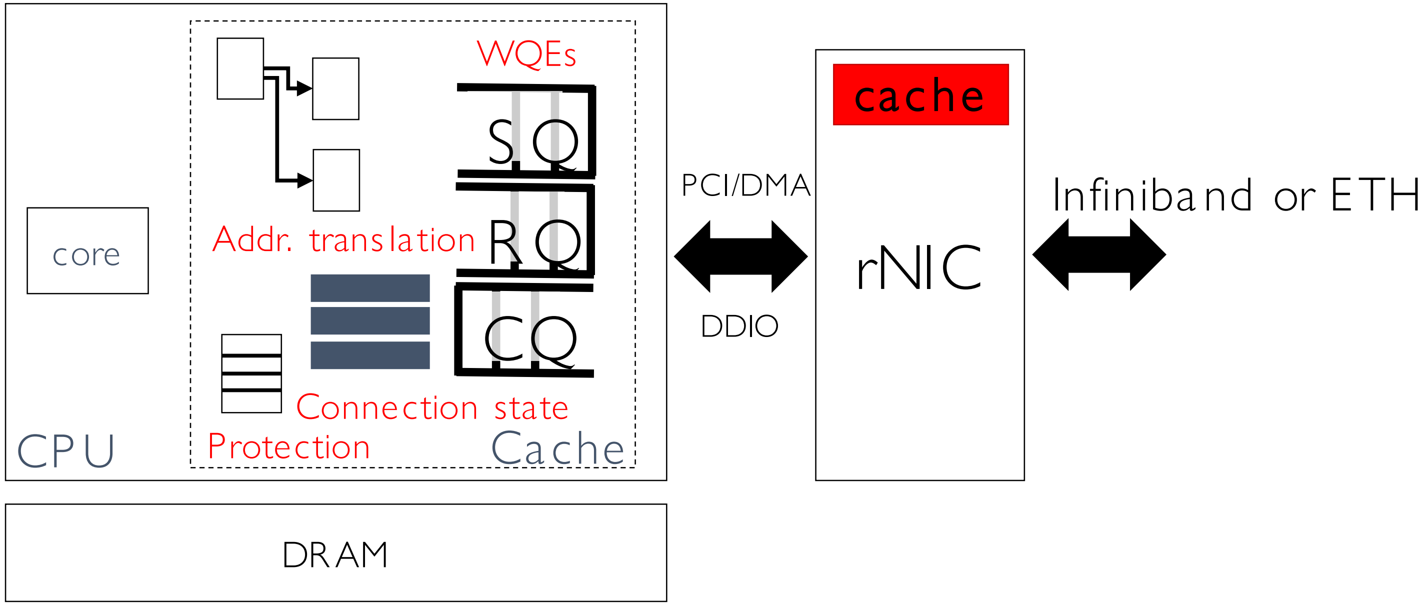
Remote data structures

- Hash tables, graphs, trees, queues, etc
  - Fine-grain accesses
  - High fan-out
  - Pointer-linked
  - Transactional access
  - Throughput (IOPS) bound
  - Latency Service Level Objective (SLO)

- Other (perhaps less interesting) use cases: analytics, VM migration
  - Bulk transfers, bandwidth-bound

What are common concerns?

1. Scalability: network state kept in limited hardware resources



2. Round-trips: pointer-linked data structures

What are common concerns?

1. Scalability: network state kept in limited hardware resources
    - FARM: Use locks to share QP connections (Dragojevic’14)
    - FaSST/eRPC: Don’t use connections (Kalia’19)
    - LITE: Enforce protection in kernel (Tsai’17)

2. Round-trips: pointer-linked data structures
    - FARM: Use Hopscotch algorithm, one RTT common case
    - FaSST/eRPC: Leverage RPCs rather than one-sided reads

Outline

- Problem statement
- Key insights
- Storm design
- Results

Key insights (1/2)

- Hardware has gotten much better!!!
  - ConnectX-4/5 (CX4/5) vs. ConnectX-3 (CX3)
    - 40M IOPS on CX4 → 4x higher than CX3
    - Scales up to 64 machines → on CX3 IOPS collapses for >10 machines
    - CX4 achieves 10M IOPS when zero cache hits → max IOPS for uncontended CX3
    - Break-even point with datagram send/recv currently at ~4k connections
- Possible further improvements with ConnectX-6
- How is HW getting better?
  - More concurrency, better prefetching, larger caches, etc

Key insights (2/2)

- FARM:
  - Locks degrade throughput unnecessarily
  - Large buckets (due to larger keys) wastes throughput

- FaSST/eRPC:
  - Two-sided doesn’t allow for maximum full-duplex throughput
    - Especially for requests larger than a cache line (no inlining)
  - Onloaded congestion control adds overhead

- LITE:
  - Kernel adds overhead (fine-grain accesses)
  - No support for async. operations

Our approach / Storm design principles

1. Use connections but minimal count
    - Lock-free QP sharing if really necessary
    - Offloaded congestion control and retransmissions

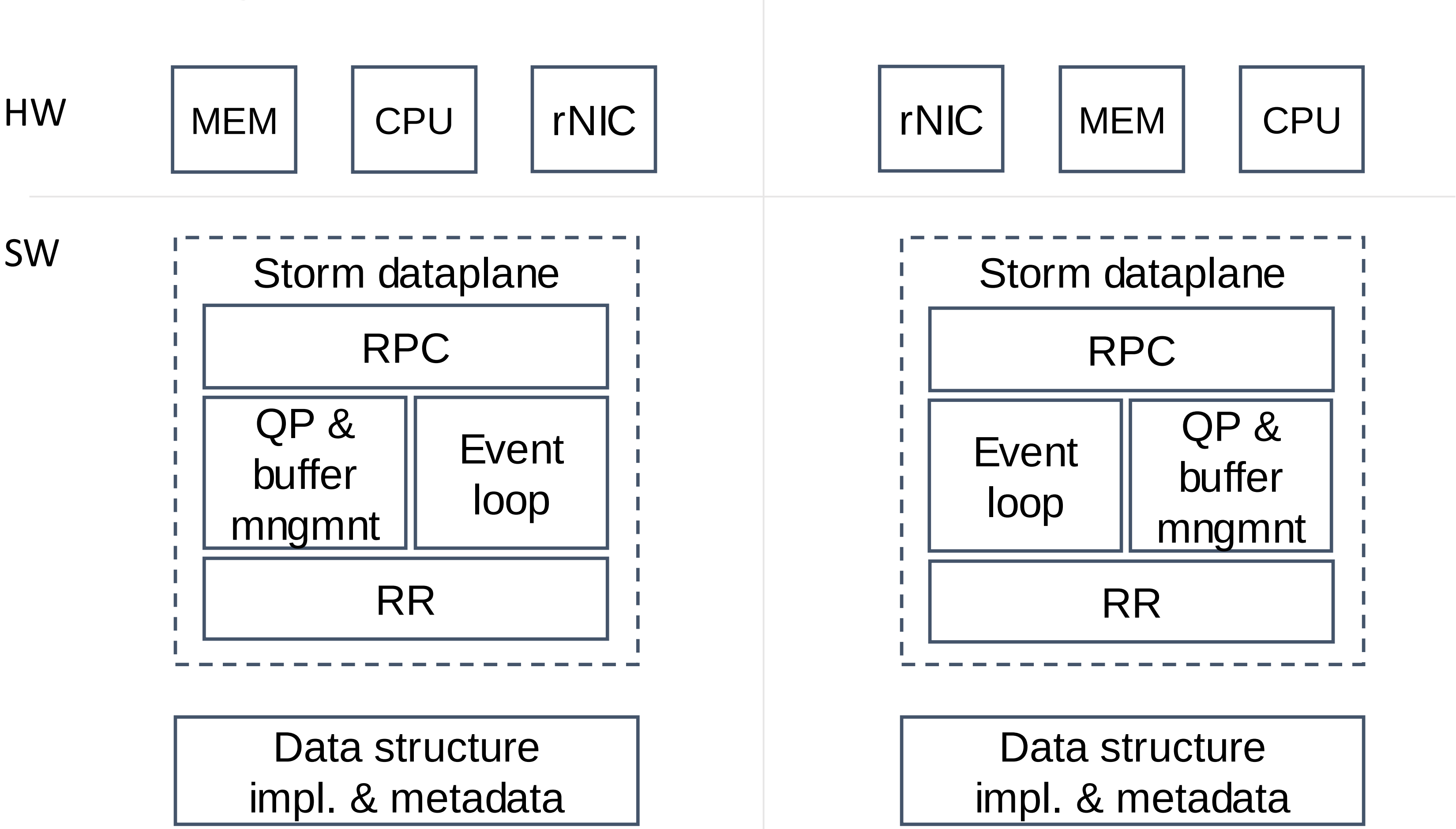
2. Use one-sided reads whenever possible
    - First one-sided, then RPC (*one-two-sided*)
    - RPC also implemented using one-sided writes

3. Leverage abundant memory
    - Cache metadata and/or reduce collisions in hash tables

4. Minimize translation & protection state
    - Use contiguous physical allocation

5. And don't forget to deploy on new hardware!!!

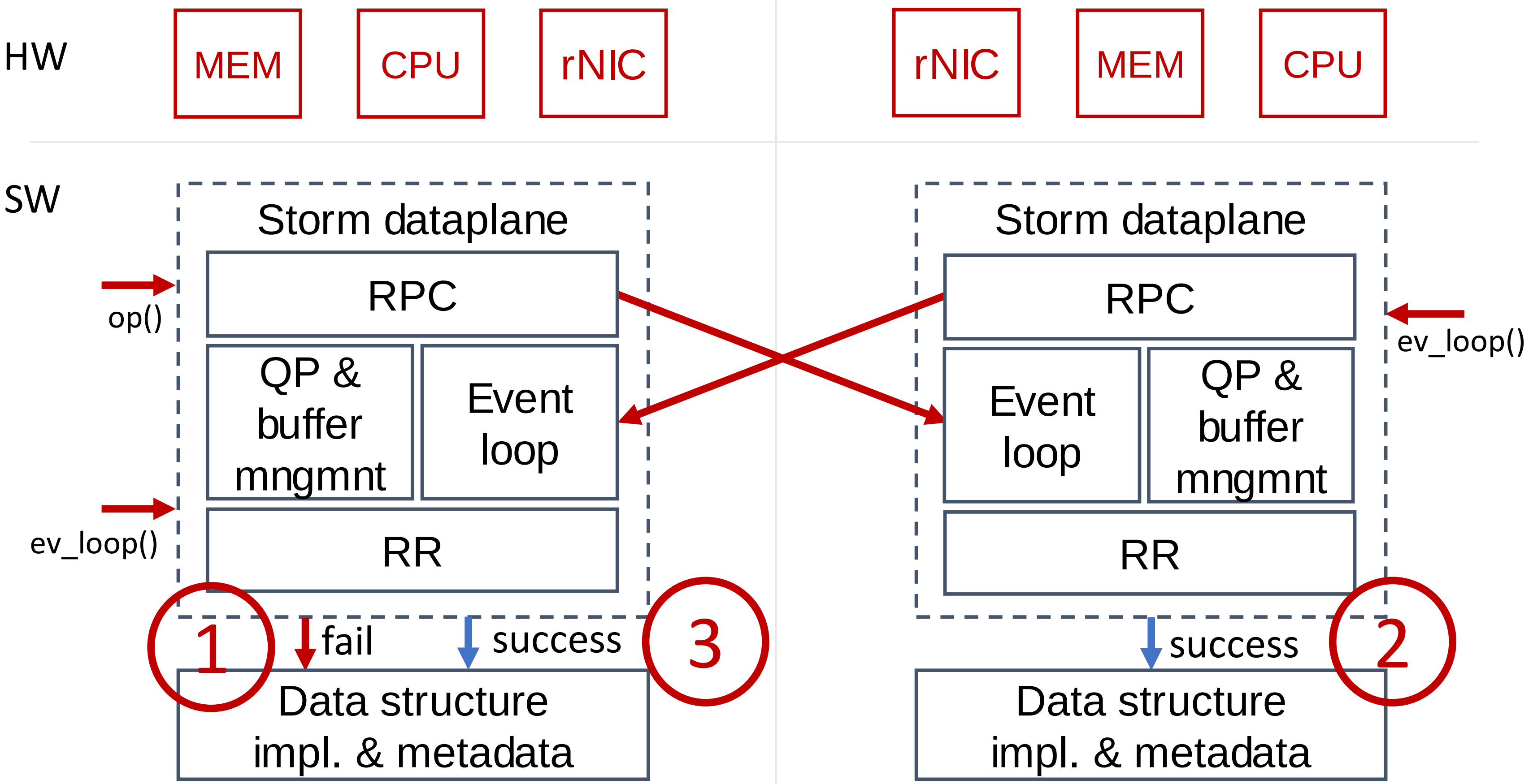
Storm design



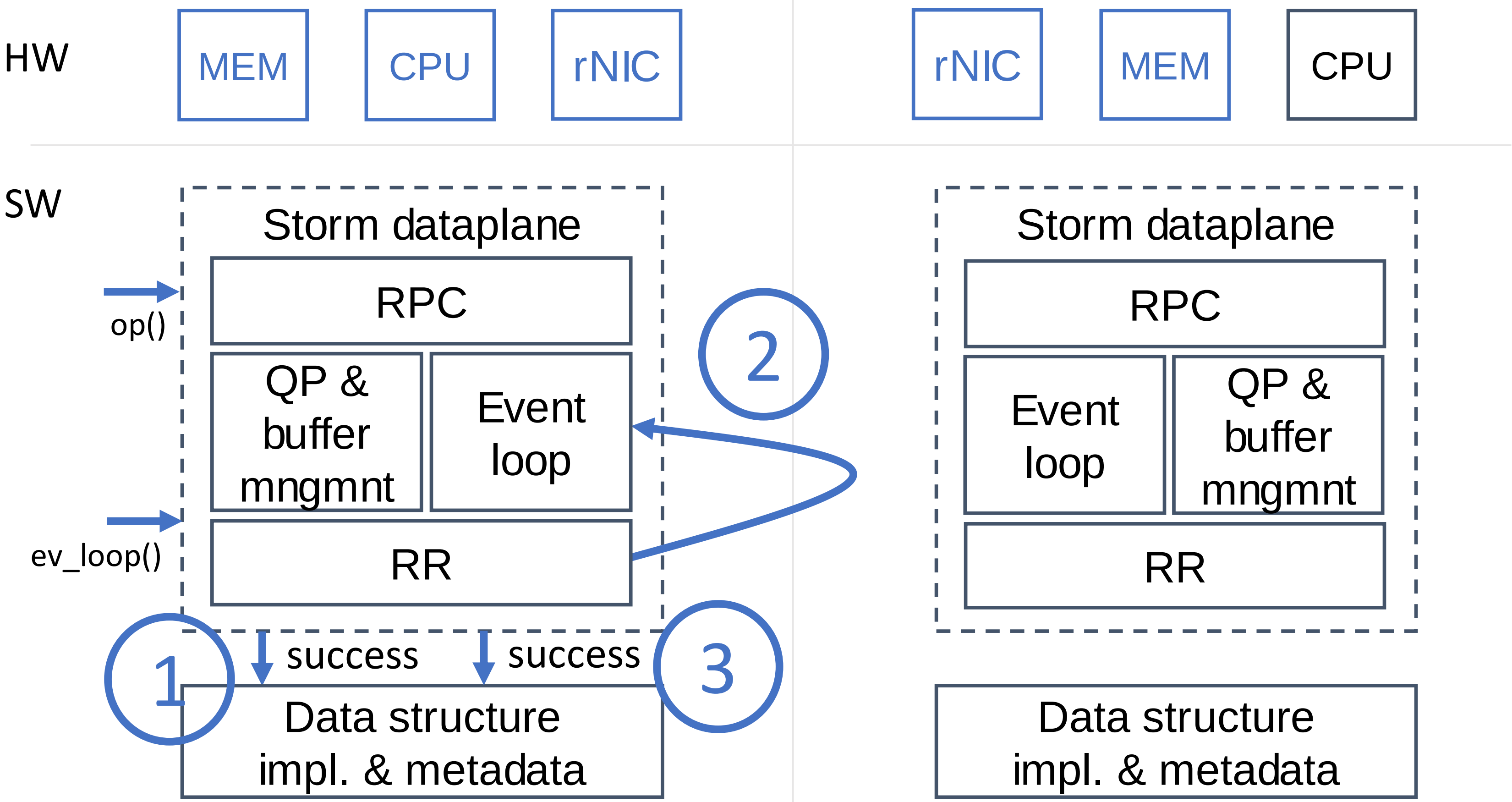
Division of responsibilities:

- **Storm DP only understands RDMA connections and memory regions**
- **Data structure understands data layout and implements metadata caching**

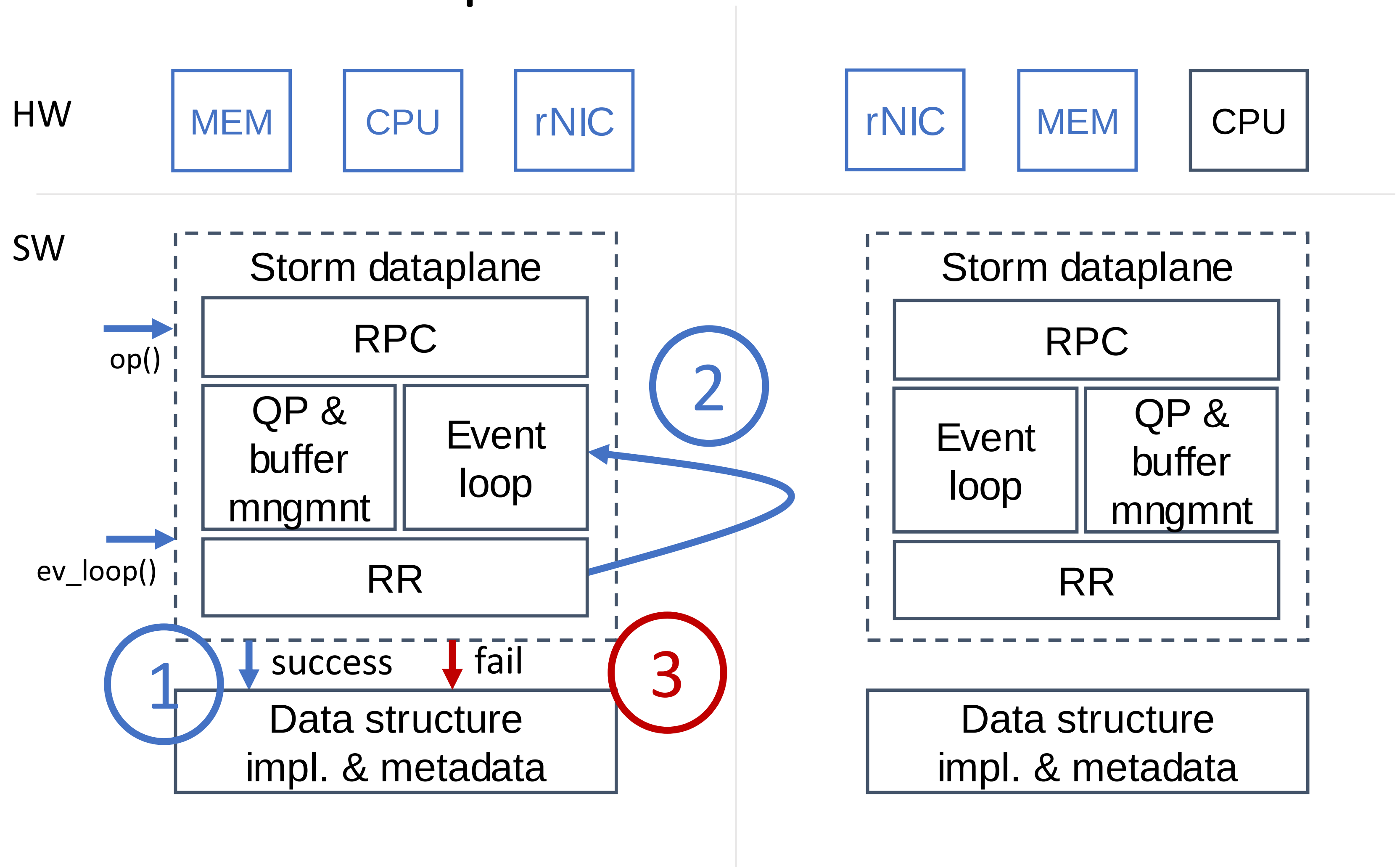
Two-sided operations



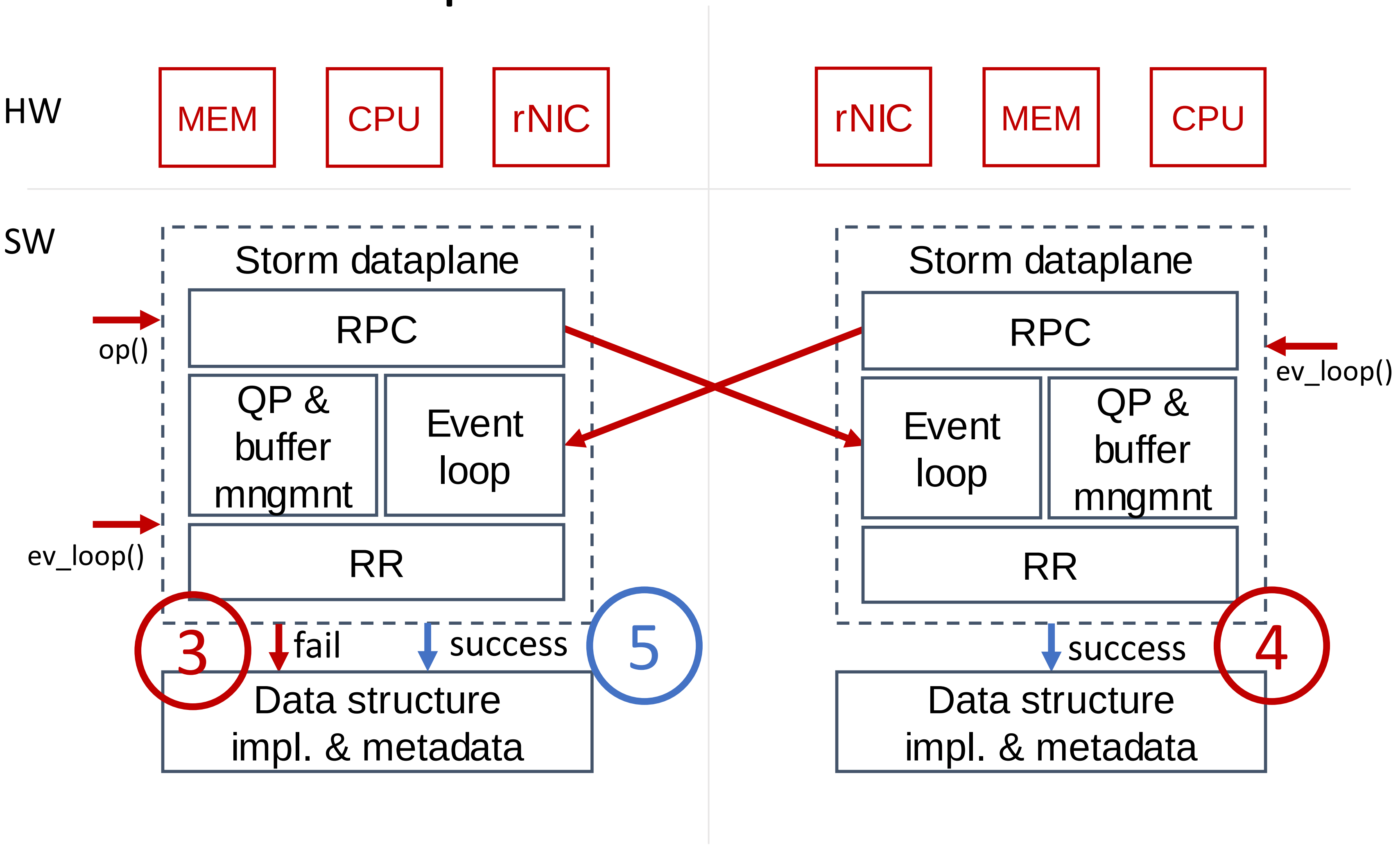
One-sided operations



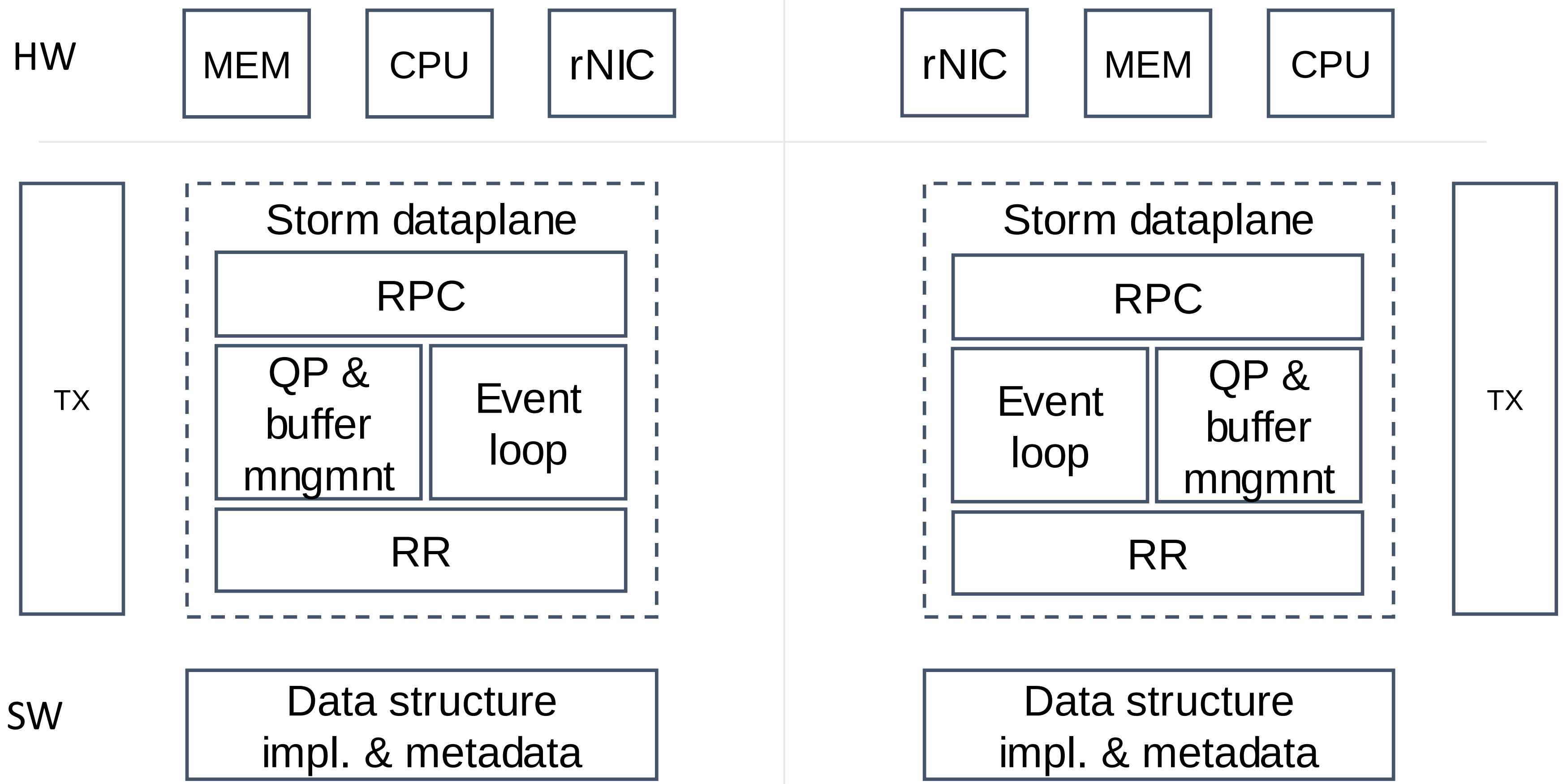
One-two-sided operations



One-two-sided operations



Distributed transactions



Support for concurrent data structures using transactions

Data structure API (three callbacks)

- RPC handler
  - Processing two-sided communication
  - Implements complex paths, such as acquiring locks and commits
- Lookup start
  - Check if address is known (cached) or we can guess
  - If yes, leverage RDMA read
- Lookup end
  - Check if data is valid and cache for future use

Storm implementation & exp. setup

- 13k LOC of C++, w/o MICA modifications [Lim'14]
- HPC cluster w/ 32 Dell machines
  - High-speed Infiniband network (100Gbps)
  - Mellanox ConnectX-4 – similar in perf to CX5
  - Emulation of 3-4x larger clusters possible on Storm
- Benchmarks:
  - Key-value transactional micro-benchmark
  - Telecommunication Application Transaction Processing (TATP)

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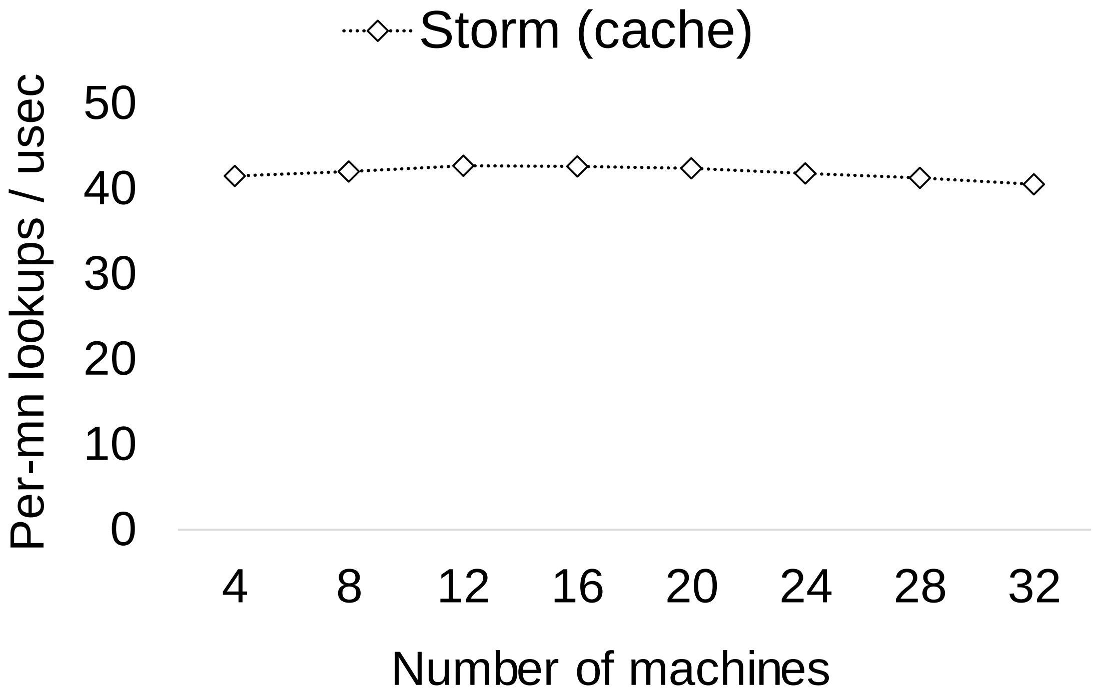
Baselines

- Emulated FARM (modified: Lock-free_FaRM)
  - No connection sharing, 1KB “neighborhoods”
- eRPC
  - With and without active congestion control
- LITE (modified: Async_LITE)
  - Added support for asynchronous operations

Storm results

- Single-lookup workload
  - 128B KV pairs, 100M items, 20 threads per mn



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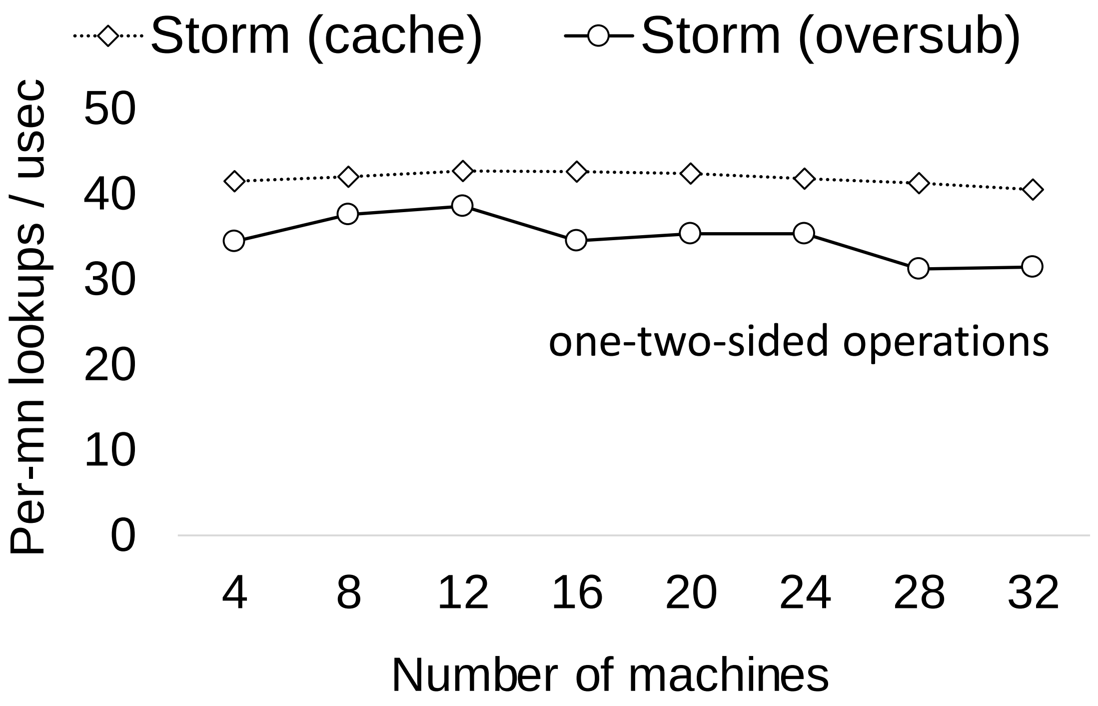
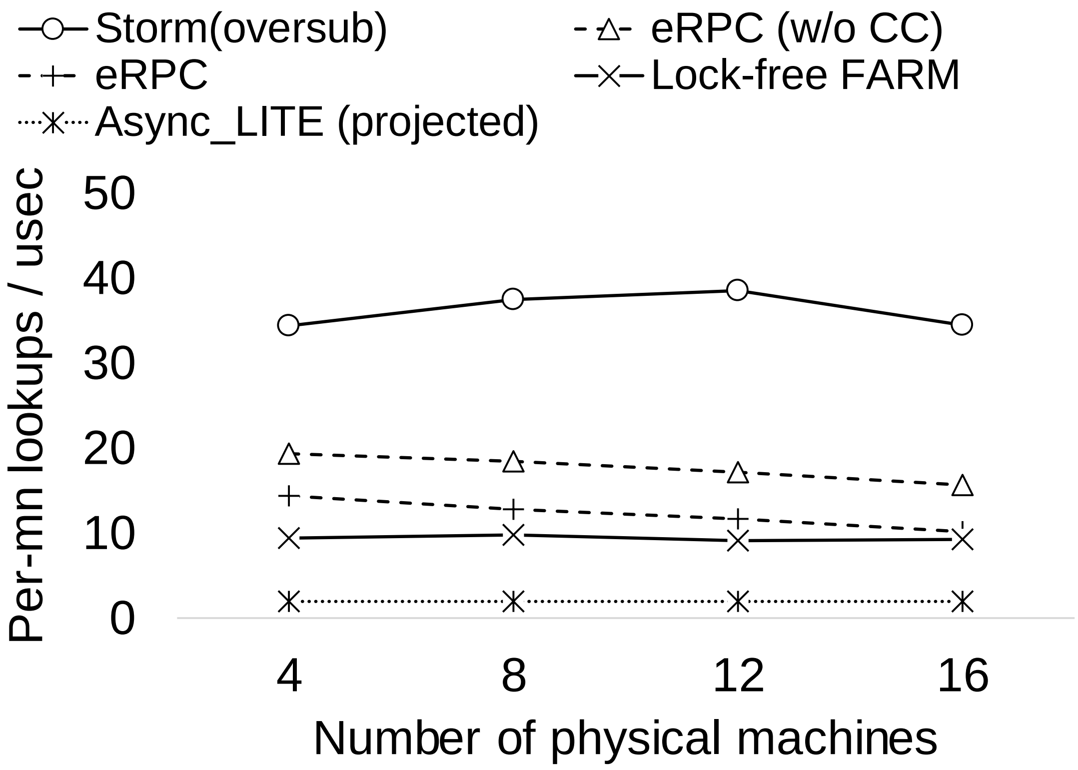




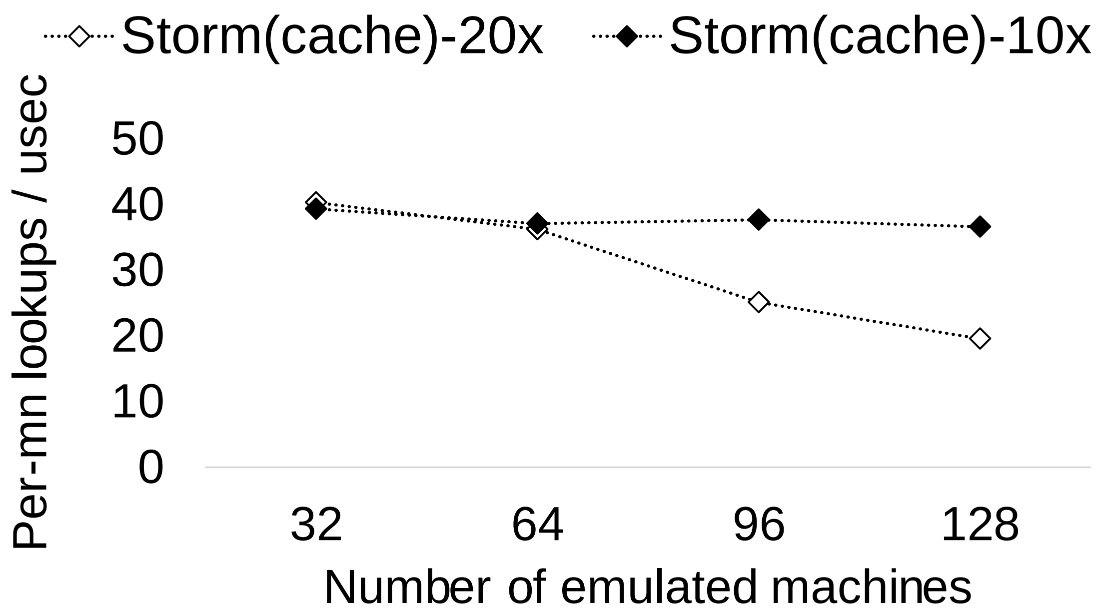
- TATP: 11.8 million per node with Storm (oversub)

Does Storm scale well?

- Storm scales well up to 64mn

- Reduce thread count by 2x
  - 2x fewer threads → 2x fewer QPs

- Do we need more than 10 threads?
  - Lock-free QP sharing



Conclusion & future work

- RDMA datacenter users should get a hardware upgrade
  - More scalable hardware available
  - Take advantage of one-sided primitives

- Leverage caching and oversubscription (in hash tables)
  - One-sided read in the common case

- Ongoing research threads:
  - Designing “far” memory data structures (HotOS’19)
  - Memory allocator for repurposing unused memory
  - Lock-free mechanisms for QP sharing