Performance-Optimal Read-only Transactions

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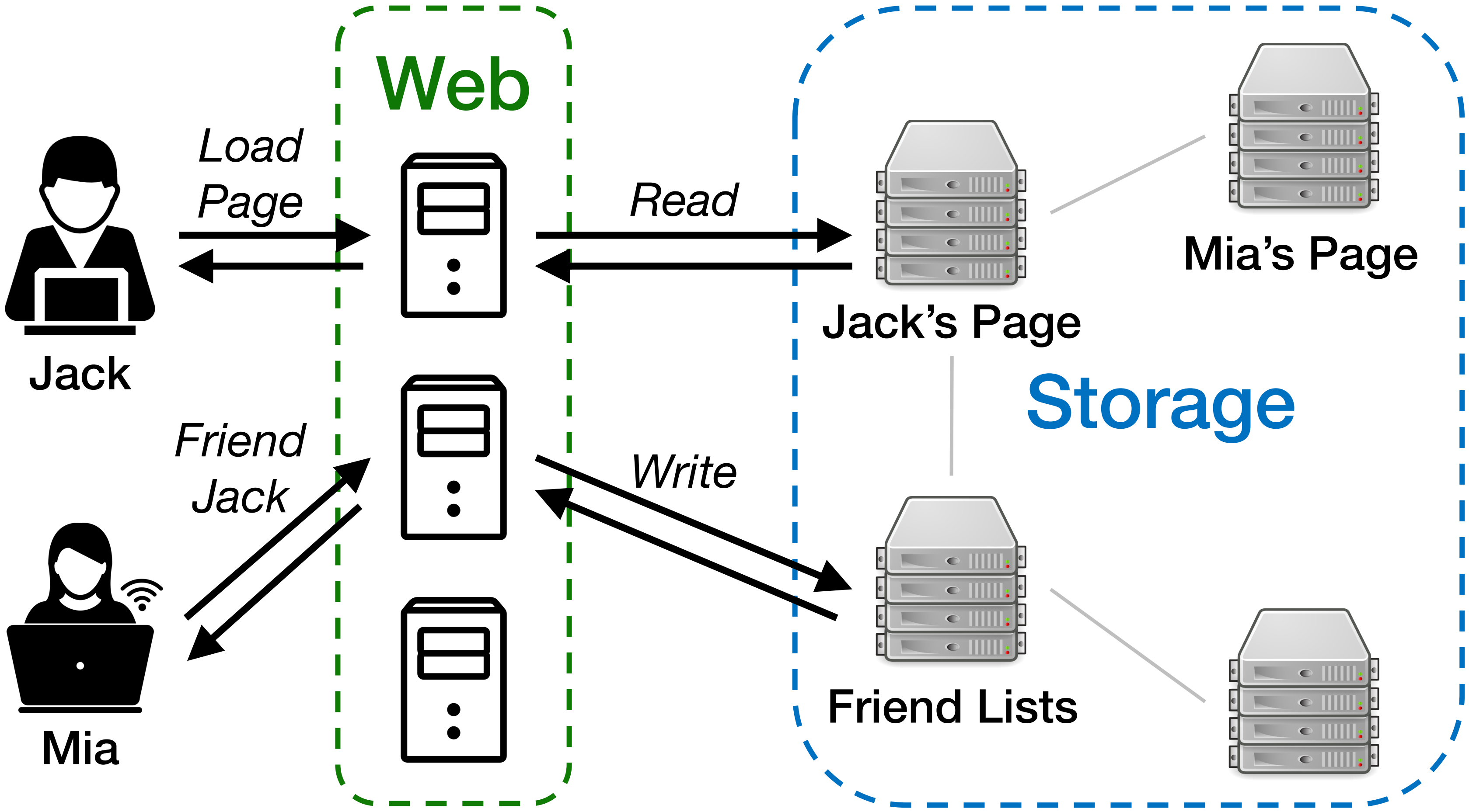
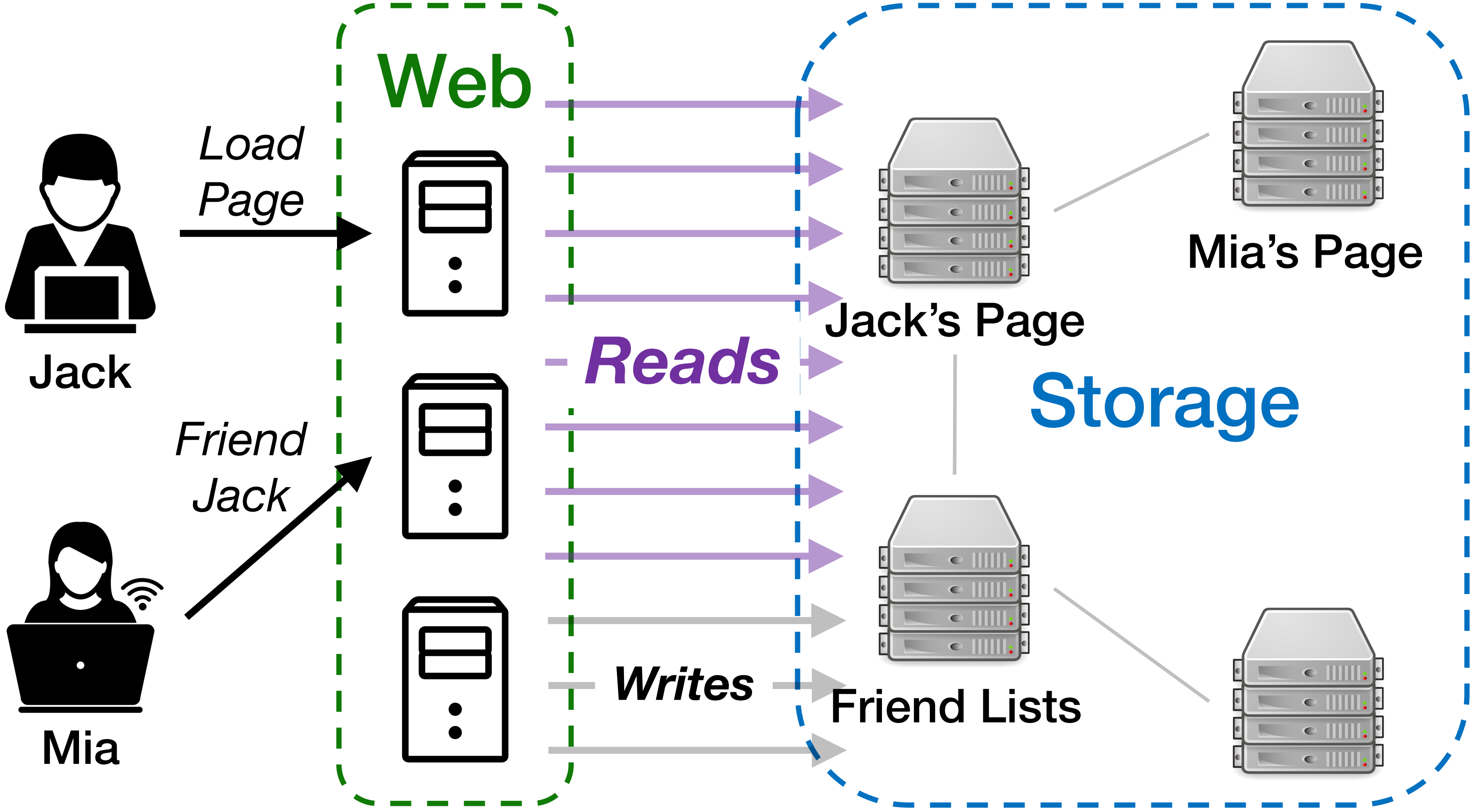
Distributed Storage Systems
Enable Today's Web Services



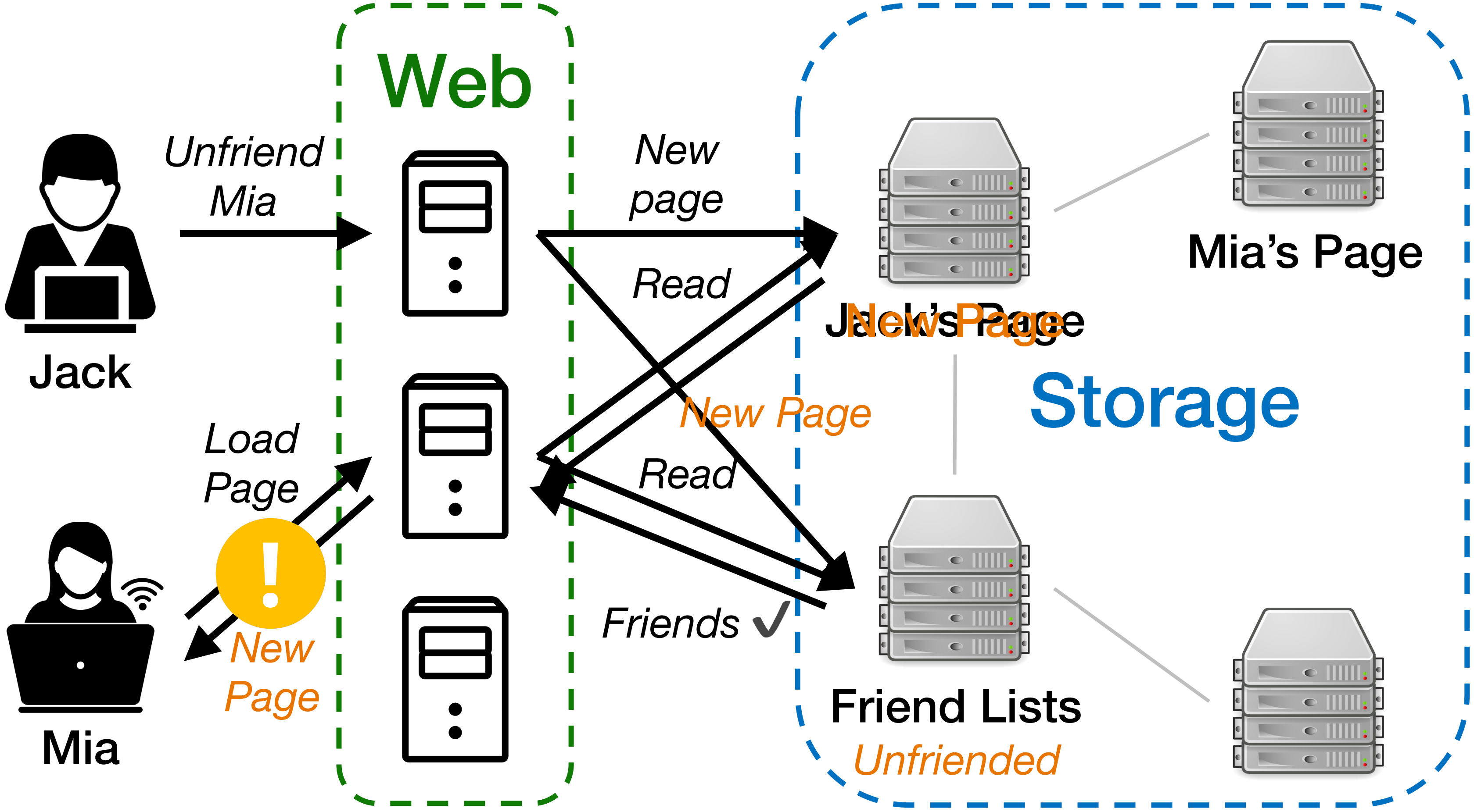
Distributed Storage Systems

Reads Dominate Workloads



Distributed Storage Systems

Simple Reads Are Insufficient



Read-Only Transactions

- A group of simple reads sent in parallel

- Do not write data
  - Writes are allowed in the system

- Coordinate a consistent view across shards

Coordination overhead causes higher latency and lower throughput

Goal:

Read-only transaction
performance as close
as possible to simple reads

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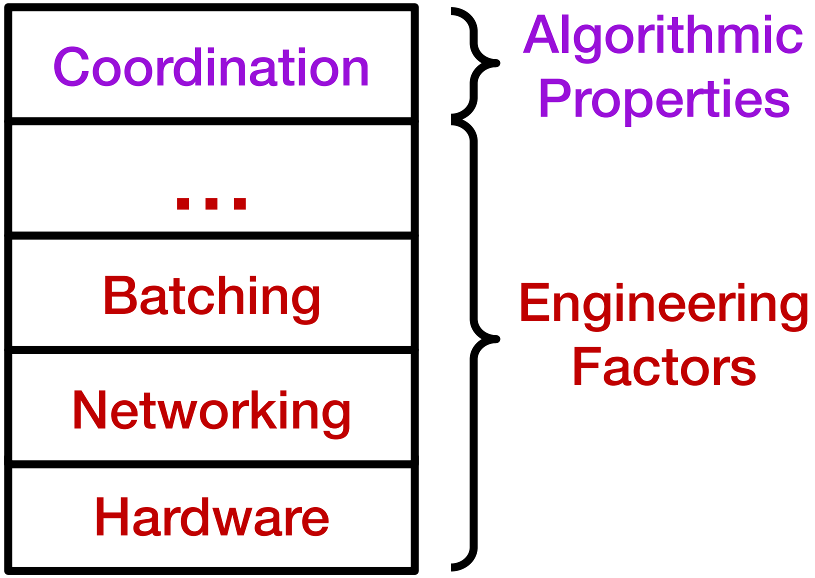
Read-only transaction performance as close as possible to simple reads

We answer:

- What does optimal performance mean for read-only transactions?
- When is optimal performance achievable?
- How can we design performance-optimal read-only transactions?

Performance Factors
Engineering vs. Algorithmic



Coordination

...

Batching

Networking

Hardware

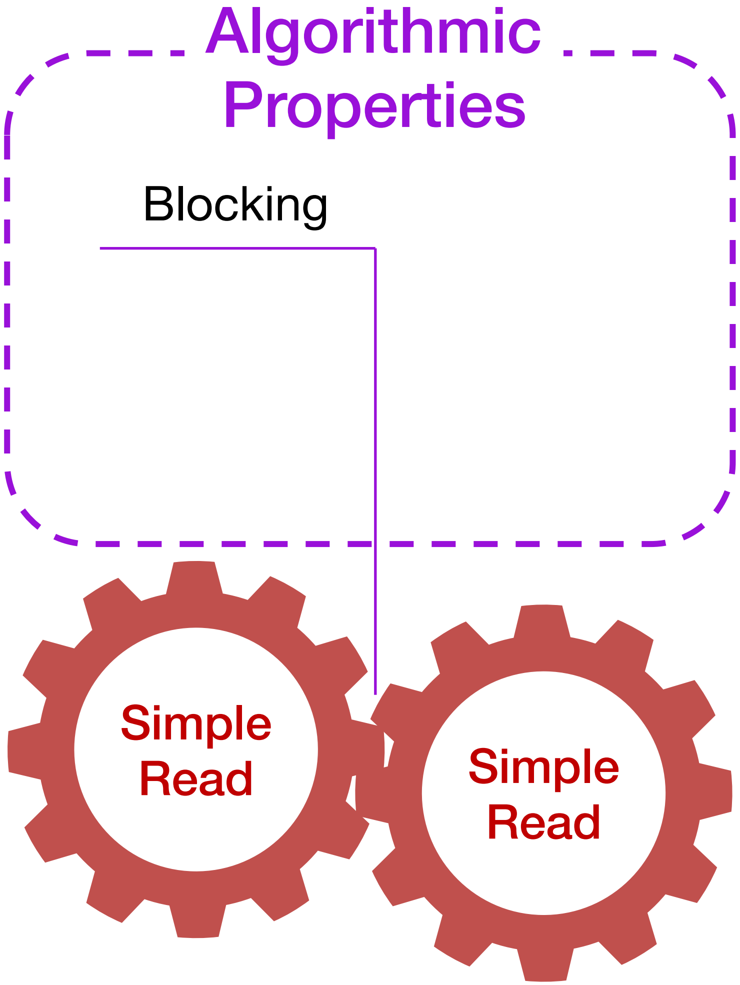
Algorithmic Properties

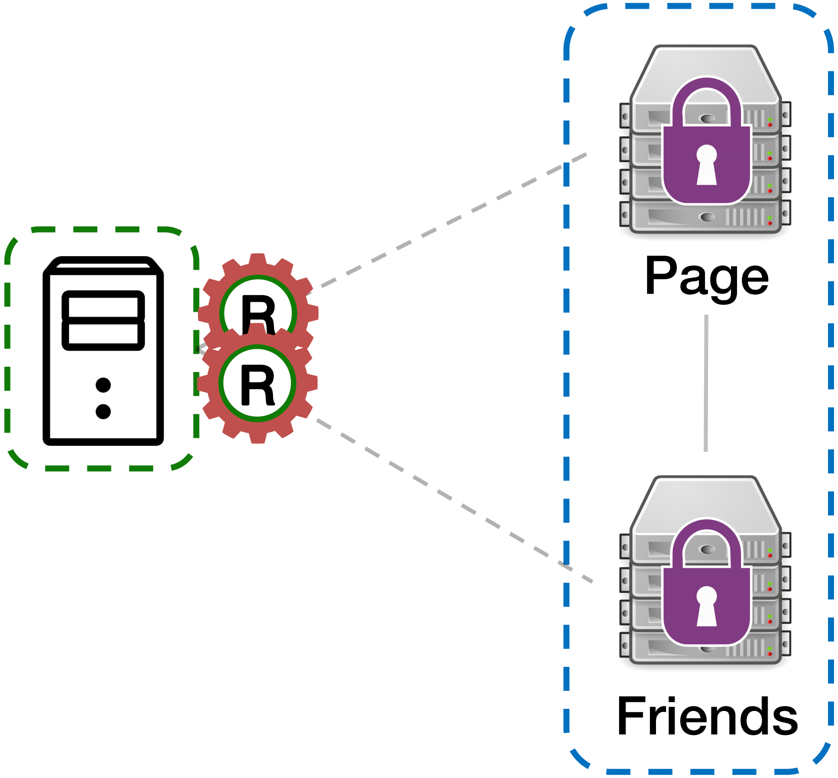
Engineering Factors

- Focus on the algorithmic properties due to coordination
- Equally impact simple reads and read-only transactions
- Abstract engineering factors by comparing to simple reads

Performance Factors

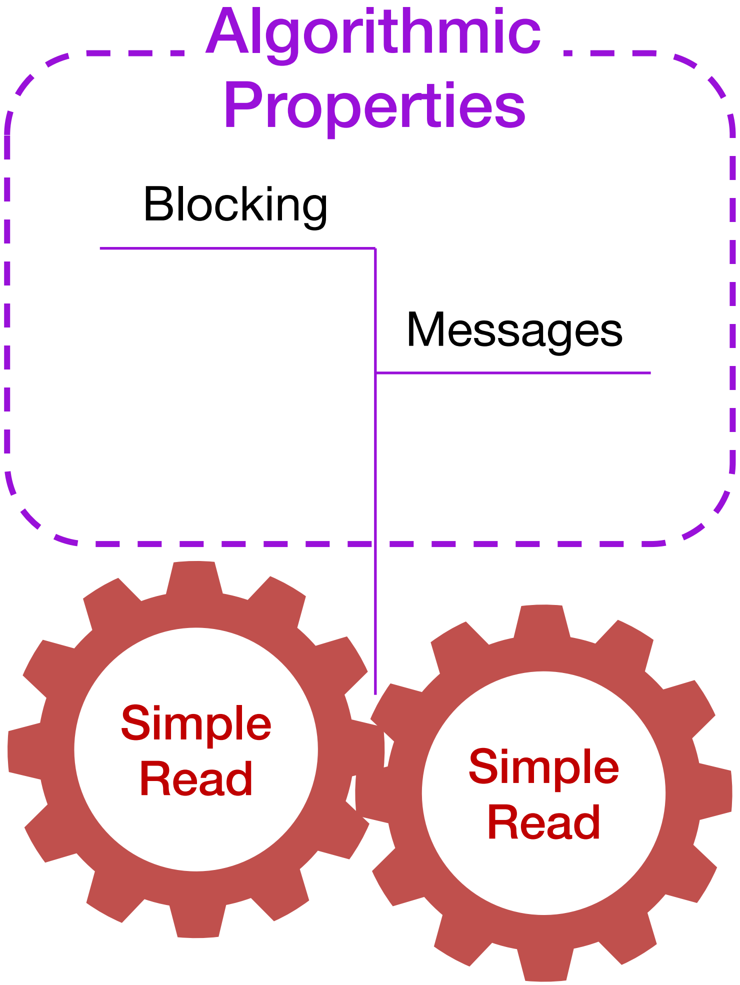
Algorithmic Properties

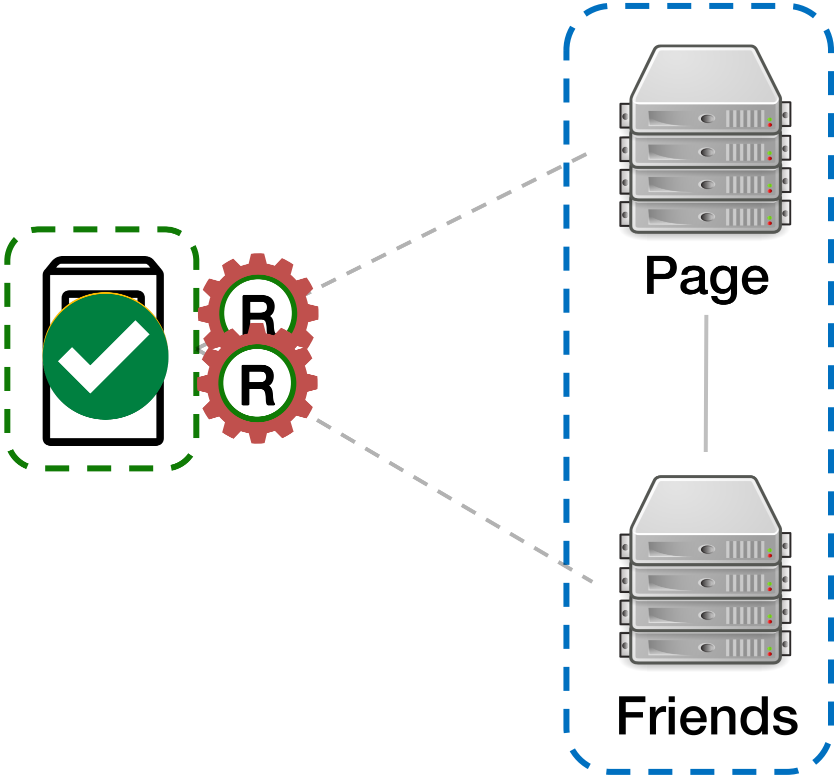




Performance Factors

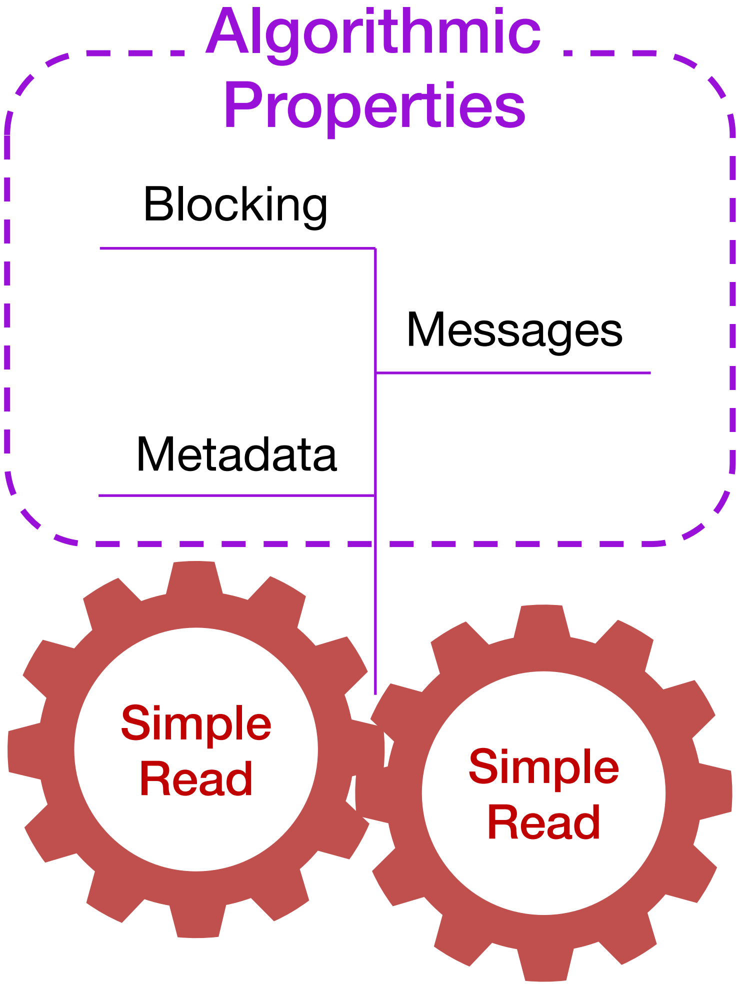
Algorithmic Properties

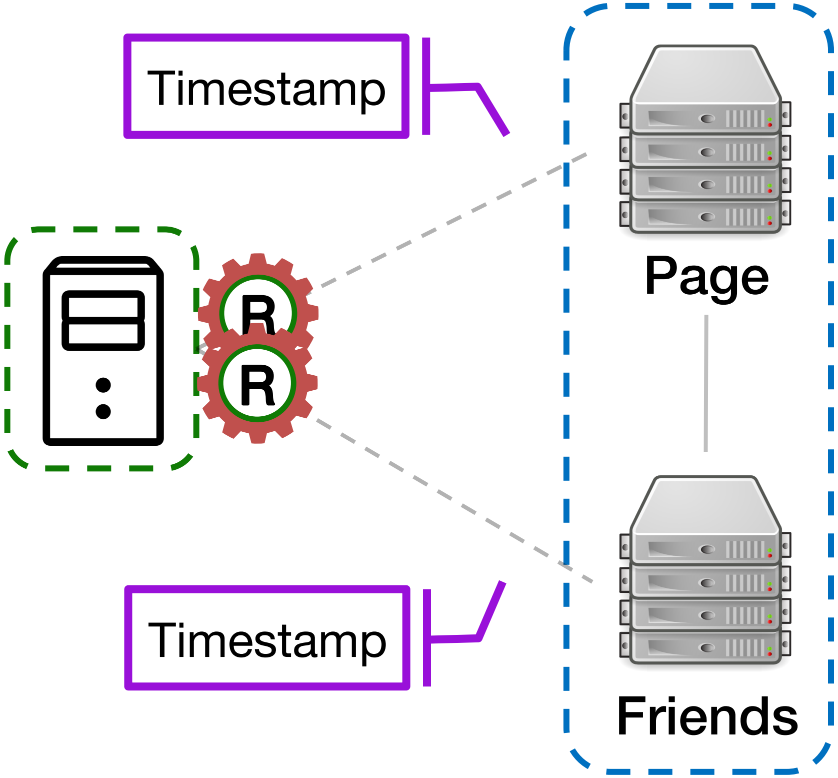




Performance Factors

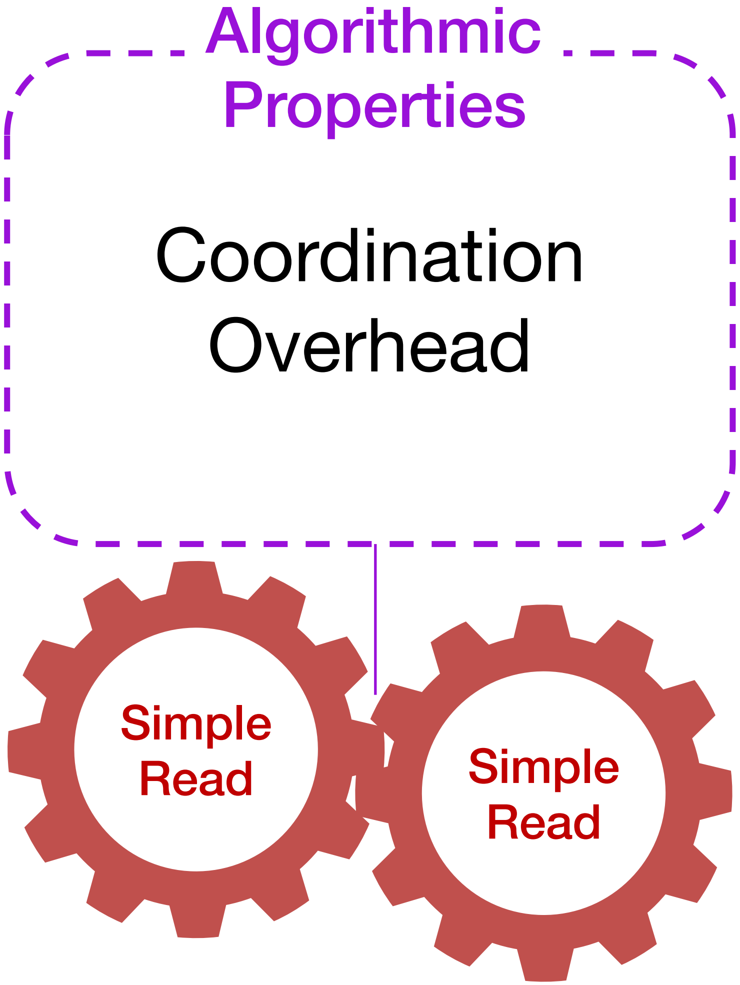
Algorithmic Properties





Performance Factors

Coordination Is Algorithmic



Algorithmic Properties

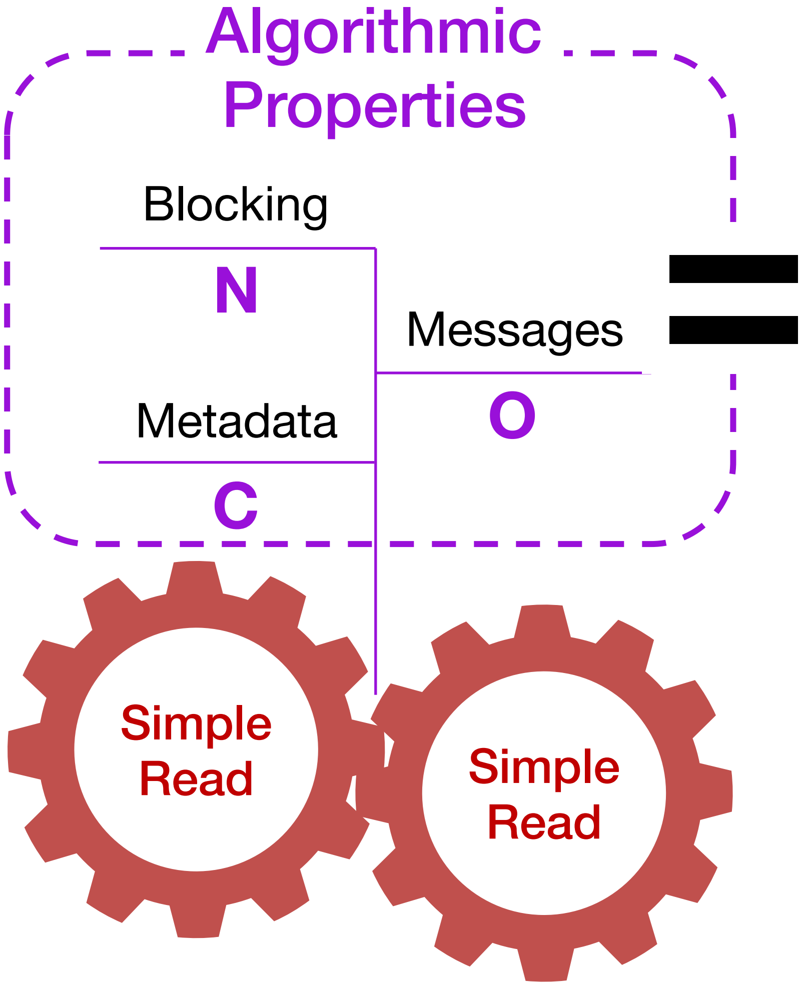
Coordination Overhead

Simple Read

Simple Read

Read-Only Transactions

Optimal Performance



Algorithmic Properties

Blocking

N

Messages

O

Metadata

C

Simple Read

Simple Read

Performance-optimal Read-only Transactions (N,O,C)

Non-Blocking Reads

- Do not wait on external events
  - Distributed locks, timeouts, messages, etc.

- Lower latency
  - Avoid any time spent blocking

- Higher throughput
  - Avoid CPU cost of context switches

One-Round Communication

- One-round on-path reads
  - Succeed in one round, i.e., no retries
- No off-path messages
  - Required by reads but off the critical path
- Lower latency
  - Avoids time for extra on-path messages
- Higher throughput
  - Avoids CPU cost of processing extra messages

Constant Metadata

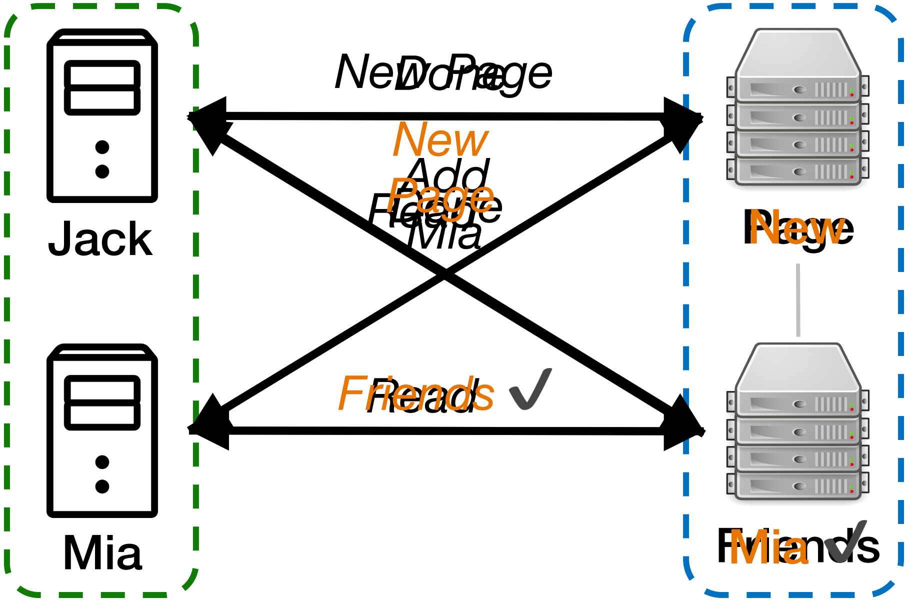
- Metadata
  - Information used to find a consistent view
  - Timestamps, transaction IDs, etc.
- Size of metadata remains constant regardless of contention
- Higher throughput
  - Avoids CPU cost of processing extra data

Performance-optimal read-only transactions are NOC:

Non-blocking messages
that complete in
One-round with
Constant metadata

Strict Serializability

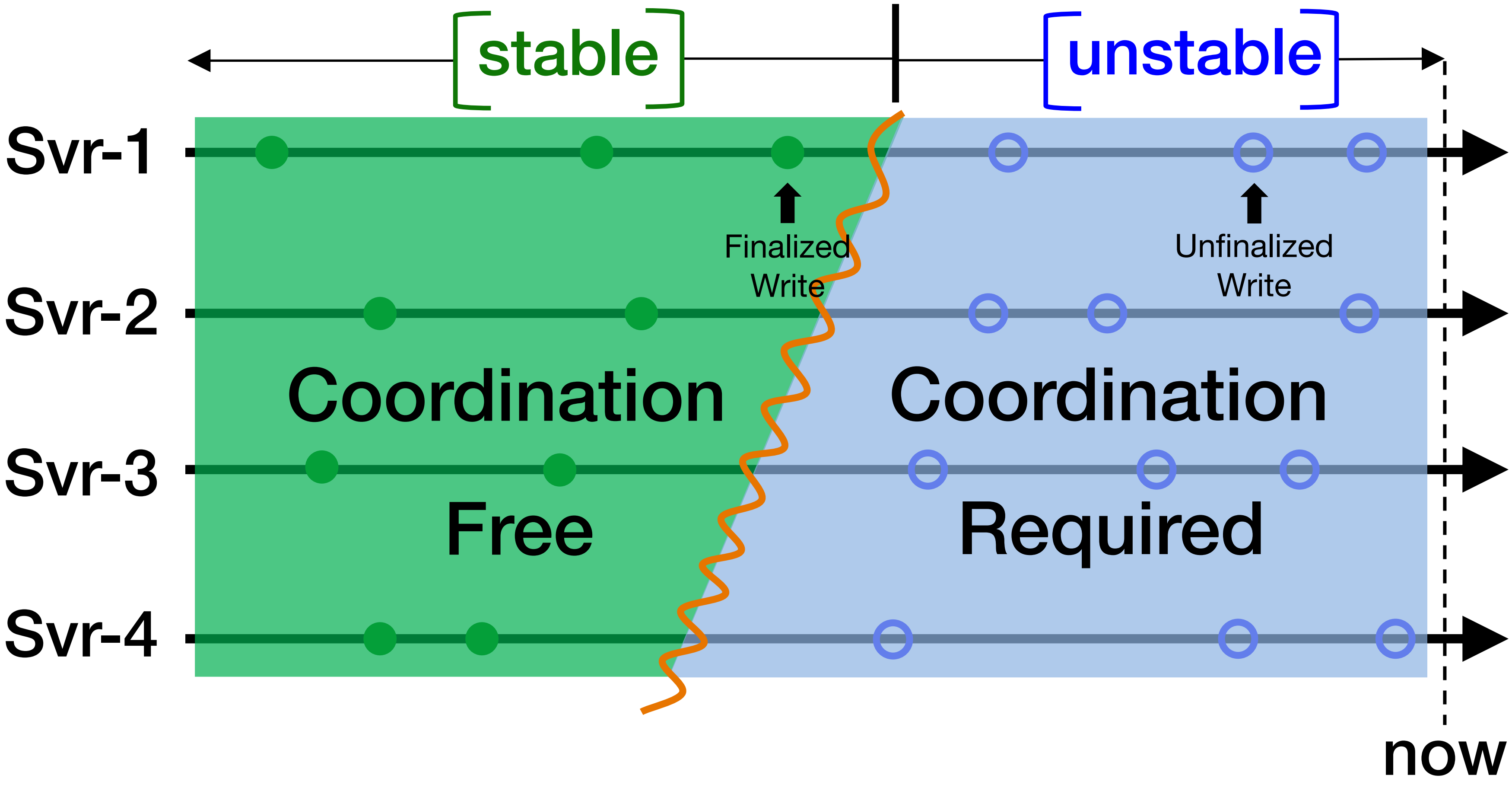
- The strongest consistency model
  - – Writing applications made easy
- Requires a total order + real-time order



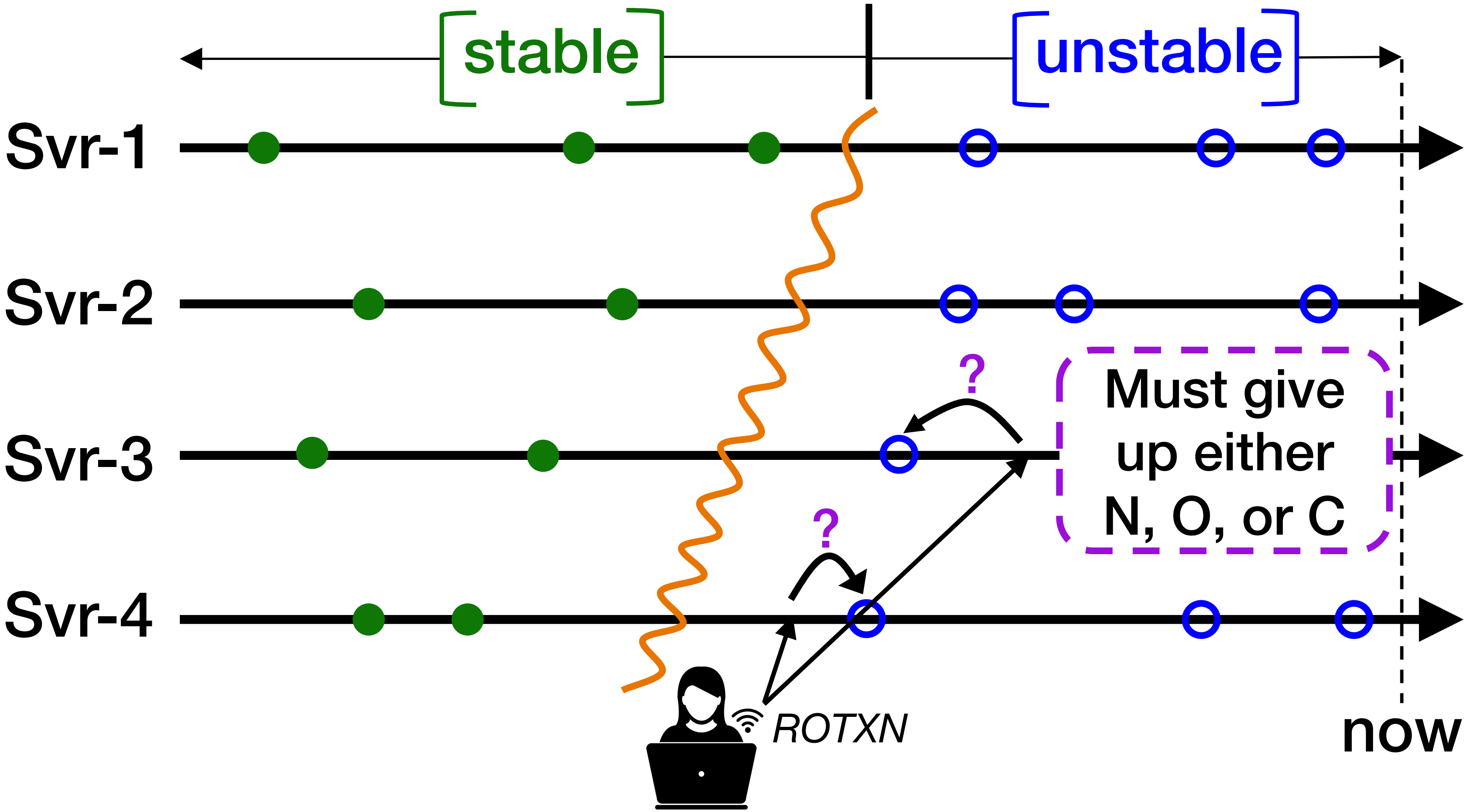
The NOCS Theorem:

Impossible for read-only transaction algorithms to achieve performance-optimality [N,O,C] and strict serializability [S]

Proof Intuition of NOCS

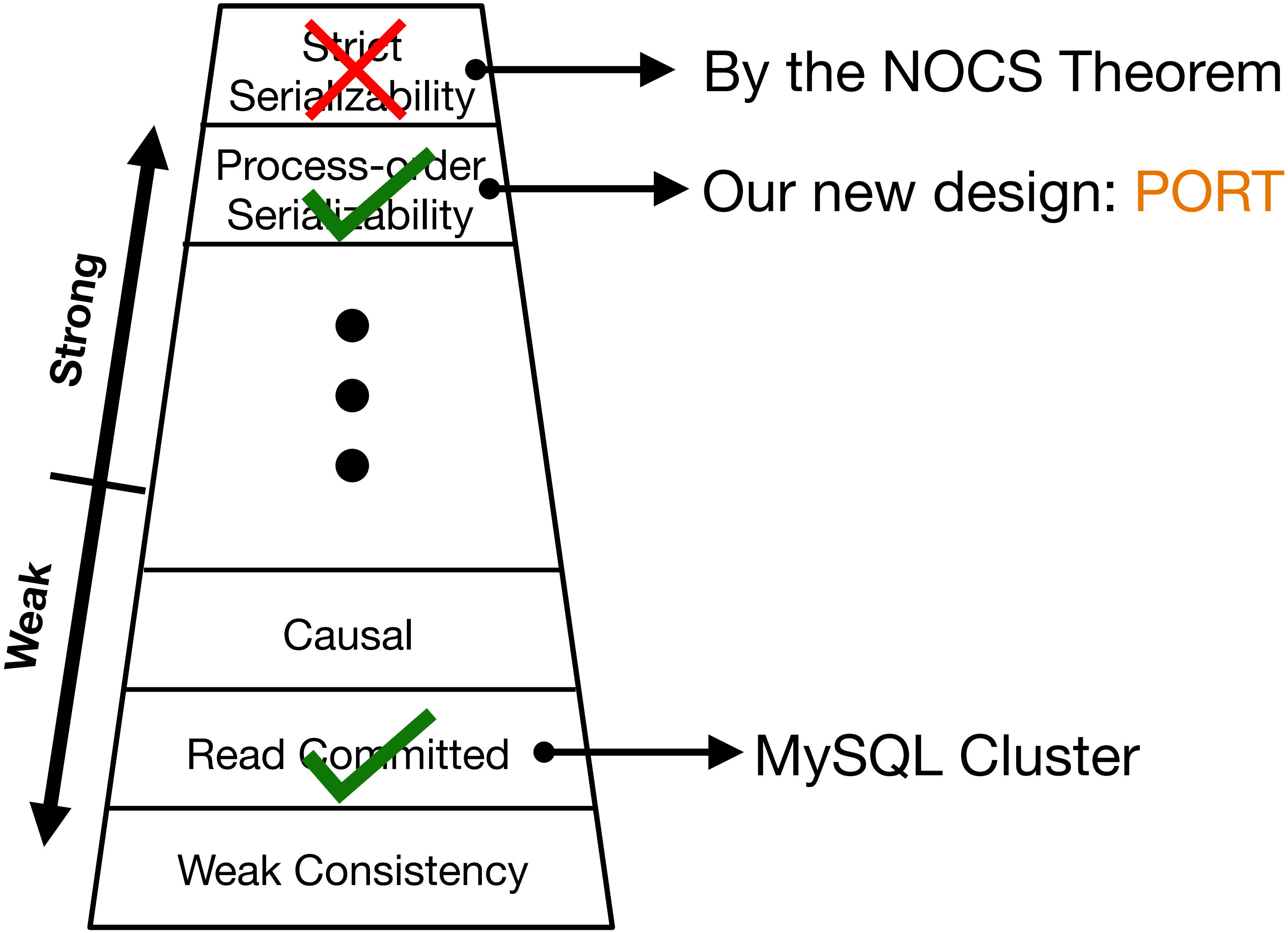


Proof Intuition of NOCS



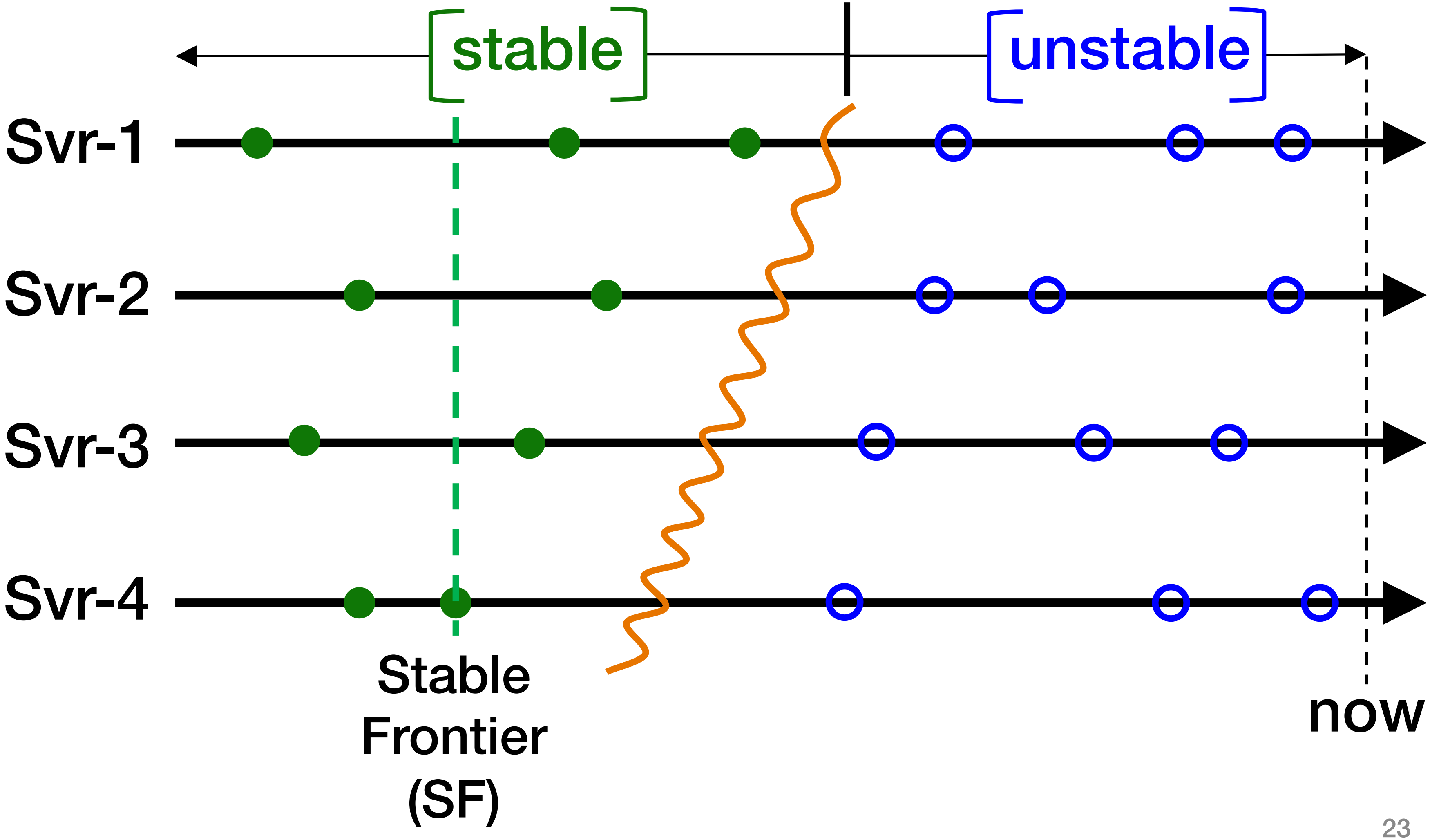
Must give up either N, O, or C

NOC Designs


Strict Serializability
By the NOCS Theorem
Process-order Serializability
Our new design: PORT
Strong
Weak
Causal
Read Committed
MySQL Cluster
Weak Consistency

Design Insight

Capturing the Stable Frontier



Version Clock

- A type of logical clock
  - Specialized for distributed storage systems
- Treat reads and writes differently
  - Enable optimizations for reads and writes
- Capture the stable frontier

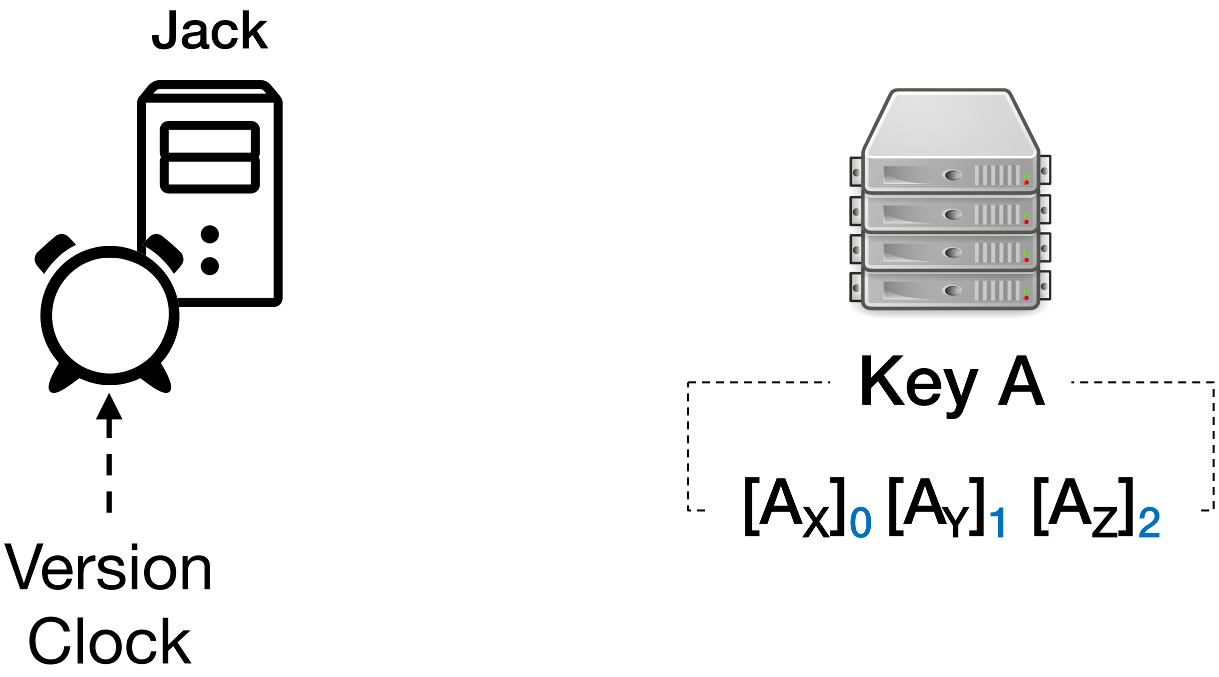
PORT Overview

Jack

Web Client

Storage Server

PORT Overview



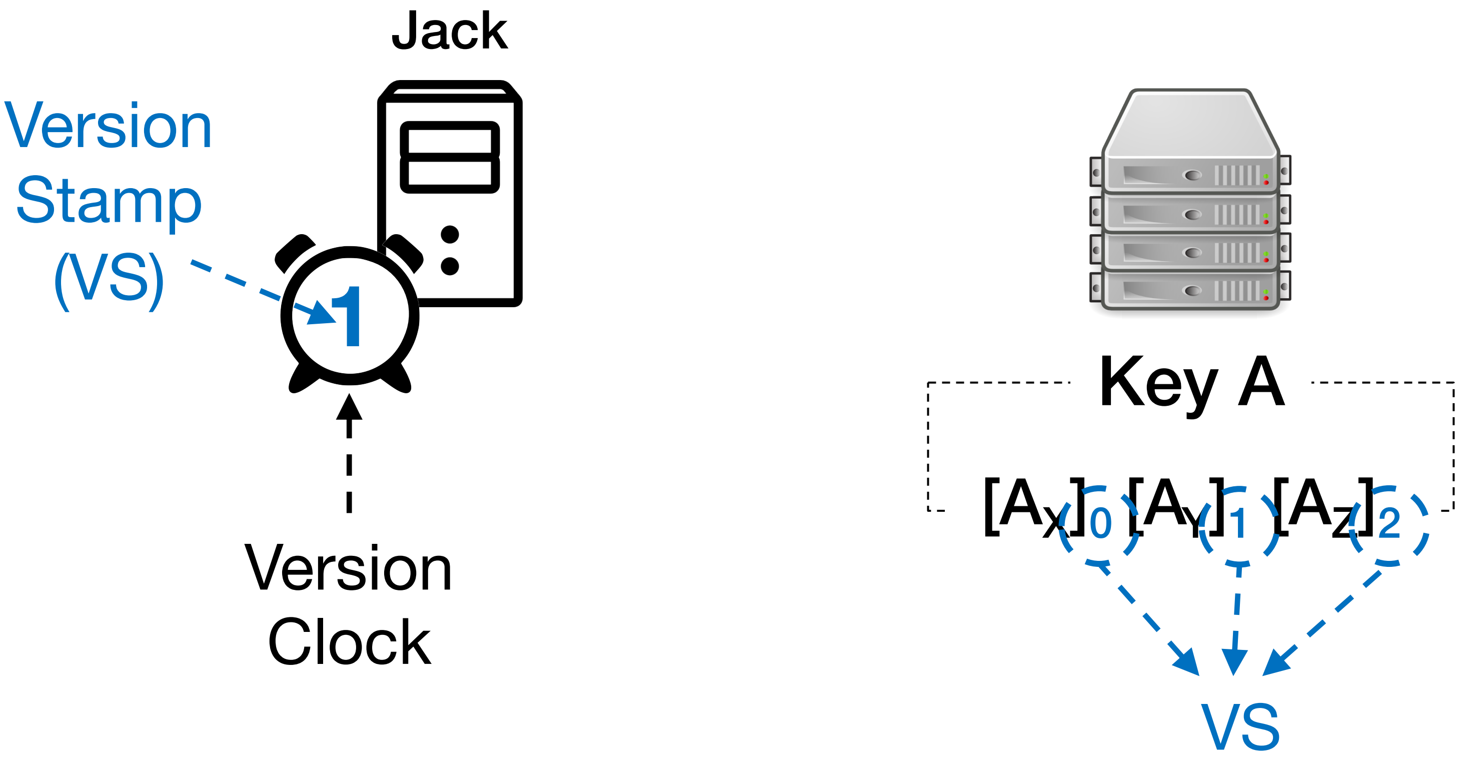
Jack

Version Clock

Key A

$[A_X]_0$ $[A_Y]_1$ $[A_Z]_2$

PORT Overview



Jack

Version Stamp (VS)

1

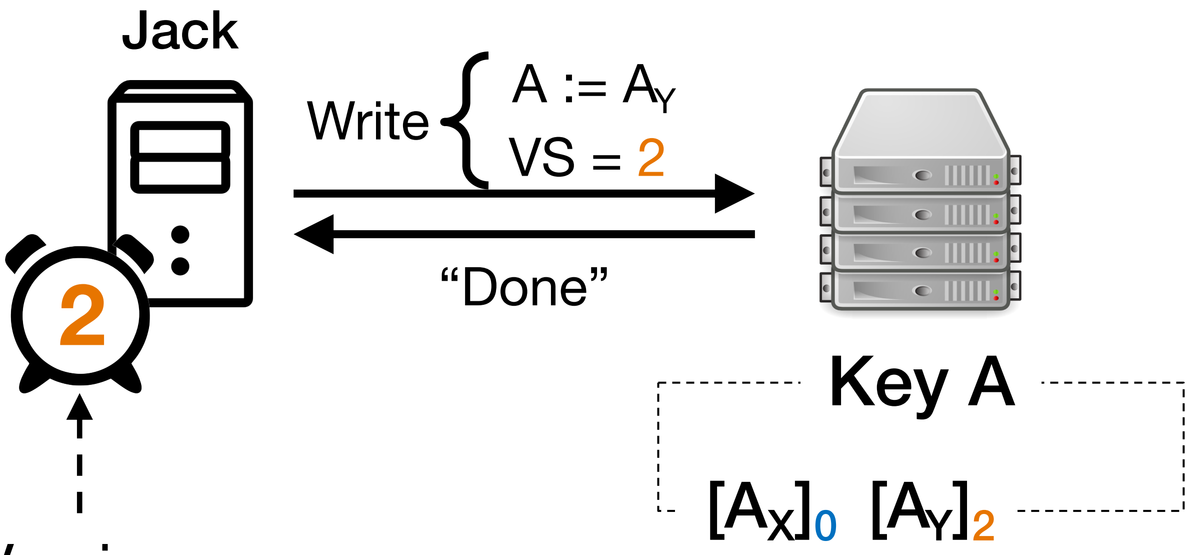
Version Clock

Key A

$[A_X]_0$ $[A_Y]_1$ $[A_Z]_2$

VS

Write in PORT



Jack

Write $\begin{cases} A := A_Y \\ VS = 2 \end{cases}$

"Done"

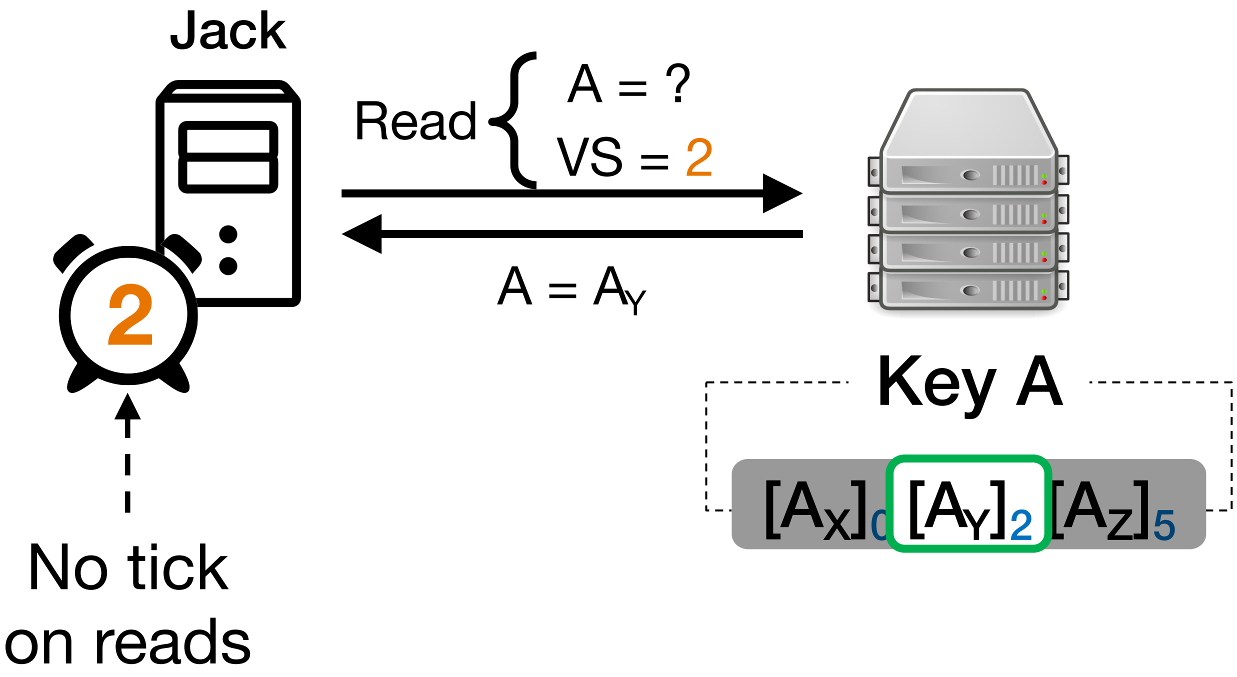
2

Key A

$[A_X]_0$ $[A_Y]_2$

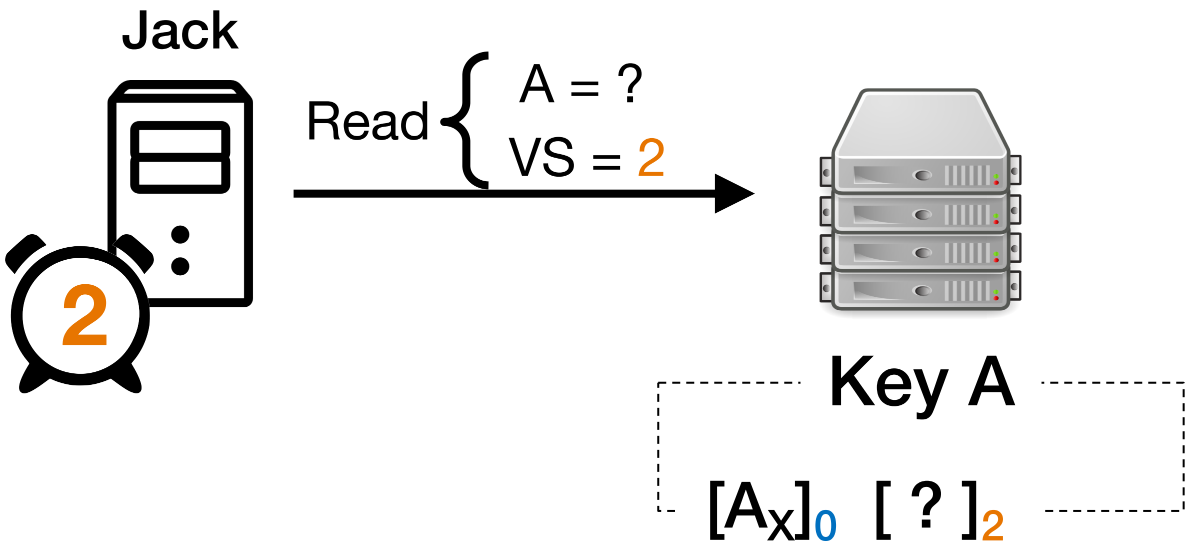
Version clocks tick on writes

Read in Port



Read Promotion

Ensures a Total Order



Jack

2

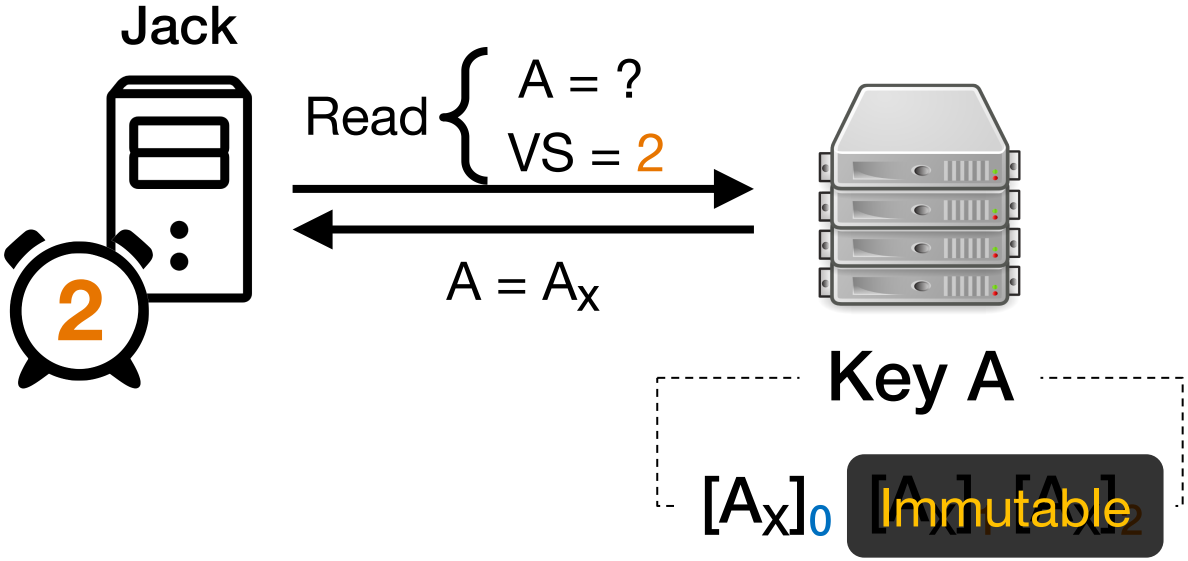
Read {A = ?, VS = 2}

Key A

$[A_X]_0$ $[\ ?\ ]_2$

Read Promotion

Ensures a Total Order



Jack

2

Read

$A = ?$

$VS = 2$

$A = A_X$

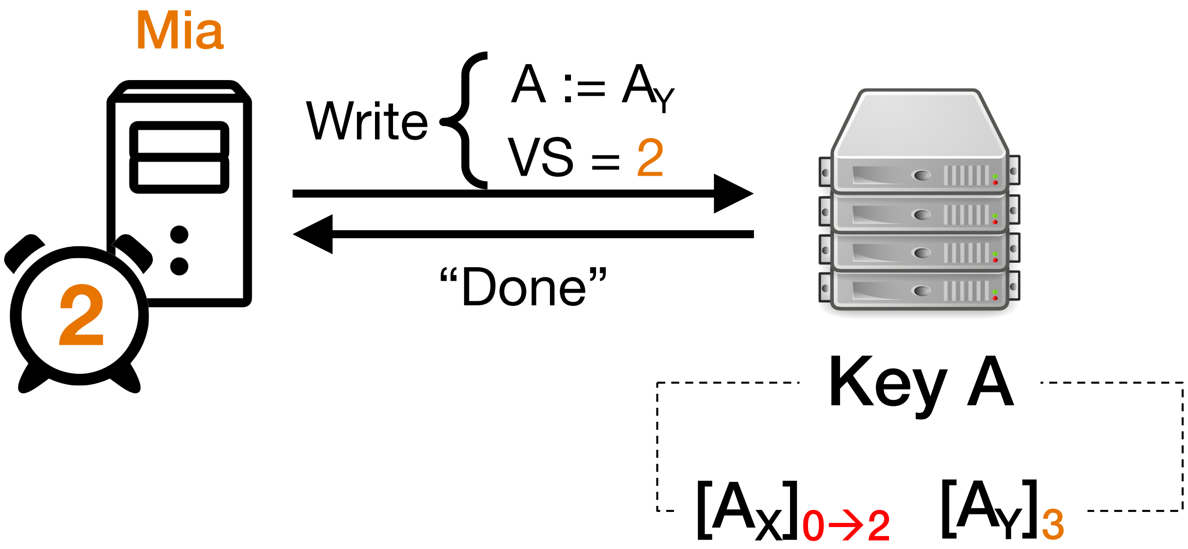
Key A

$[A_X]_0$ $[A_X]_1$ $[A_X]_2$

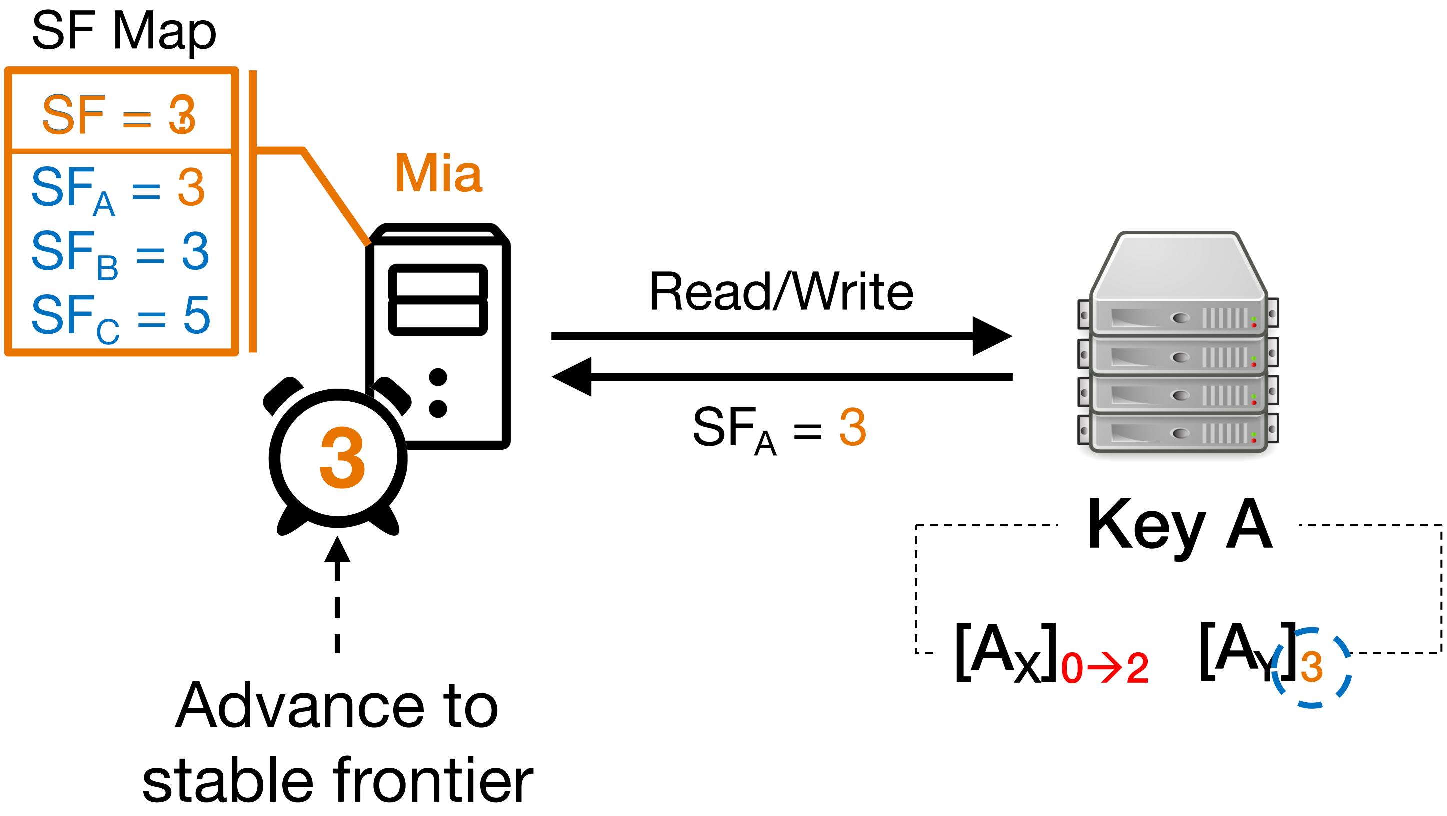
Immutable

Read Promotion

Ensures a Total Order



Track Stable Frontier



SF Map

SF = 3

$SF_A = 3$

$SF_B = 3$

$SF_C = 5$

Mia

3

Read/Write

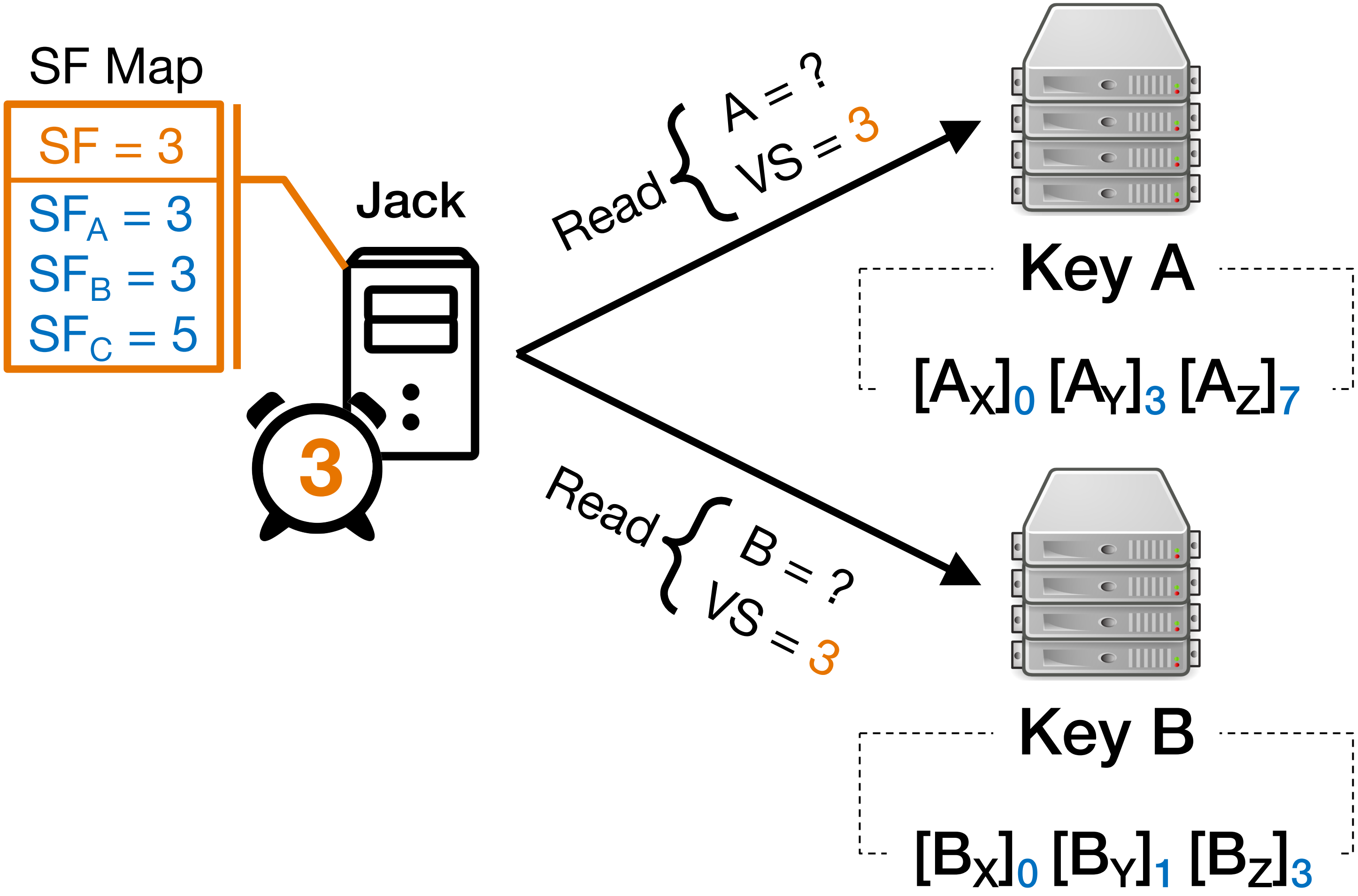
$SF_A = 3$

Key A

$[A_X]_{0 \rightarrow 2}$ $[A_Y]_3$

Advance to stable frontier

Read-Only Transaction Logic



SF Map

SF = 3

$SF_A = 3$

$SF_B = 3$

$SF_C = 5$

Jack

3

Read $\{$ A = ? , VS = 3

Read $\{$ B = ? , VS = 3

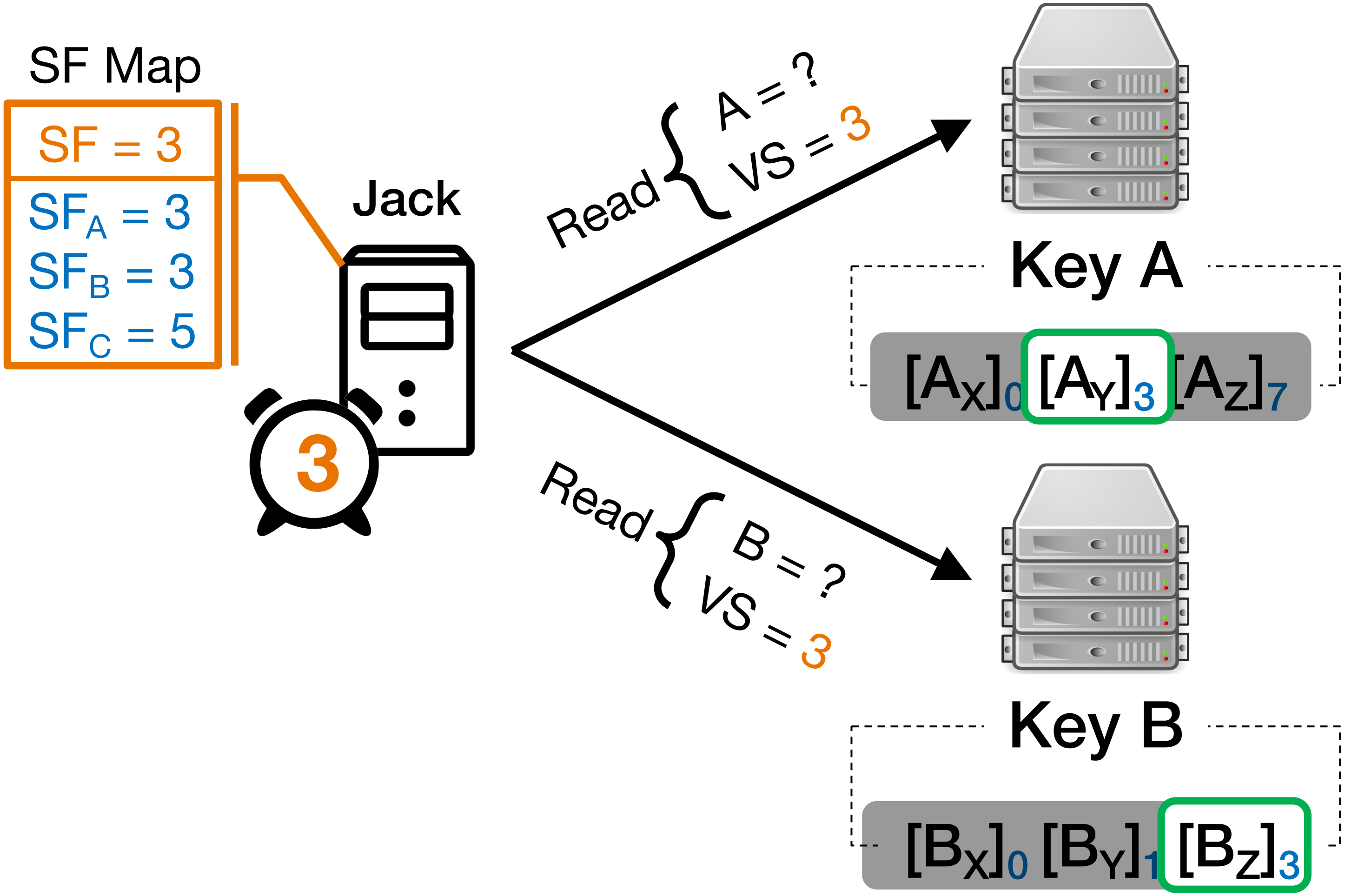
Key A

$[A_X]_0$ $[A_Y]_3$ $[A_Z]_7$

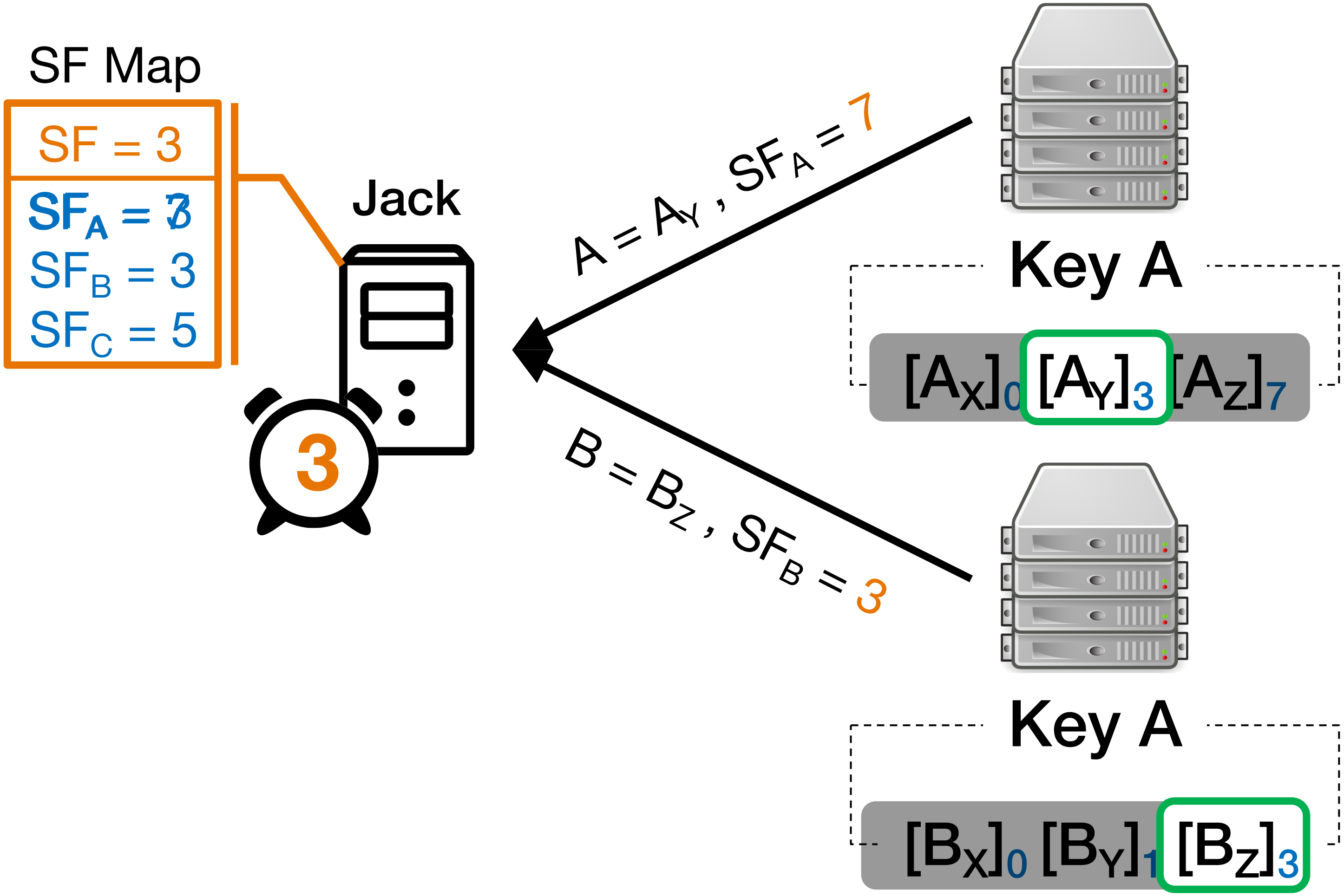
Key B

$[B_X]_0$ $[B_Y]_1$ $[B_Z]_3$

Read-Only Transaction Logic



Read-Only Transaction Logic



SF Map

SF = 3

$SF_A = 7$

$SF_A = 3$

$SF_B = 3$

$SF_C = 5$

Jack

3

$A = A_Y$, $SF_A = 7$

$B = B_Z$, $SF_B = 3$

Key A

$[A_X]_0$ $[A_Y]_3$ $[A_Z]_7$

Key A

$[B_X]_0$ $[B_Y]_1$ $[B_Z]_3$

PORT Is NOC

- Reading at the stable frontier ensures reads are non-blocking (N)
- Client pre-determined snapshot with VS ensures one-round communication (O)
- One VS per read request ensure constant metadata (C)

PORT Systems

- Scylla-PORT
  - – Base system: ScyllaDB (non-transactional)
    - Highly optimized → sensitive to overhead
  - – NOC + Process-ordered serializability
  - – Supports simple writes (not write transactions)

- Eiger-PORT
  - – Base system: Eiger (N, ~~O~~, ~~C~~)
    - Existing read-only and write transactions
  - – NOC + Causal consistency
  - – Supports write transactions

Evaluation of Scylla-PORT

- To understand
  - Overhead in latency and throughput compared to simple reads
  - Performance advantages compared to other protocols, e.g., OCC.

- Experiment configuration
  - YCSB benchmark with customized parameters for skew and read-to-write ratios
  - Evaluated latency, throughput, scalability, freshness

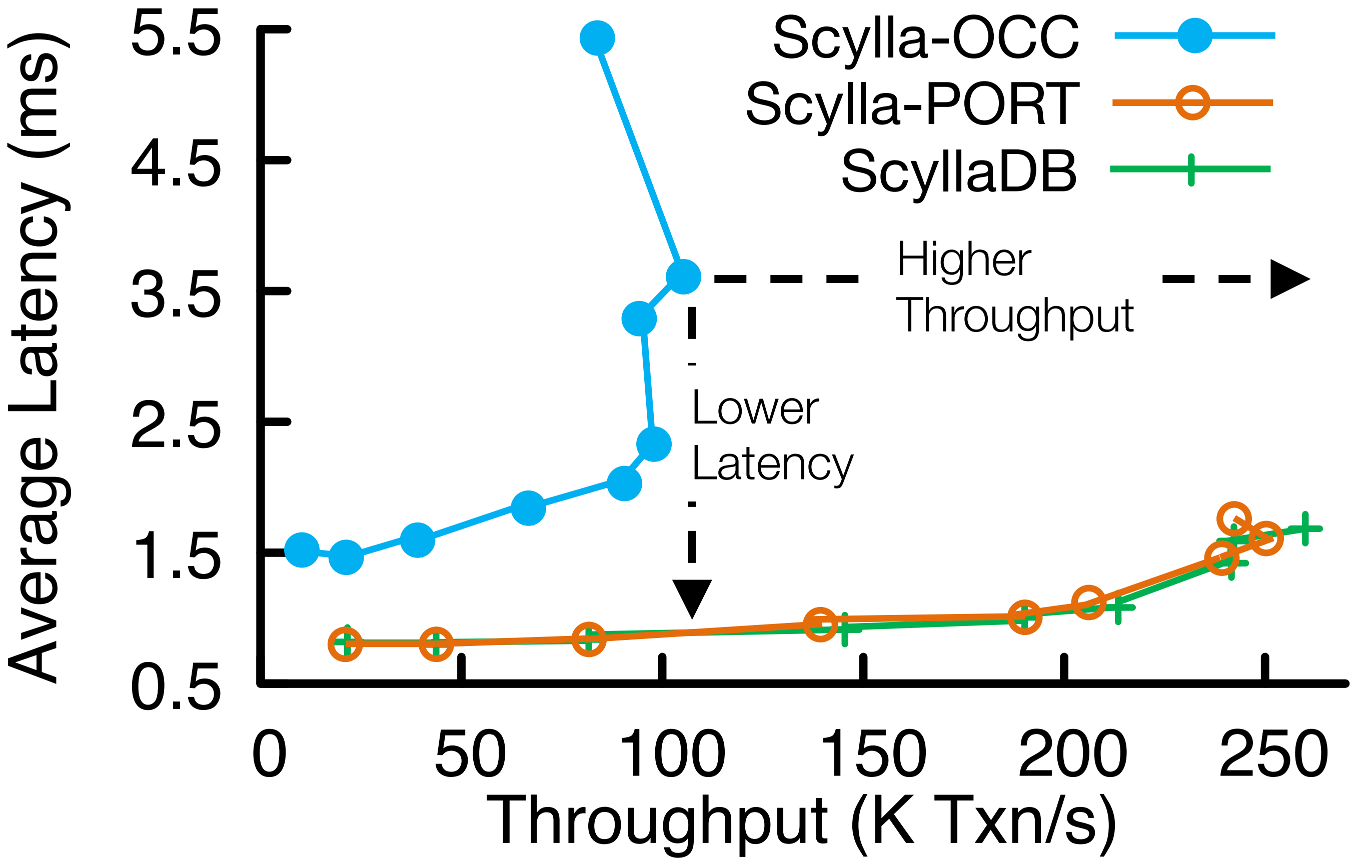
ARTIFACT EVALUATED usenix ASSOCIATION AVAILABLE

ARTIFACT EVALUATED usenix ASSOCIATION FUNCTIONAL

ARTIFACT EVALUATED usenix ASSOCIATION REPRODUCED

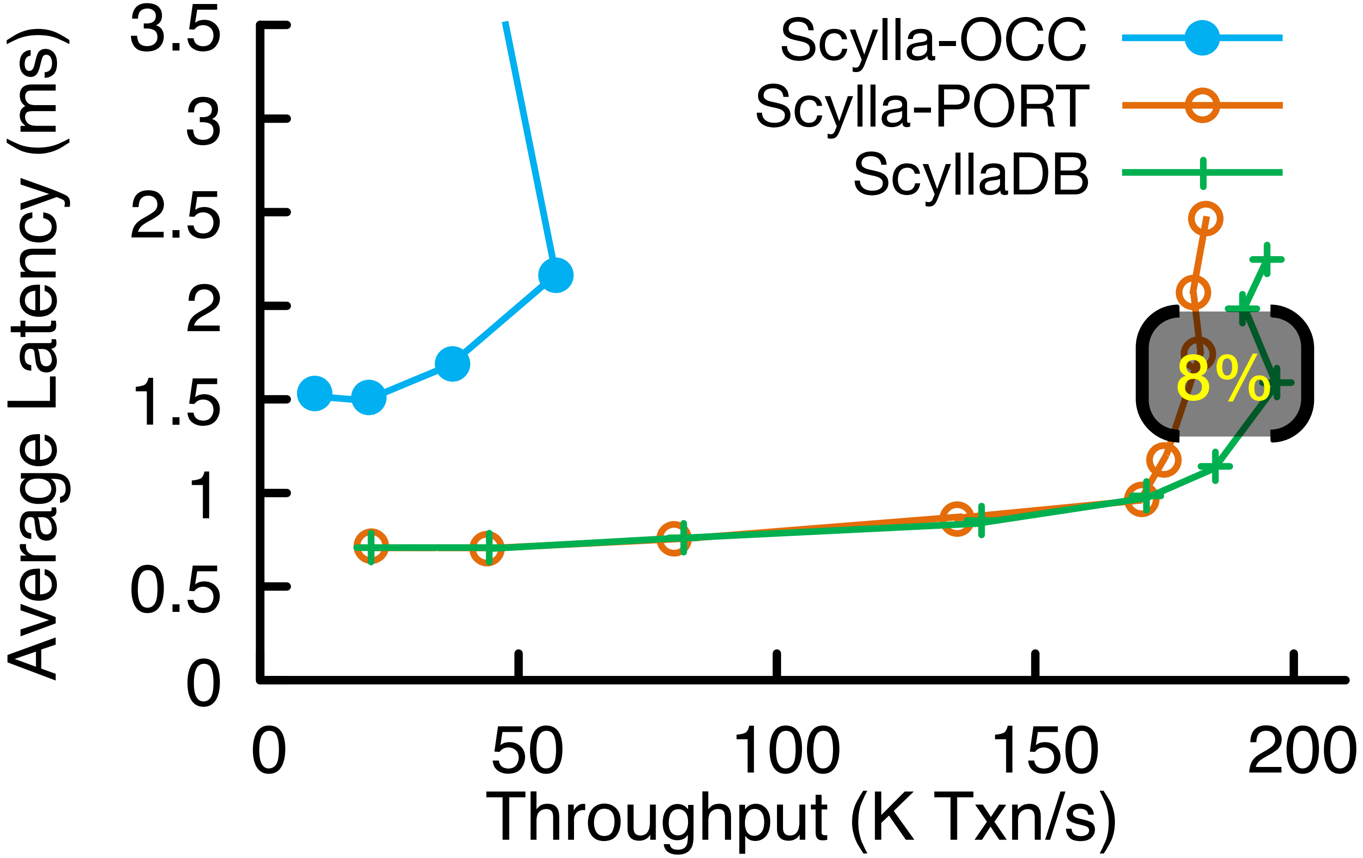
Latency-Throughput

Uniform, 5% Writes



Latency-Throughput

Zipf = 0.99, 5% Writes



Conclusion

- Performance-optimal read-only transactions: NOC
- The NOCS Theorem for read-only transactions
  - Impossible to have all of the NOCS properties
- The design of PORT
  - NOC with the strongest consistency to date
- Scylla-PORT
  - Minimum performance overhead compared to simple reads
  - Significantly outperforms the standard OCC

Contact Information
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