All You Need is a Concurrent Data Structure

Hagit Attiya

Concurrent Data Structures

- Constructs for **efficiently storing and retrieving data**
- **Different types**: lists, hash tables, trees, queues, … specified with an **interface** and expected behavior
- Can be put together to build other data structures

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Fuel many **multiprocessing software systems**

- Specifically, **multi-threaded** and **multi-core** environments or even **geo-replicated** systems

Jargon Alert

They say **key-value store**

We say **register(s)**

Jargon Alert

They say **index**

We say **search structure**

monetdb

RocksDB

LEVELDB

Jargon Alert

They say **concurrency package**

We say **synchronization primitives**

Me & My Research

Approaches

Fine-grained locking

No locking

Transactional memory

Wide-area replication

Methodologies

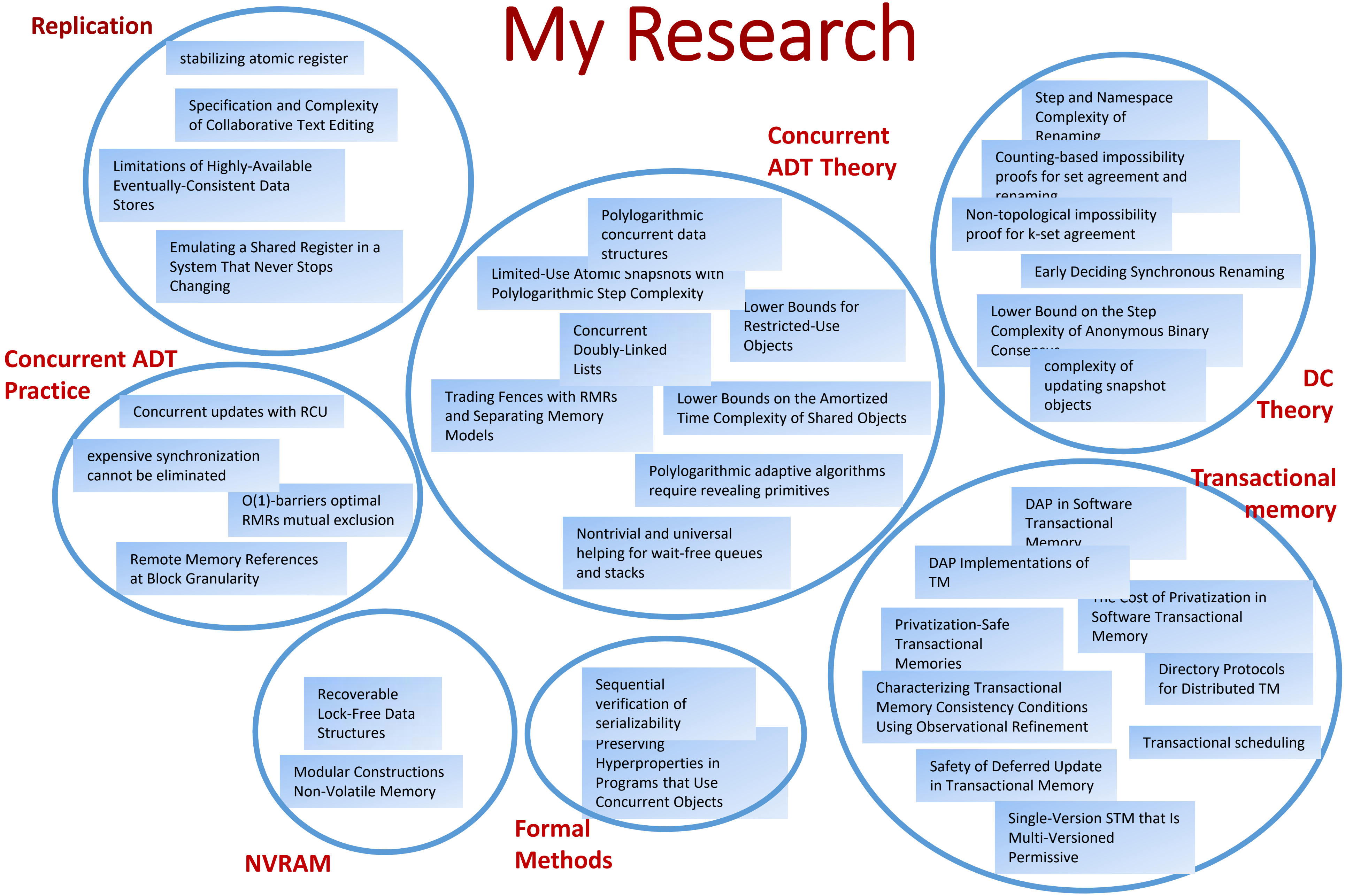
Theory (algorithms, lower bounds)

Practice

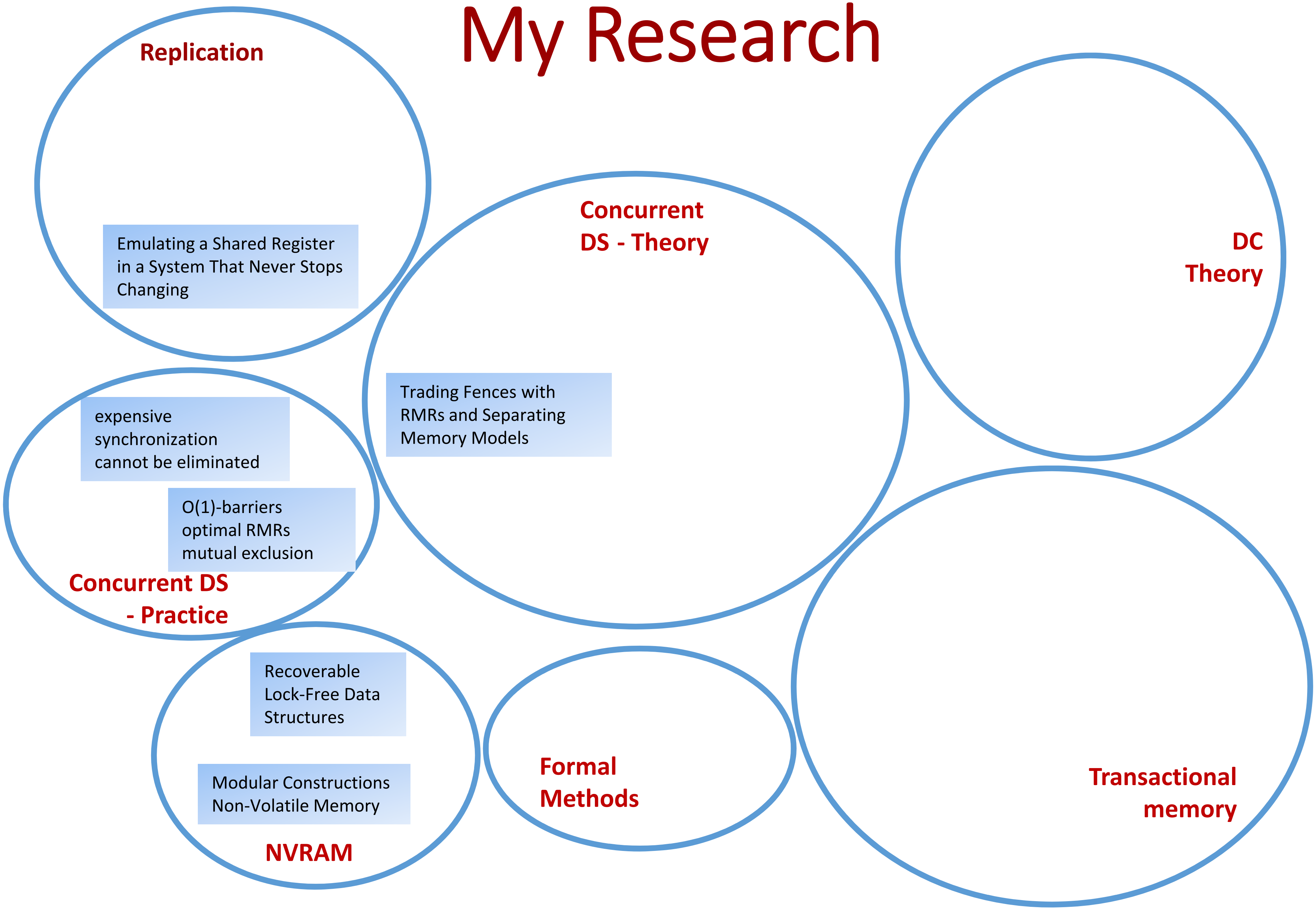
Formal methods (proof methods, specifications)

Related core theoretical questions in distributed computing

My Research


Replication
stabilizing atomic register
Specification and Complexity of Collaborative Text Editing
Limitations of Highly-Available Eventually-Consistent Data Stores
Emulating a Shared Register in a System That Never Stops Changing
Concurrent ADT Theory
Polylogarithmic concurrent data structures
Limited-Use Atomic Snapshots with Polylogarithmic Step Complexity
Lower Bounds for Restricted-Use Objects
Concurrent Doubly-Linked Lists
Trading Fences with RMRs and Separating Memory Models
Lower Bounds on the Amortized Time Complexity of Shared Objects
Polylogarithmic adaptive algorithms require revealing primitives
Nontrivial and universal helping for wait-free queues and stacks
DC Theory
Step and Namespace Complexity of Renaming
Counting-based impossibility proofs for set agreement and renaming
Non-topological impossibility proof for k-set agreement
Early Deciding Synchronous Renaming
Lower Bound on the Step Complexity of Anonymous Binary Conse
complexity of updating snapshot objects
Concurrent ADT Practice
Concurrent updates with RCU
expensive synchronization cannot be eliminated
O(1)-barriers optimal RMRs mutual exclusion
Remote Memory References at Block Granularity
Transactional memory
DAP in Software Transactional Memory
DAP Implementations of TM
The Cost of Privatization in Software Transactional Memory
Privatization-Safe Transactional Memories
Directory Protocols for Distributed TM
Characterizing Transactional Memory Consistency Conditions Using Observational Refinement
Transactional scheduling
Safety of Deferred Update in Transactional Memory
Single-Version STM that Is Multi-Versioned Permissive
NVRAM
Recoverable Lock-Free Data Structures
Modular Constructions Non-Volatile Memory
Formal Methods
Sequential verification of serializability
Preserving Hyperproperties in Programs that Use Concurrent Objects

My Research



Replication
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Concurrent DS - Theory
Trading Fences with RMRs and Separating Memory Models
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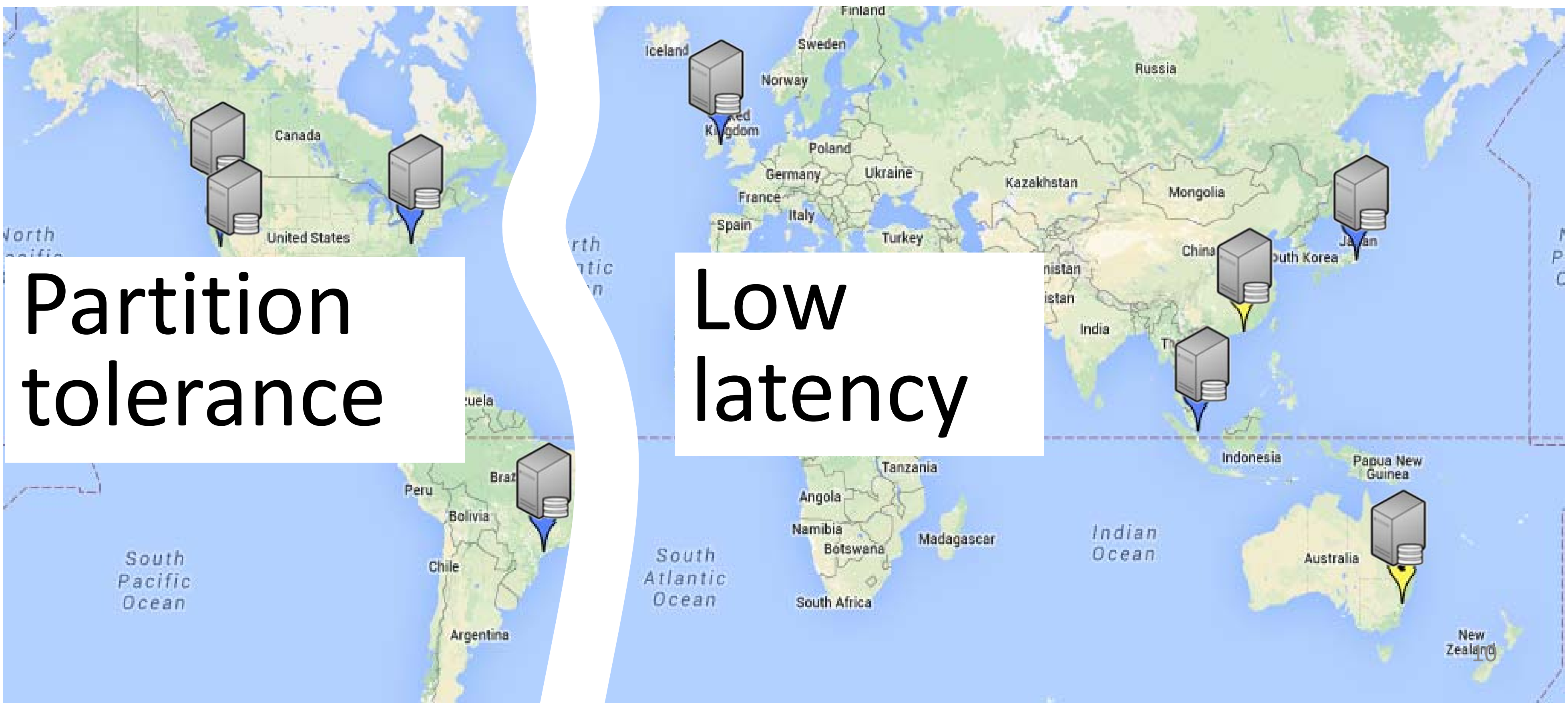
Key-Value Store

Geo-distributed systems powering Google, Facebook, Amazon, etc.

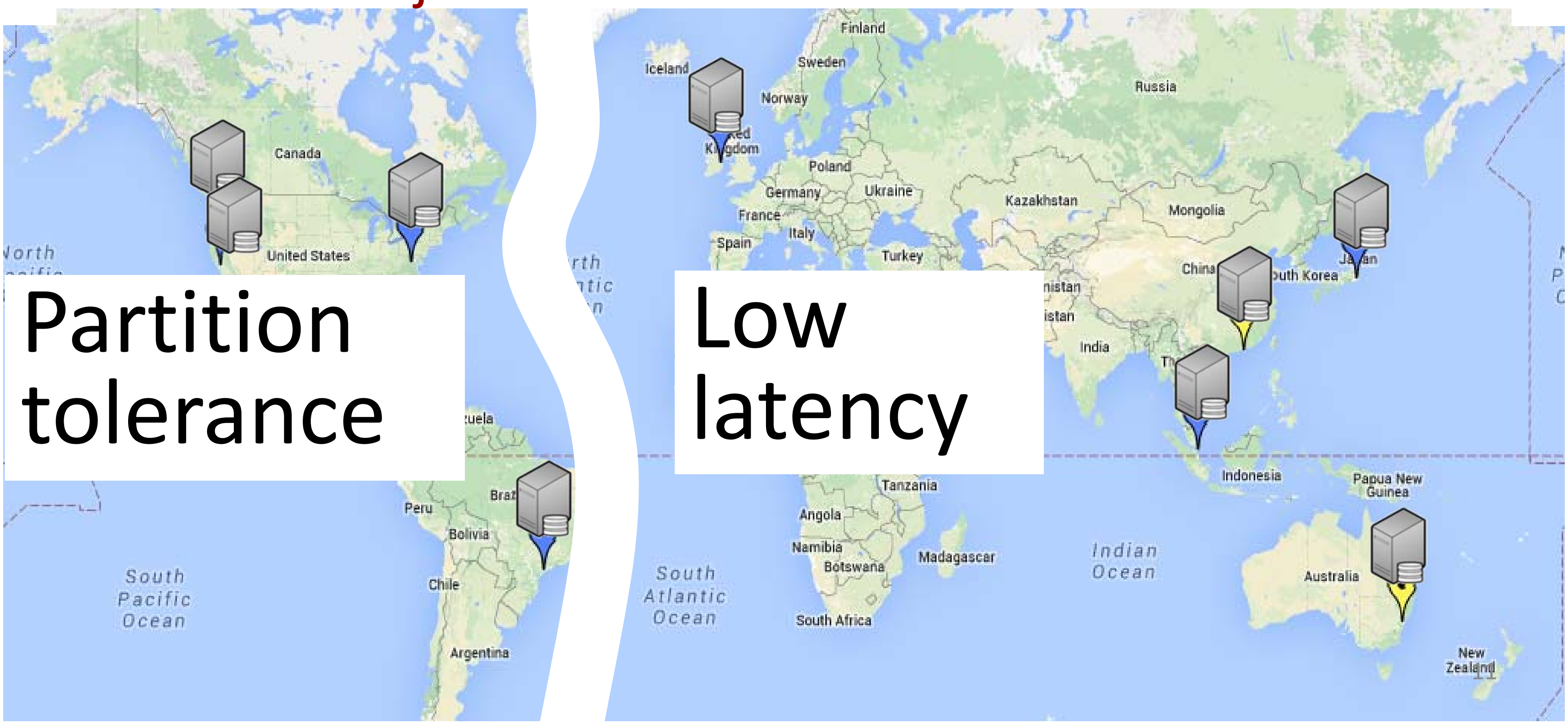


Key-Value Store: Our Approach

Simulate a register by keeping copies (replicas) of its value

Keep replicas consistent by exchanging messages

Churn: nodes join and leave at various times



Key-Value Store with Constant Churn

CCReg: First shared register simulation that allows **churn to continue forever**, and system size to fluctuate

Ensures **reads and writes complete**, and new nodes can join and access the simulated register

Churn assumption: while a message is in transit, the number of nodes entering or leaving is

$\leq \alpha \times$ number of nodes when the message was sent

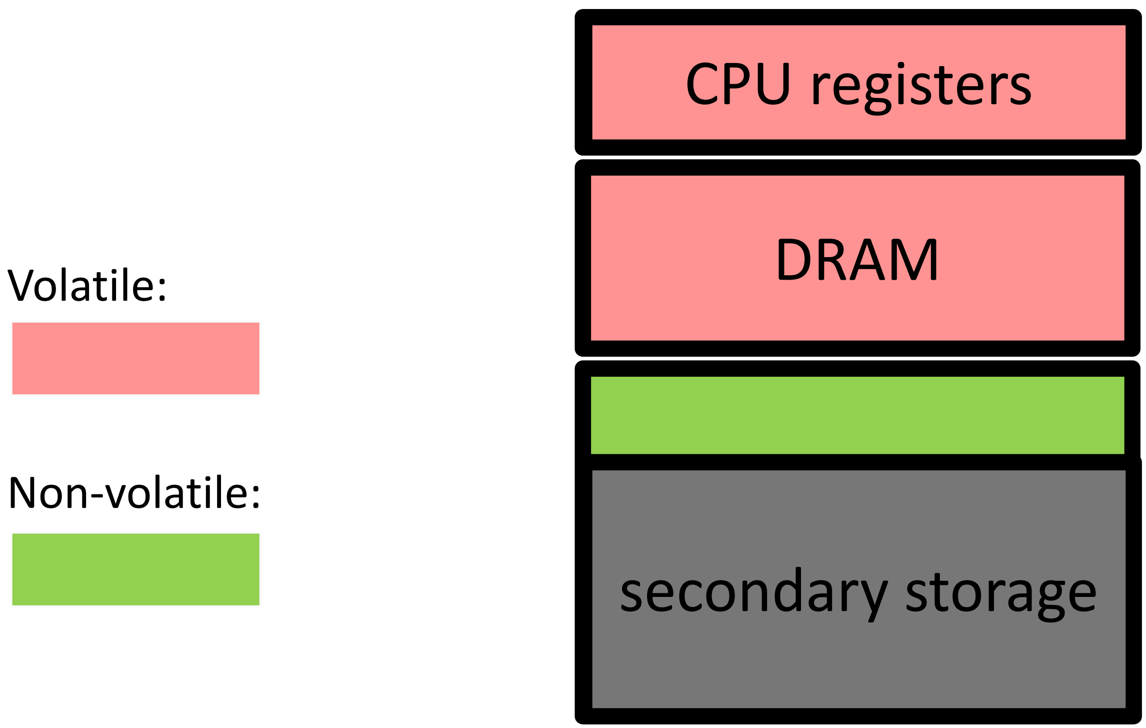
Key-Value Store with Constant Churn

Possible projects:

- Implement CCReg & its extension for Byzantine failures
- Simplify & improve bounds
- Ensure safety when churn assumption does not hold

Non-volatile RAM: Paradigm Shift

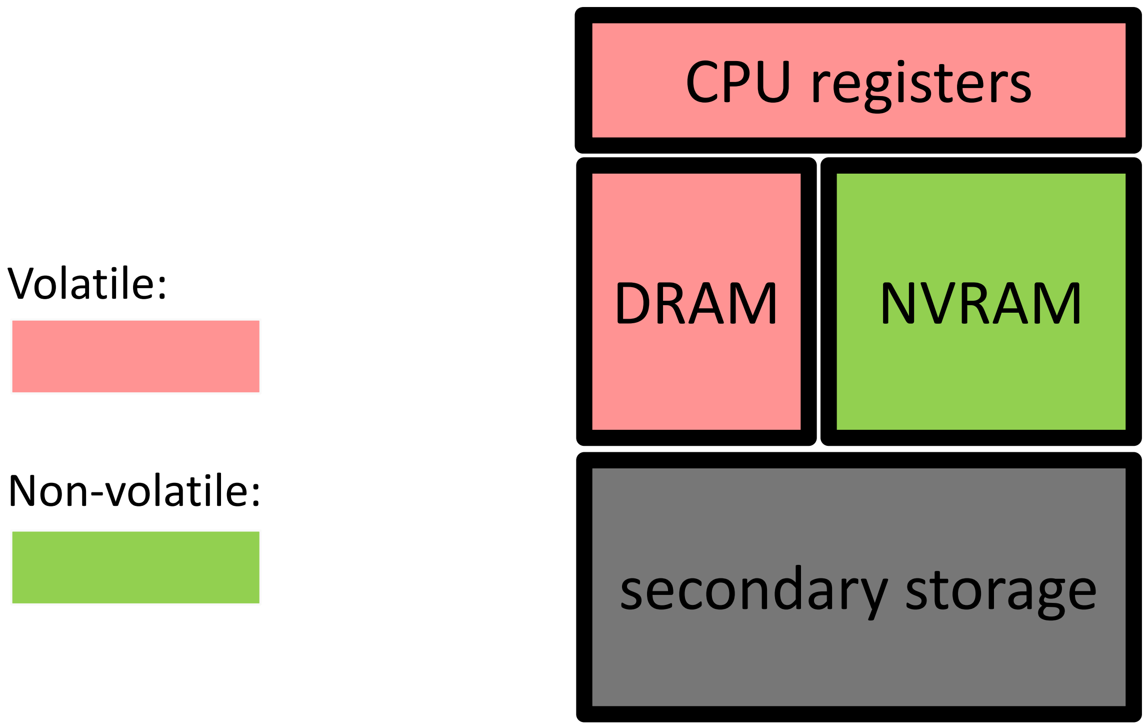
Discard and rebuild



(conventional)

Non-volatile RAM: Paradigm Shift

Recover and reuse



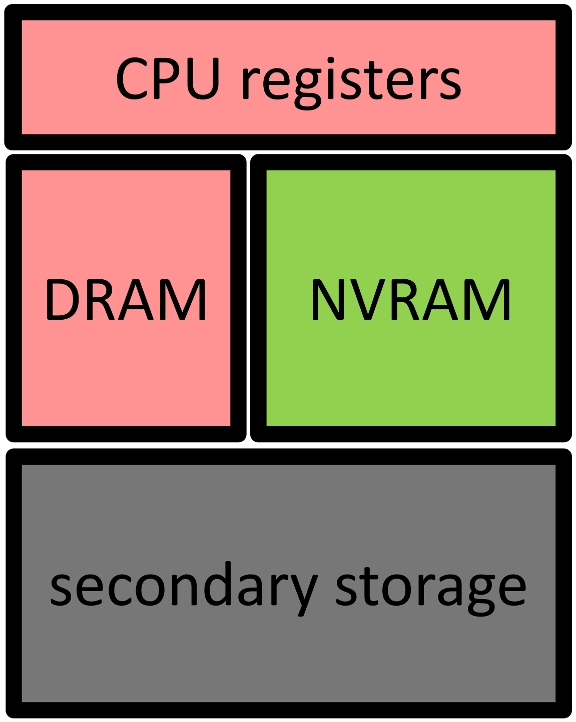
(future)

Non-volatile RAM: Paradigm Shift

We presented

* New definitions

* Simulations of **recoverable** read/write, compare-and-swap, test-and-set operations



Possible projects

* Persistence ordering and consistency ordering

* System support

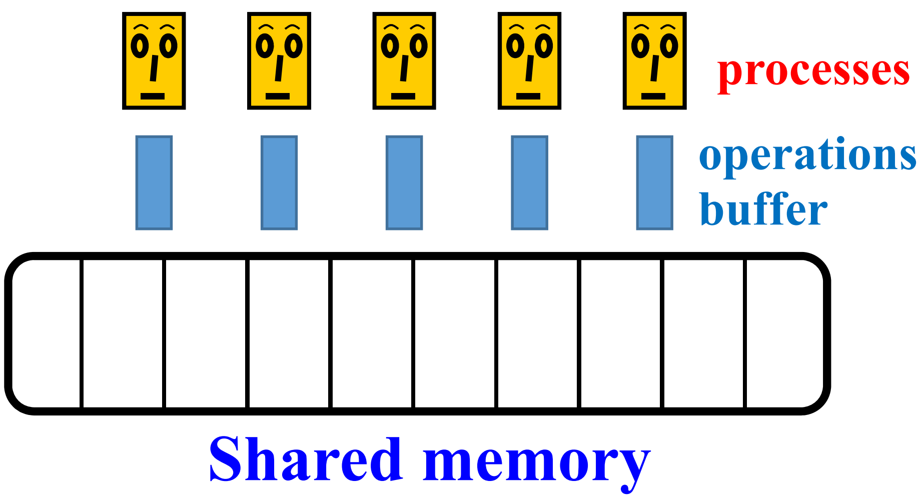
* Differences between AMD & Intel require to abstract the architecture

Out-of-Order Execution

Architectures ccompensate for slow writes by **allowing reads to bypass earlier writes** that access a different location (TSO) $\Rightarrow$ harms mutual exclusion algorithms

Avoid reordering with slow **fences**

We proved one fence is needed



Out-of-Order Execution & Caching

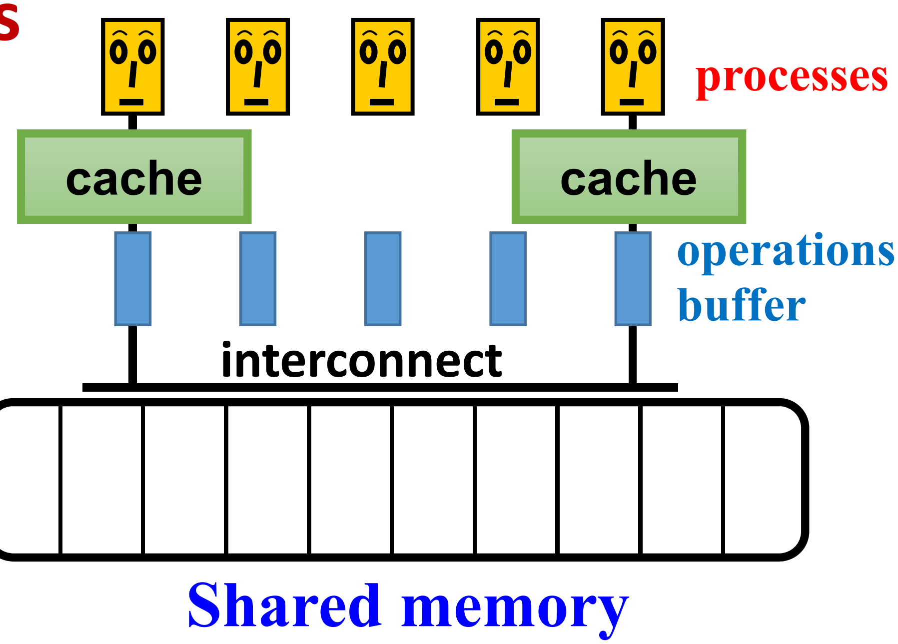
Architectures ccompensate for slow writes by **allowing reads to bypass earlier writes** that access a different location (TSO) $\Rightarrow$ harms mutual exclusion algorithms

Avoid reordering with slow **fences**

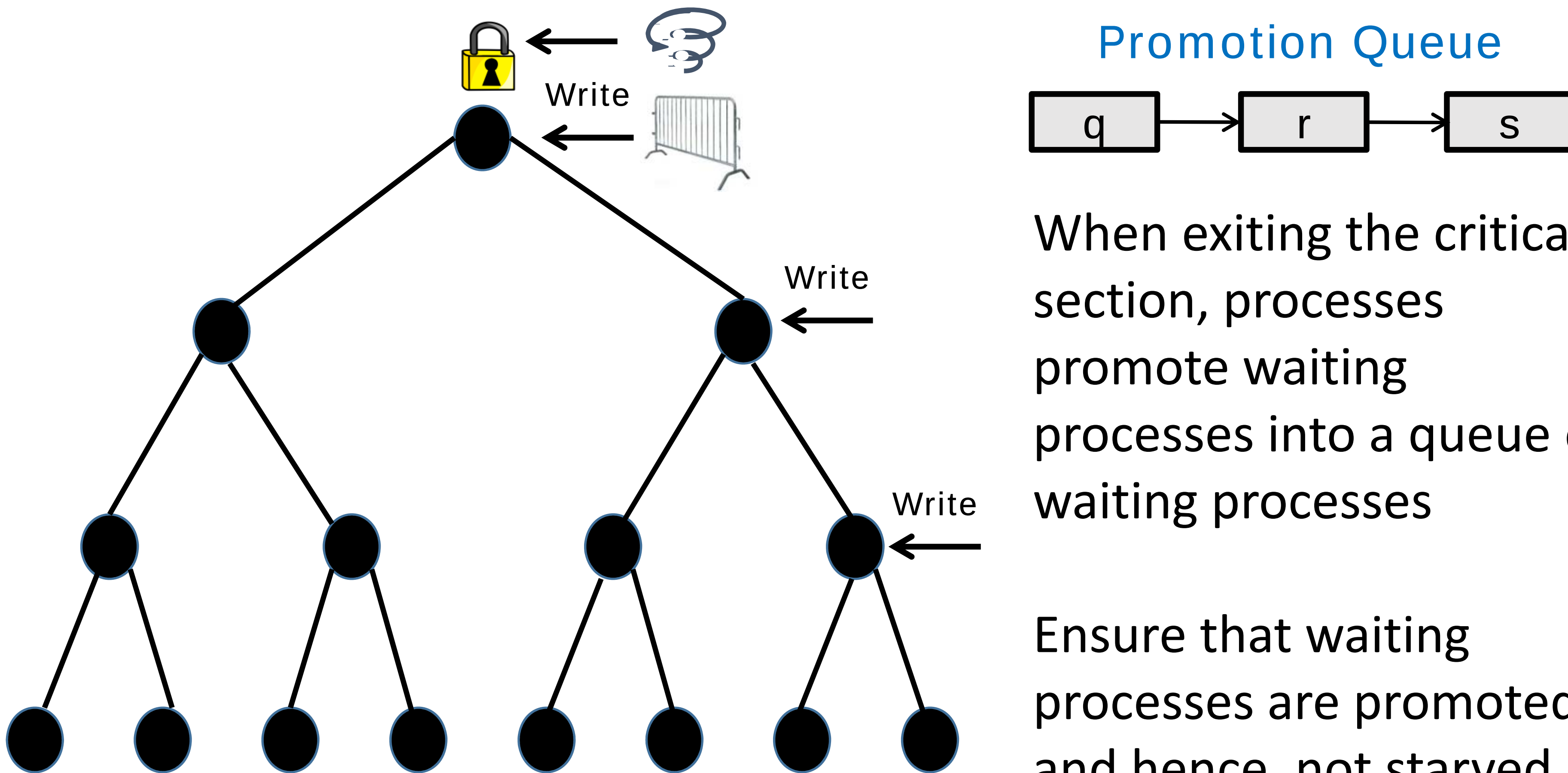
We proved one fence is needed

Reads from the cache are cheap

Remote reads are expensive



One-Fence Mutex: Entry Section



When exiting the critical section, processes promote waiting processes into a queue of waiting processes

Ensure that waiting processes are promoted, and hence, not starved

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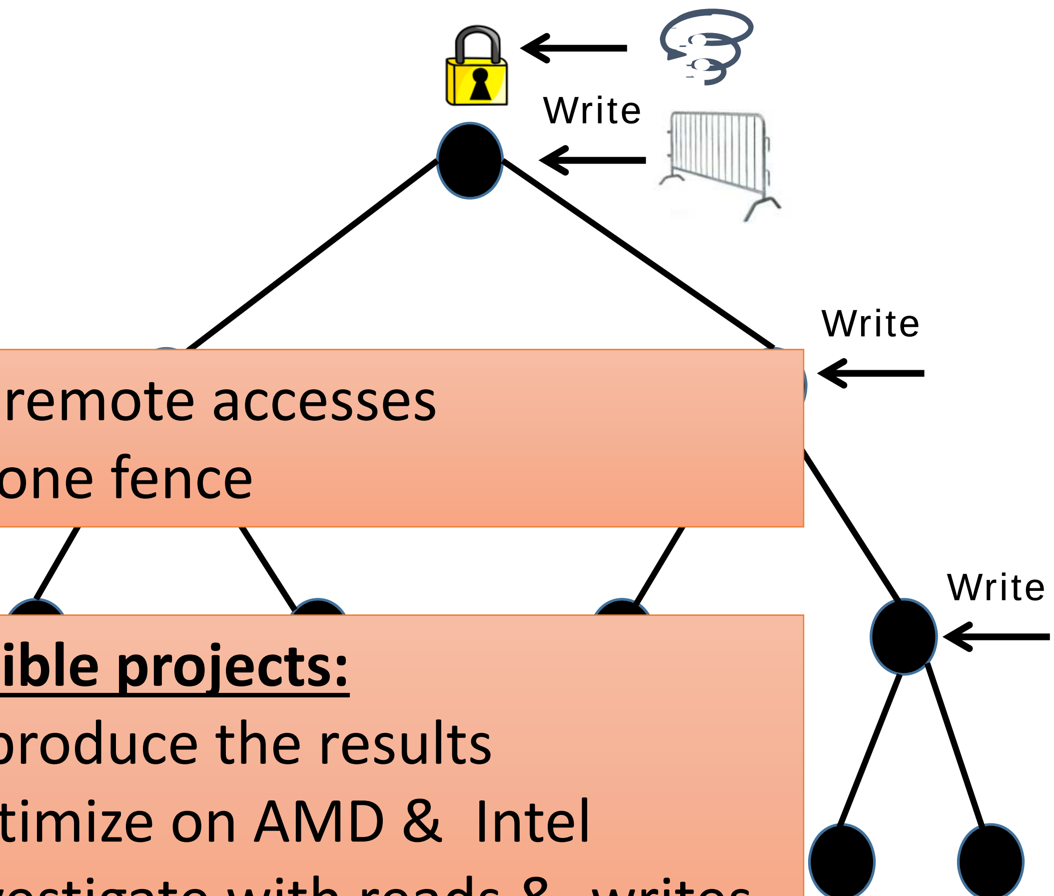
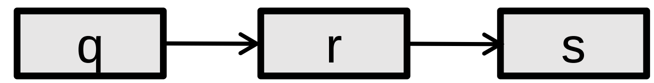


Few remote accesses
and one fence

<u>Possible projects:</u>
* reproduce the results
* optimize on AMD & Intel
* investigate with reads & writes

Promotion Queue



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