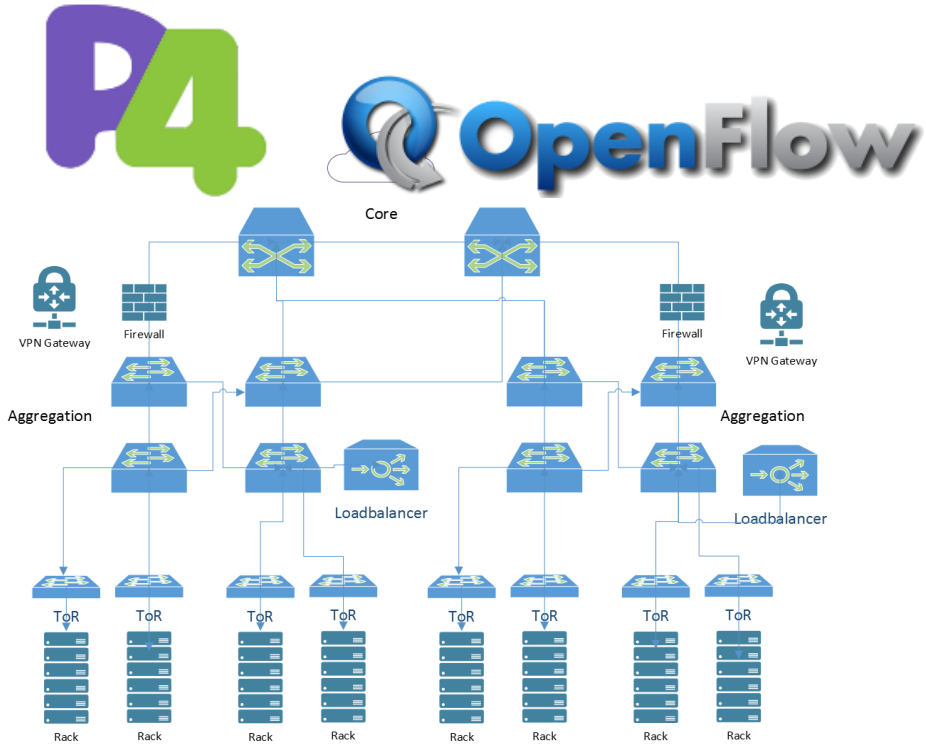
UNIVERSITY OF WATERLOO

Toward a Generic Fault Tolerance Technique for Partial Network Partitioning

Mohammed Alfatafta, Basil Alkhatib, Ahmed Alquraan, Samer Al-Kiswany

Modern Networks are Complex

- Multiple data centers
- Large scale
- Variety of middle boxes
- Heterogenous hardware and software
- Softwarization

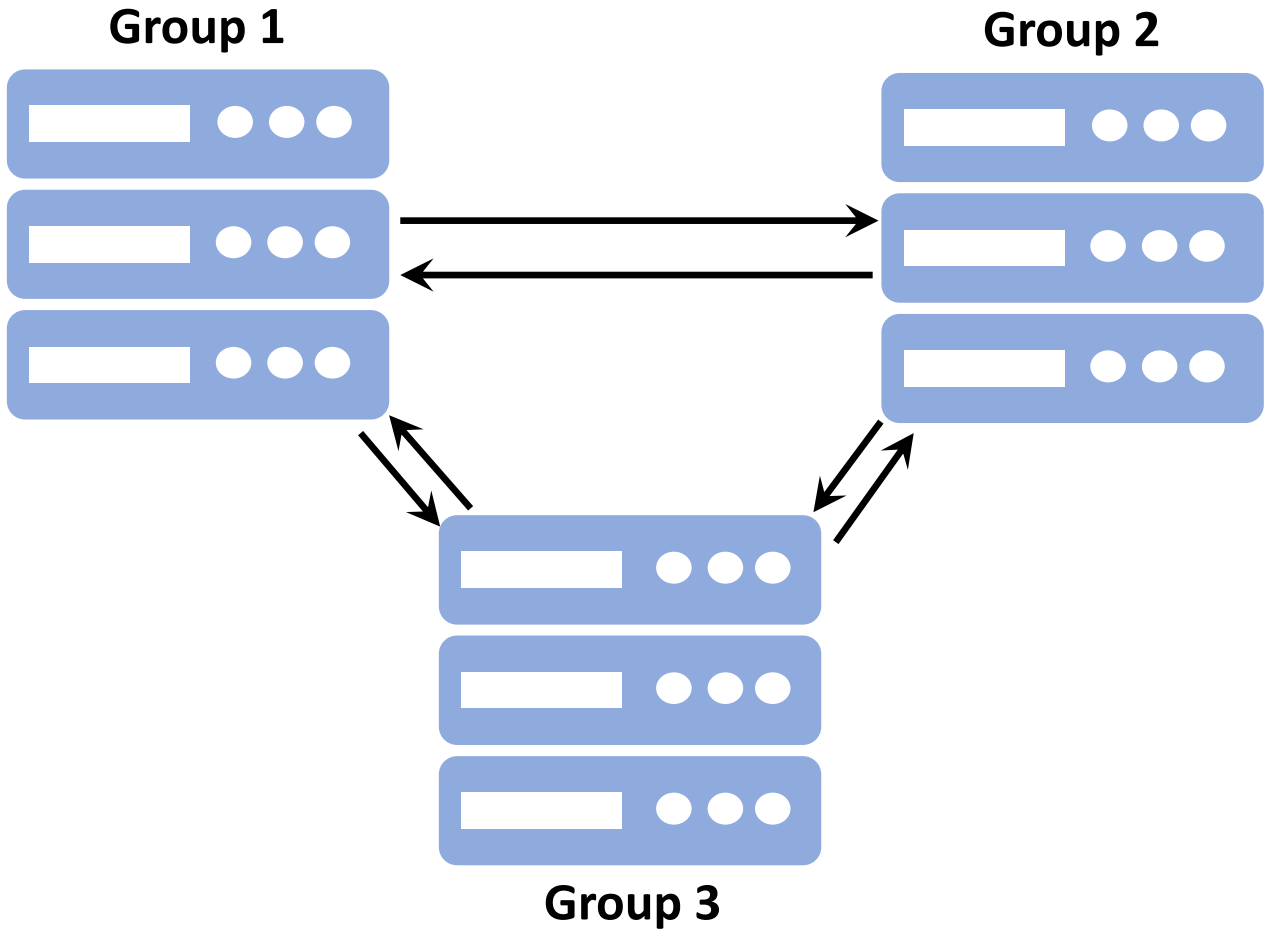


Catastrophic network failures are common [1, 2, 3, 4]

[1] Daniel Turner et. al. On failure in managed enterprise networks. HP Labs HPL-2012-101, 2012.
[2] Ramesh Govindan et. al. Evolve or die: High-availability design principles drawn from googles net-work infrastructure. 2016 ACMSIGCOMM
[3] Phillipa Gill et. al. Understanding network failures in data centers: measurement, analysis, and implications. 2011 SIGCOMM
[4] Daniel Turner et. al. California fault lines: understanding the causes and impact of network failures. 2011 SIGCOMM

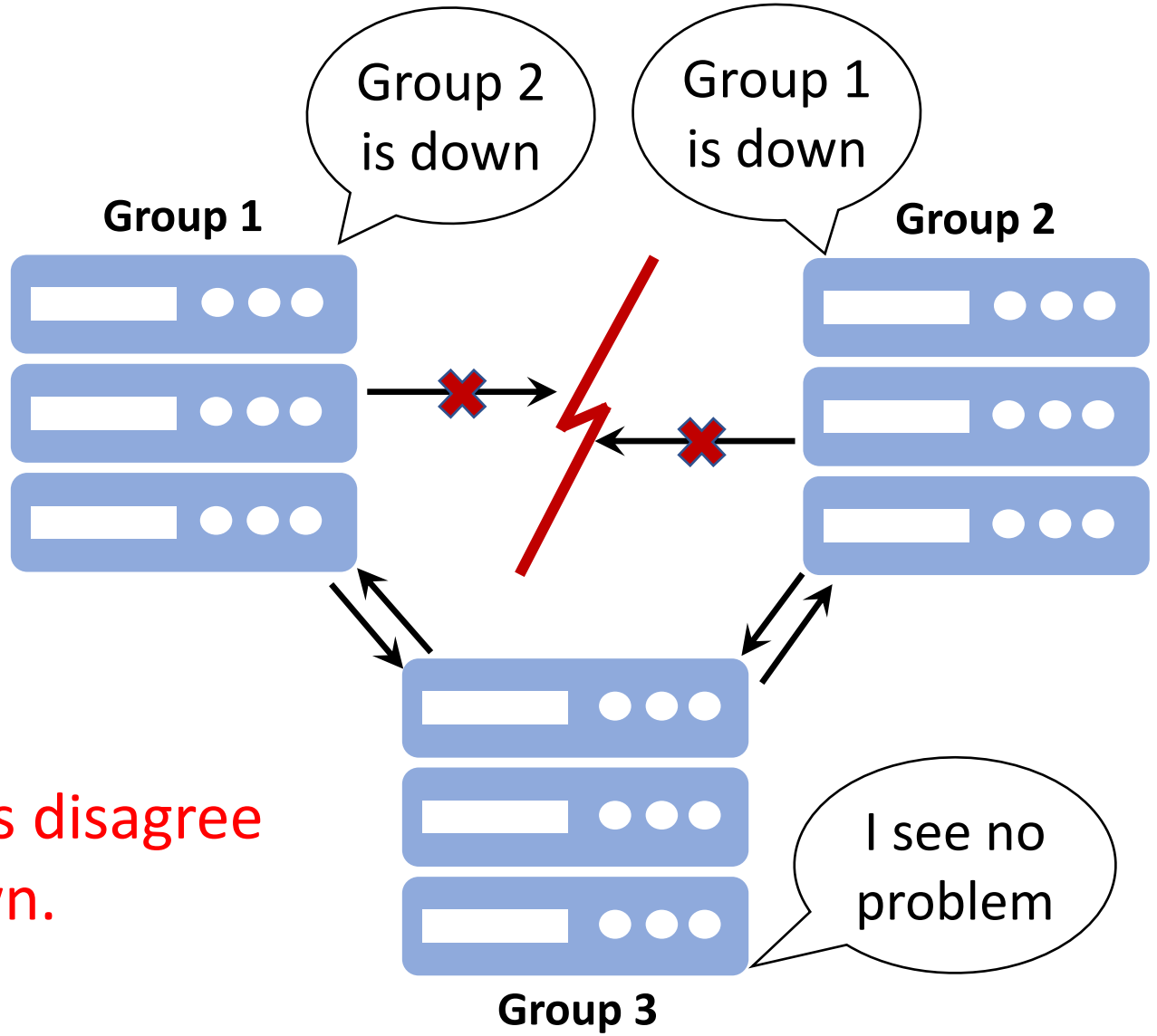
Partial partitions

Isolate a set of nodes from some, but not all, nodes in the cluster.



Partial partitions

Isolate a set of nodes from some, but not all, nodes in the cluster.



Impact: Confuses systems as nodes disagree whether a given node is up or down.

Outline

- What causes partial network partitioning?
- How do they impact systems?
- Are there any fault tolerance techniques?
- NIFTY: a generic fault tolerance technique
- Evaluation

Outline

- What causes partial network partitioning?
- How do they impact systems?
- Are there any fault tolerance techniques?
- NIFTY: a generic fault tolerance technique
- Evaluation

Causes of partial partitions

- Failure of additional links between racks [1,2]
- Network and Firewall misconfigurations [3]
- Network upgrades [4]
- Flaky links between switches [5]

[1] Elasticsearch ticket: https://github.com/elastic/elasticsearch/issues/6105
[2] Blog post: https://rachelbythebay.com/w/2012/02/16/partition/
[3] Blog post: https://www.robustperception.io/healthchecking-is-not-transitive
[4] Elasticsearch ticket: https://github.com/elastic/elasticsearch/issues/9495
[5] MapReduce ticket: https://issues.apache.org/jira/browse/MAPREDUCE-1800

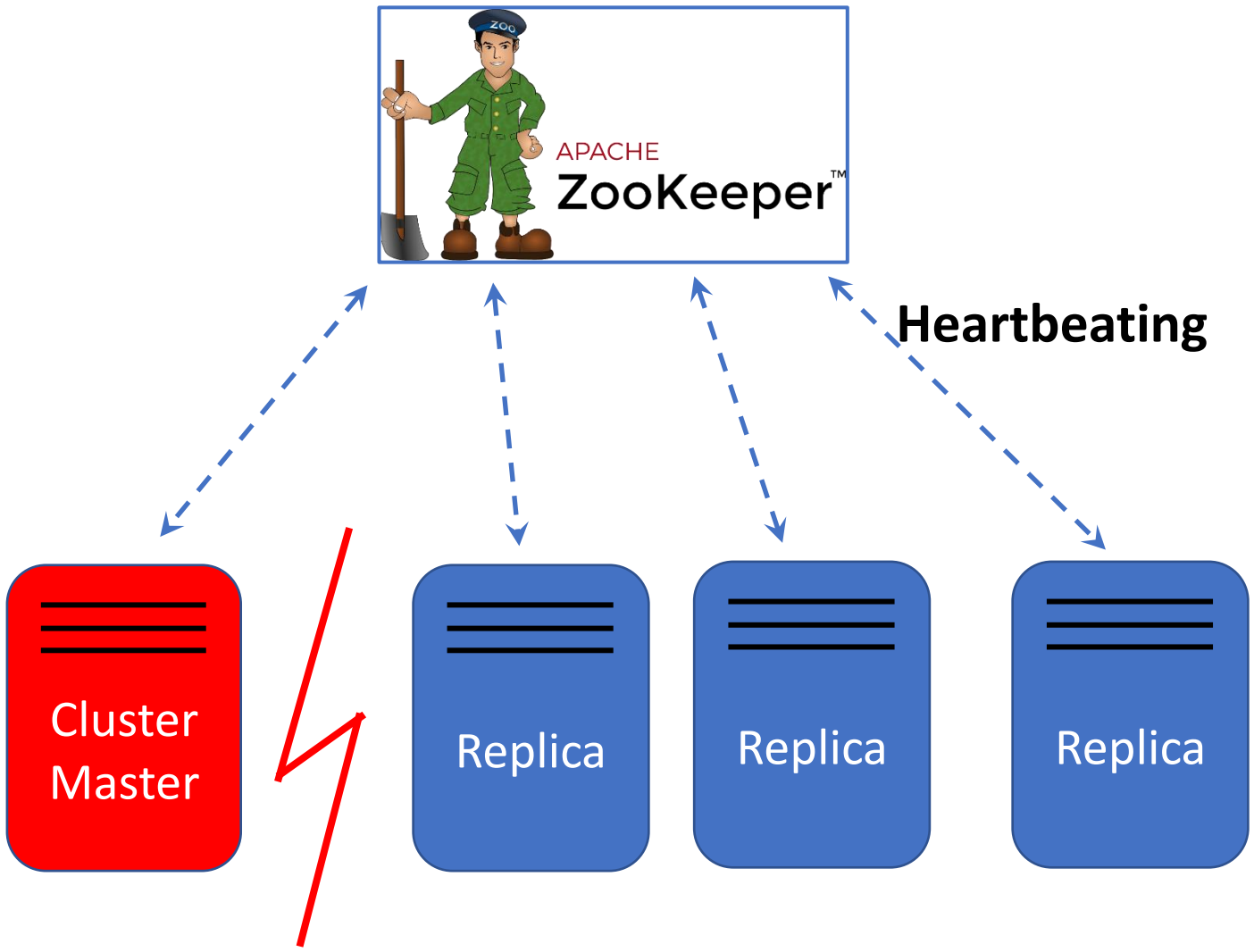
Outline

- What causes partial network partitioning?
- How do they impact systems?
- Are there any fault tolerance techniques?
- NIFTY: a generic fault tolerance technique
- Evaluation

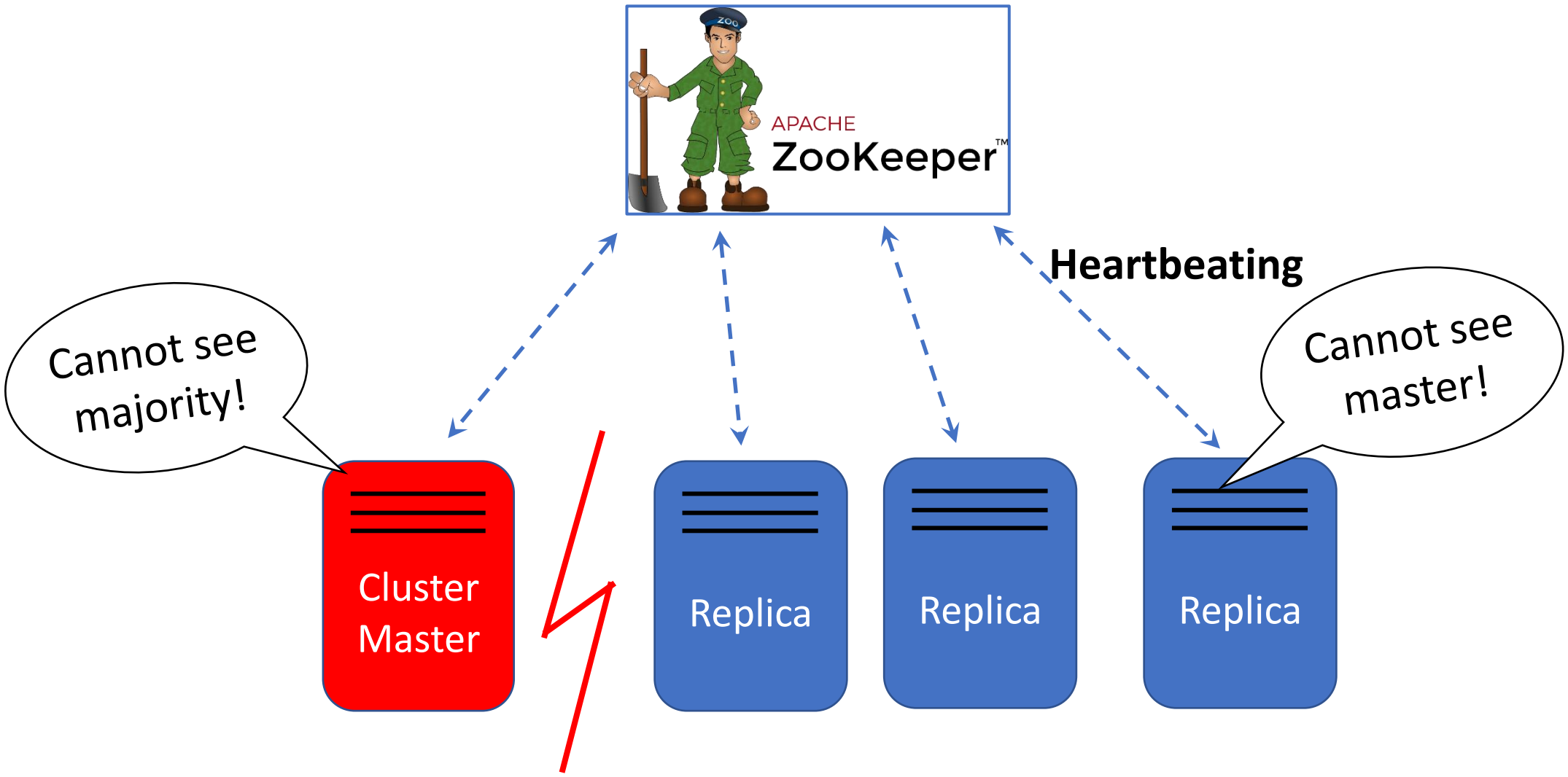
Methodology

- Study 51 high-impact partial partitioning failures from 12 systems.
- Study failure report, discussion, logs, code, and tests.
- Reproduce some of the failures.

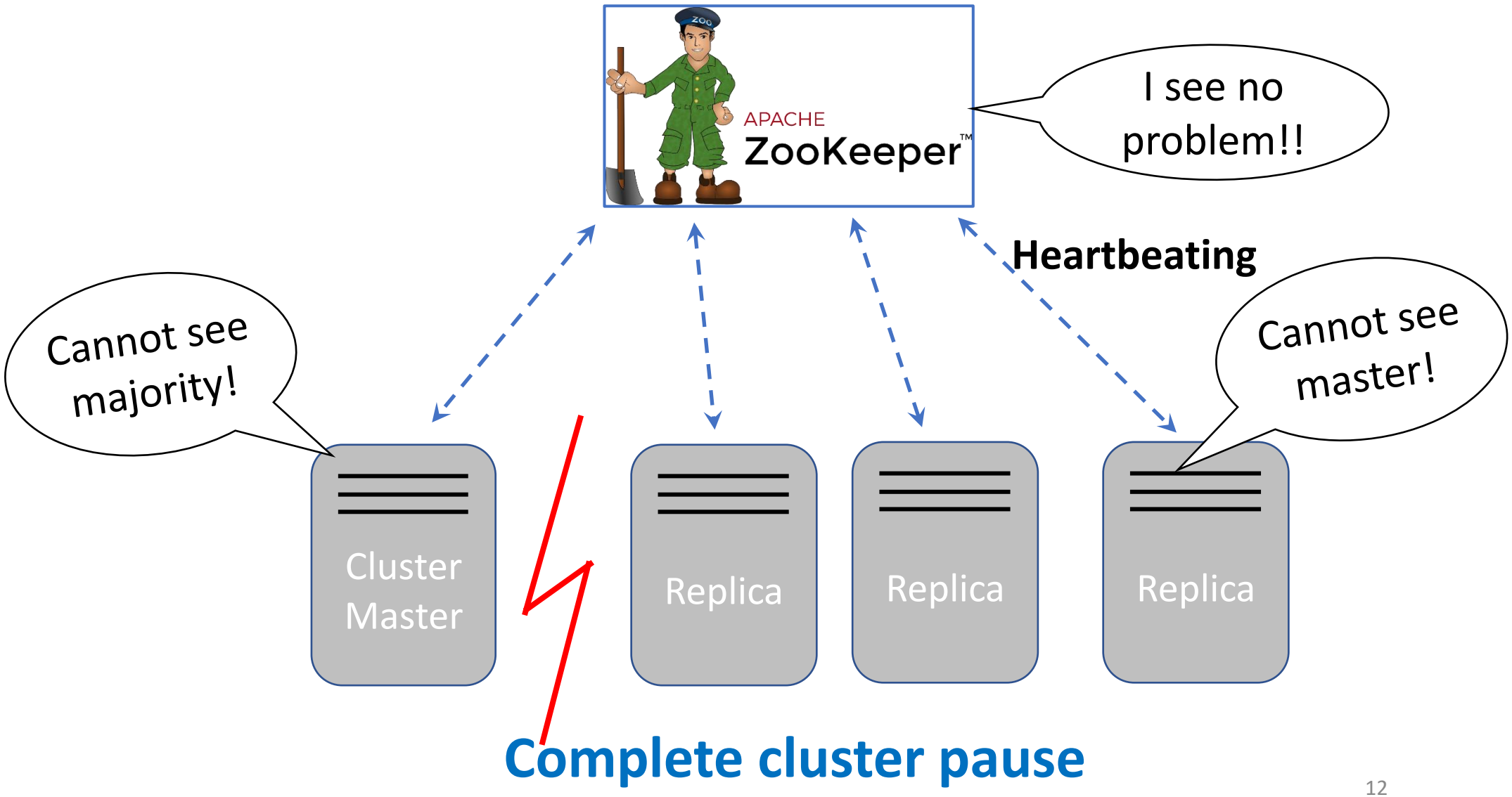
Partial network partition – ActiveMQ



Partial network partition – ActiveMQ

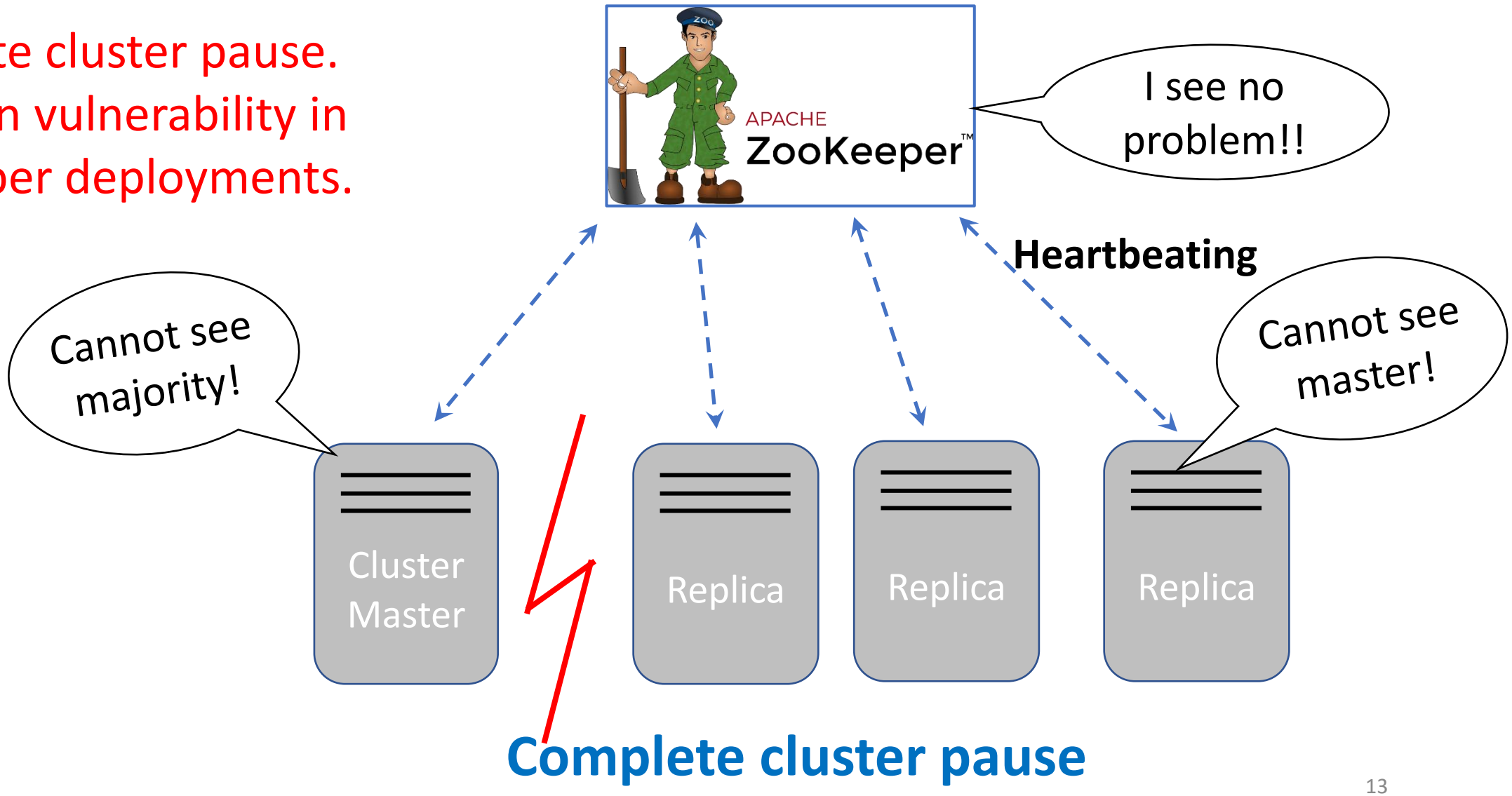


Partial network partition – ActiveMQ

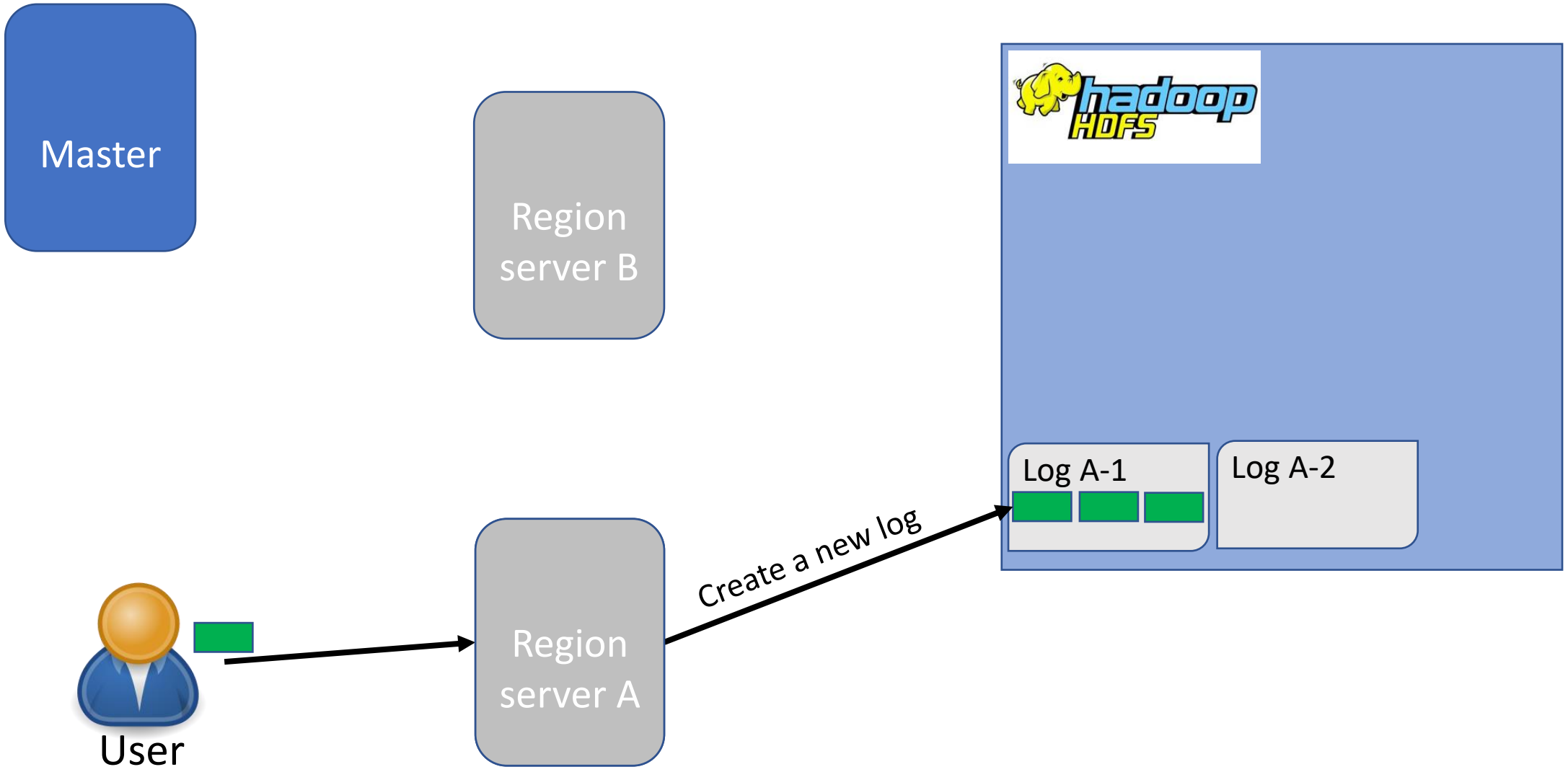


Partial network partition – ActiveMQ

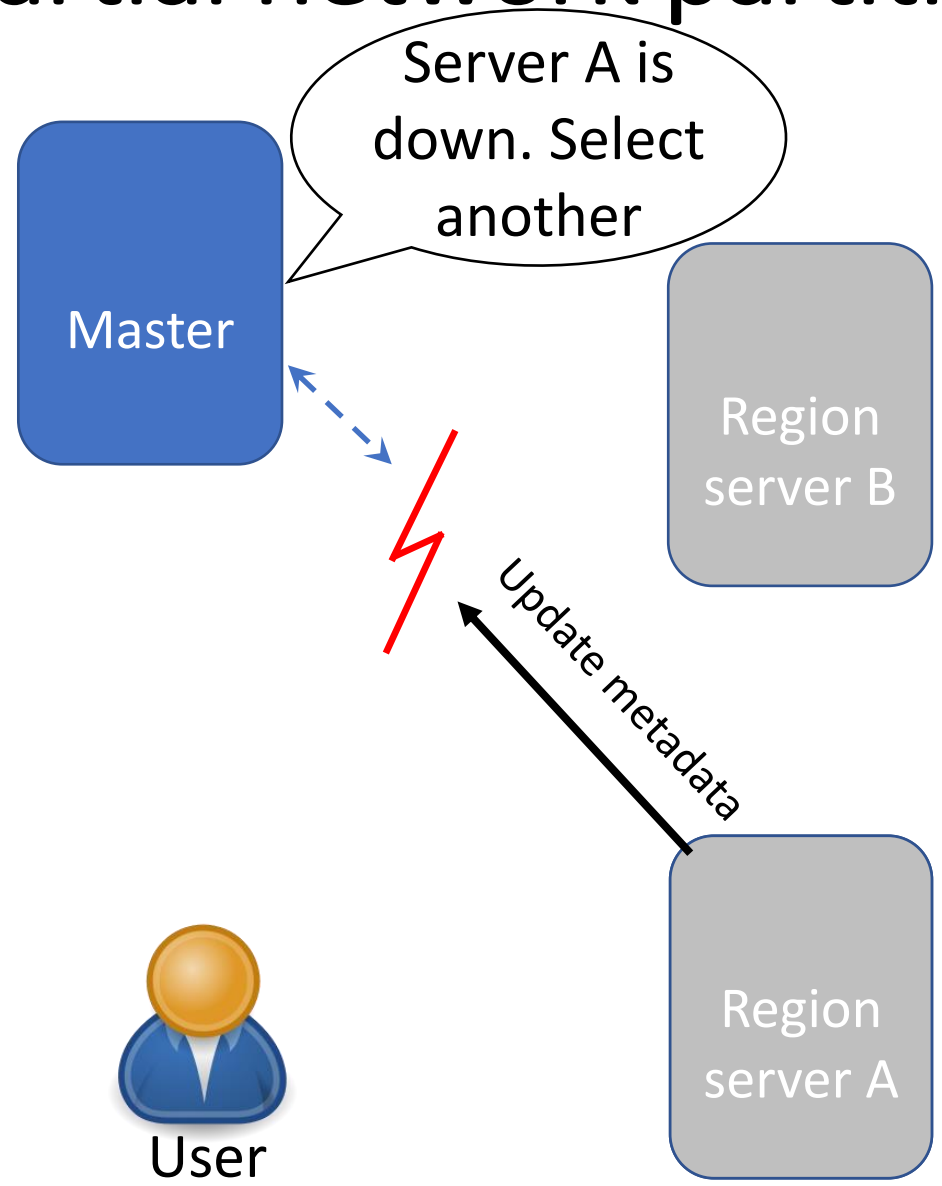
- Complete cluster pause.
- Common vulnerability in Zookeeper deployments.

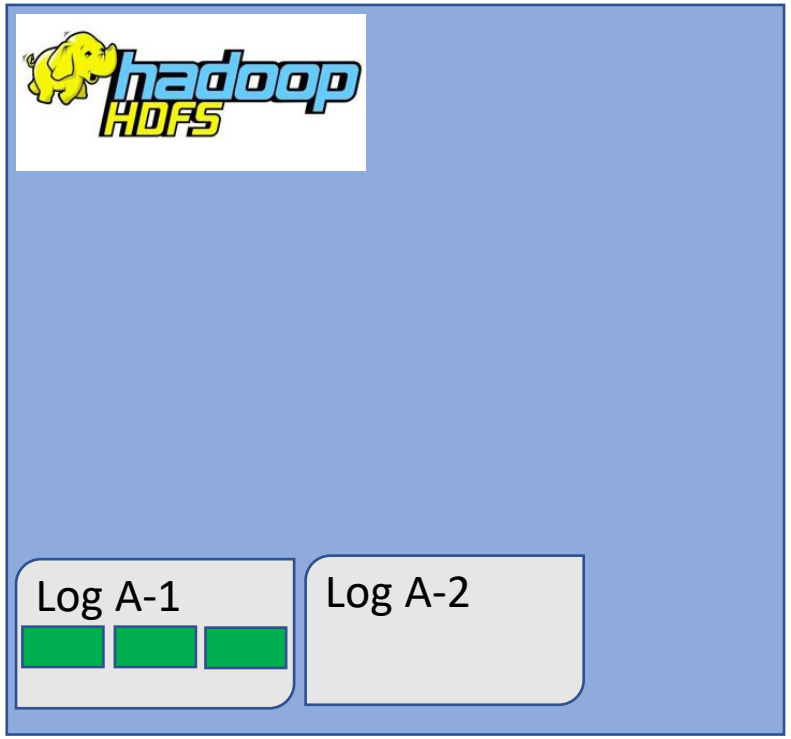


Partial network partition – HBase

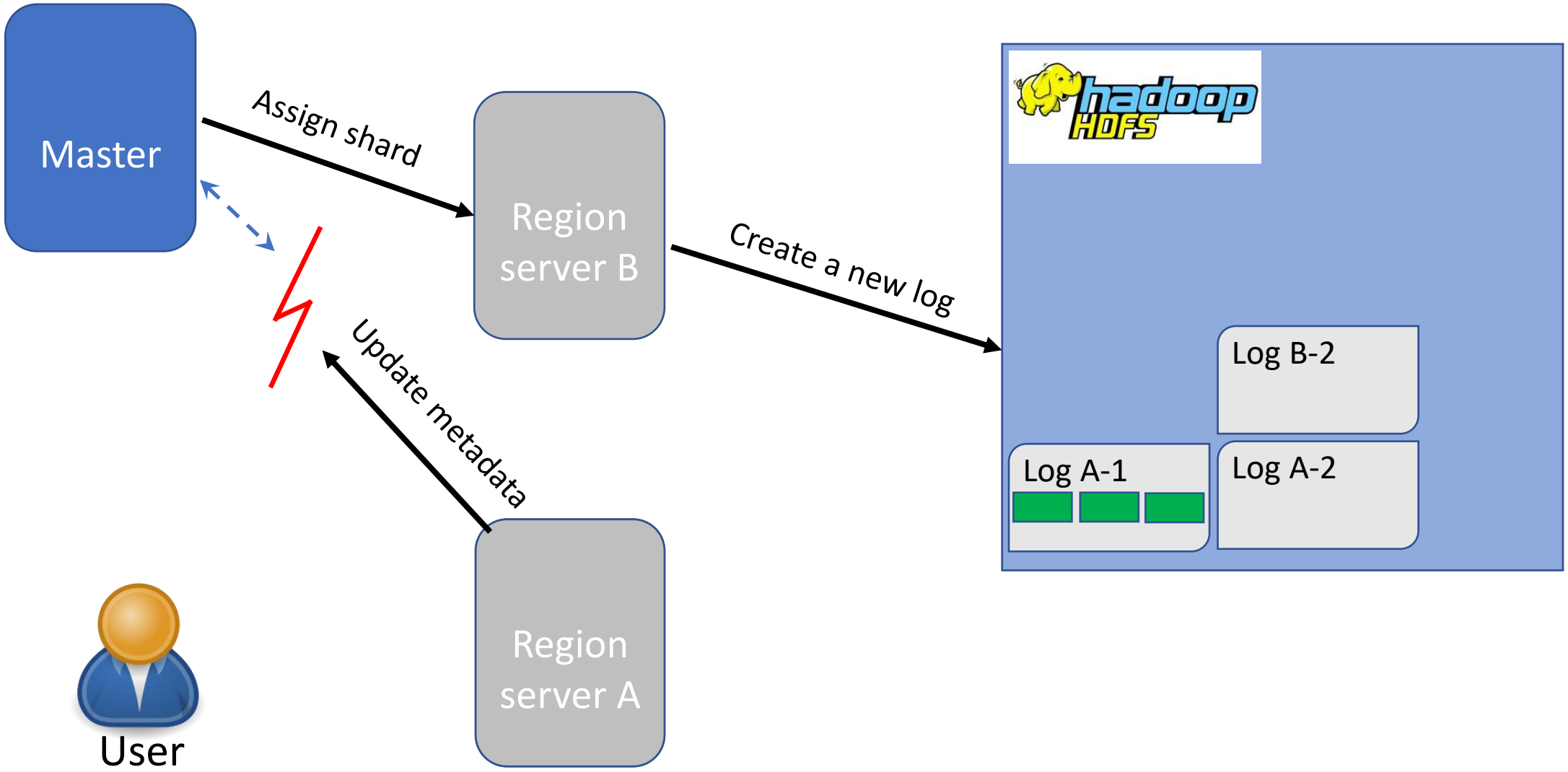


Partial network partition – HBase

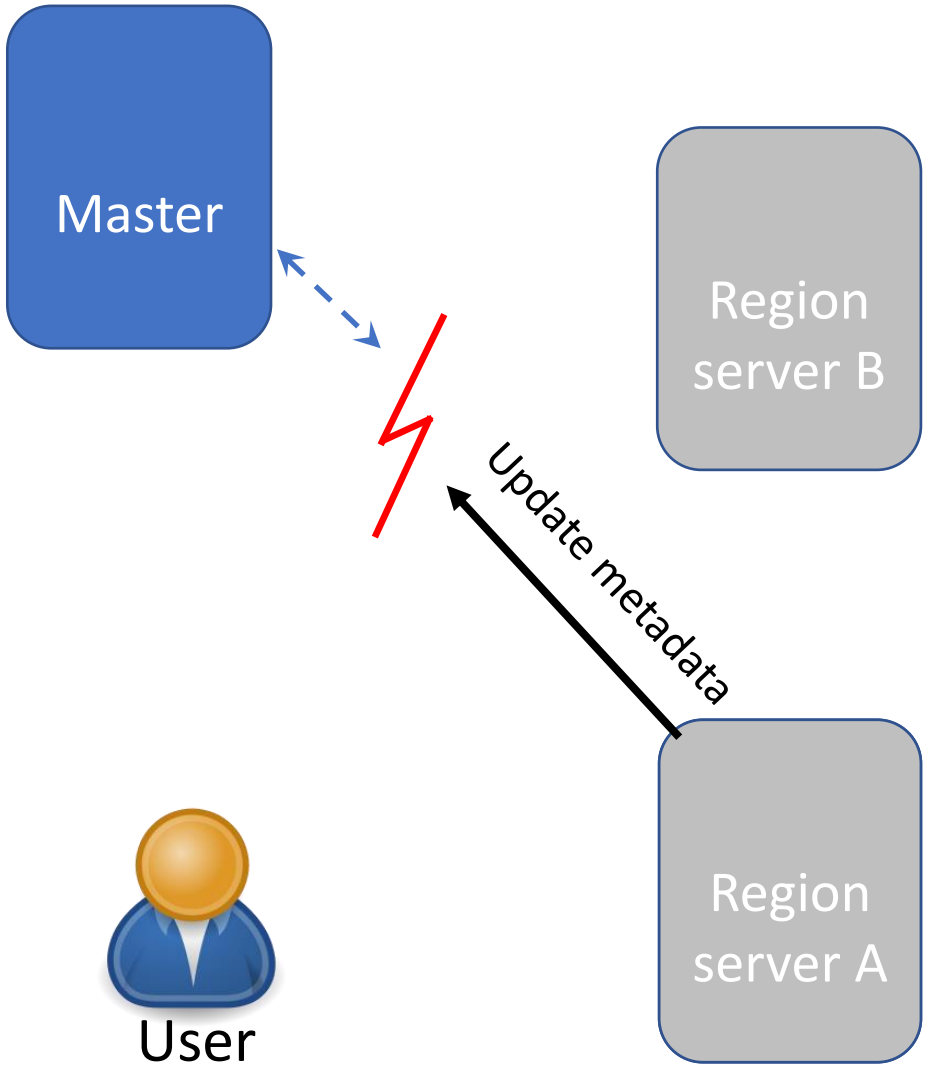


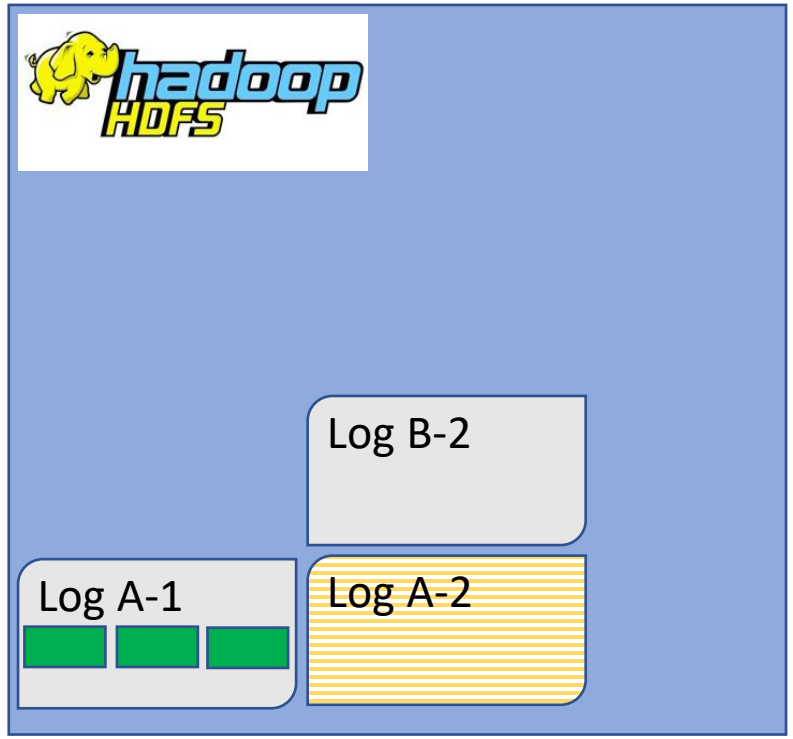


Partial network partition – HBase

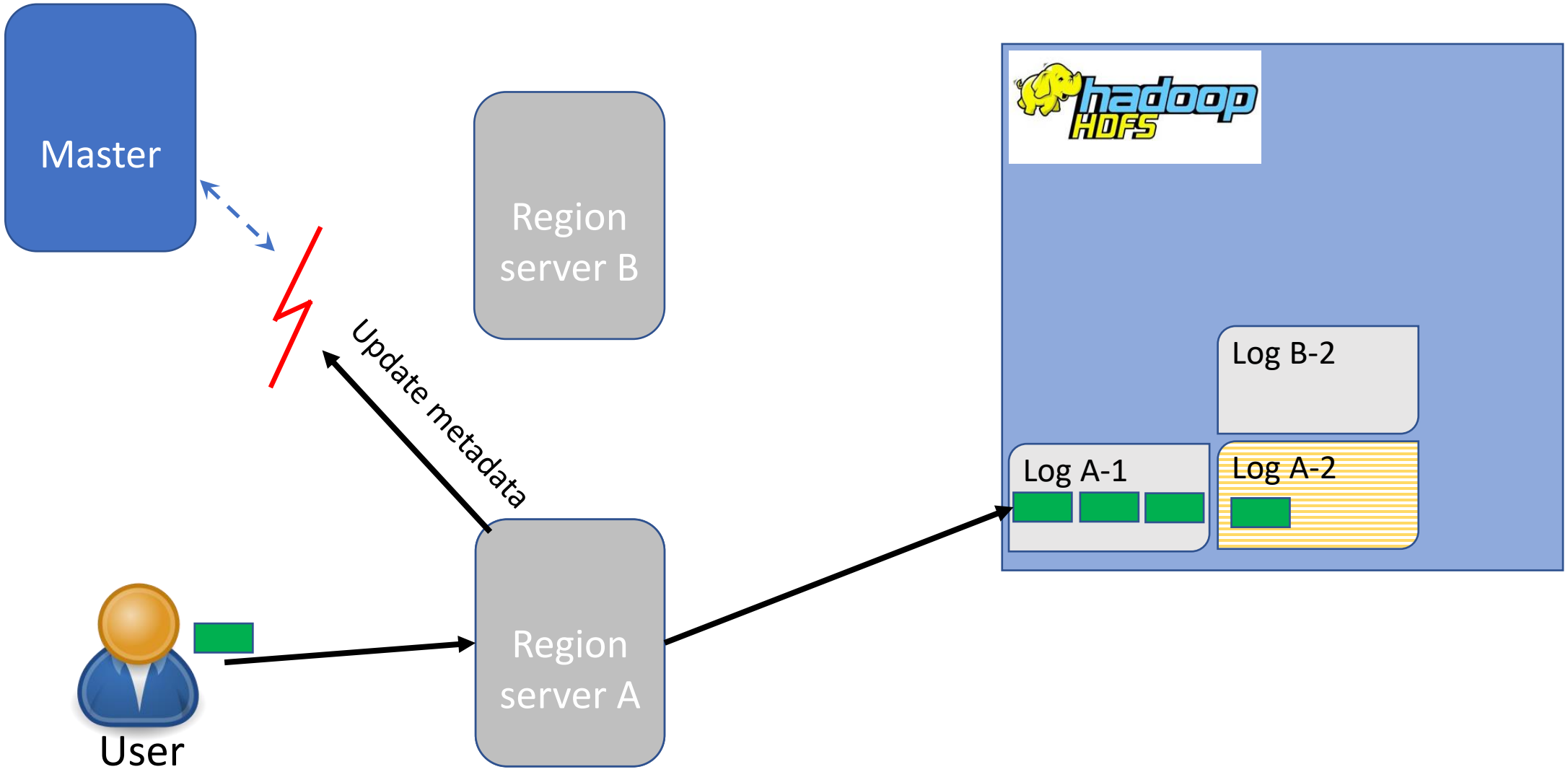


Partial network partition – HBase

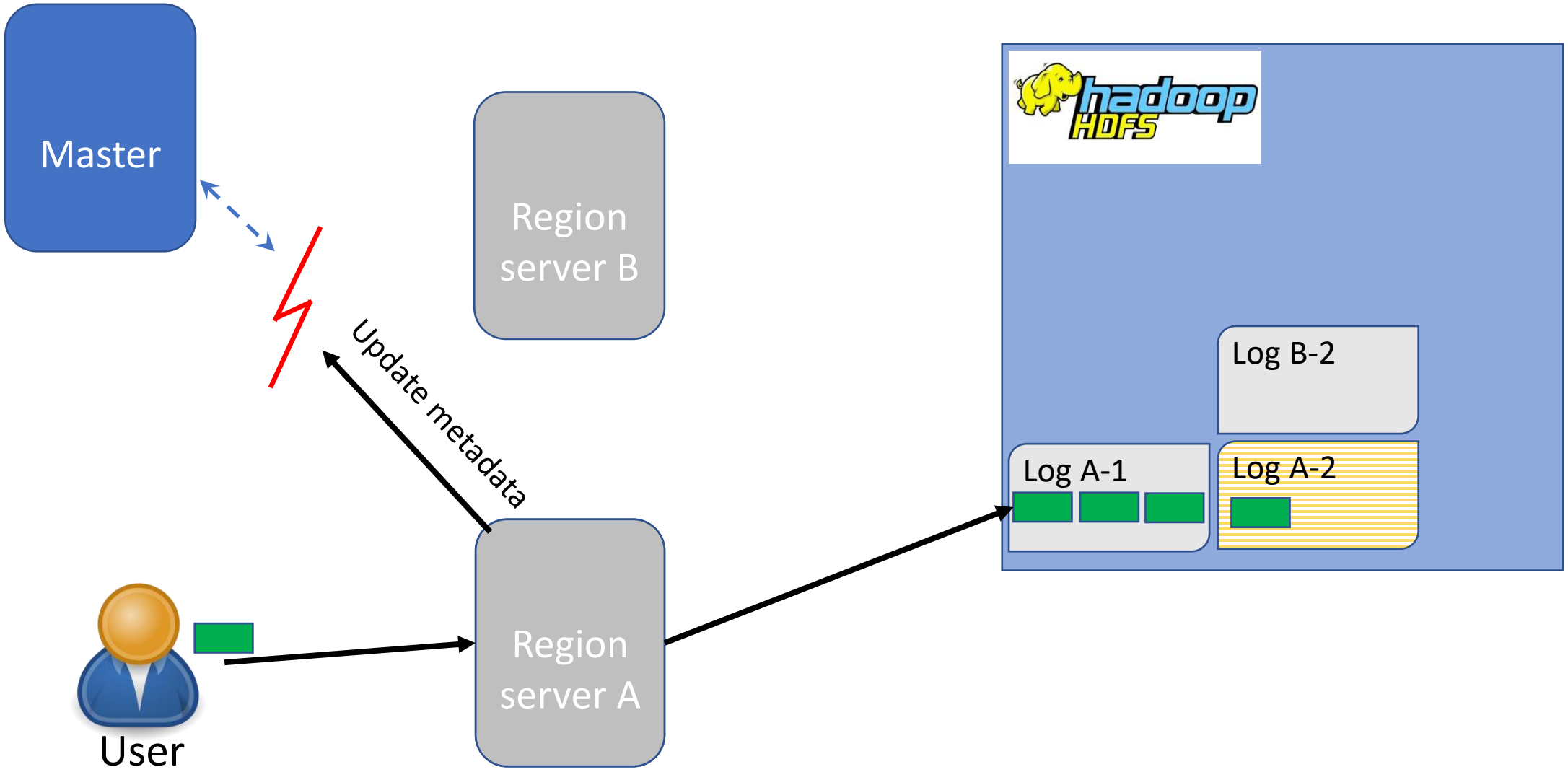




Partial network partition – HBase

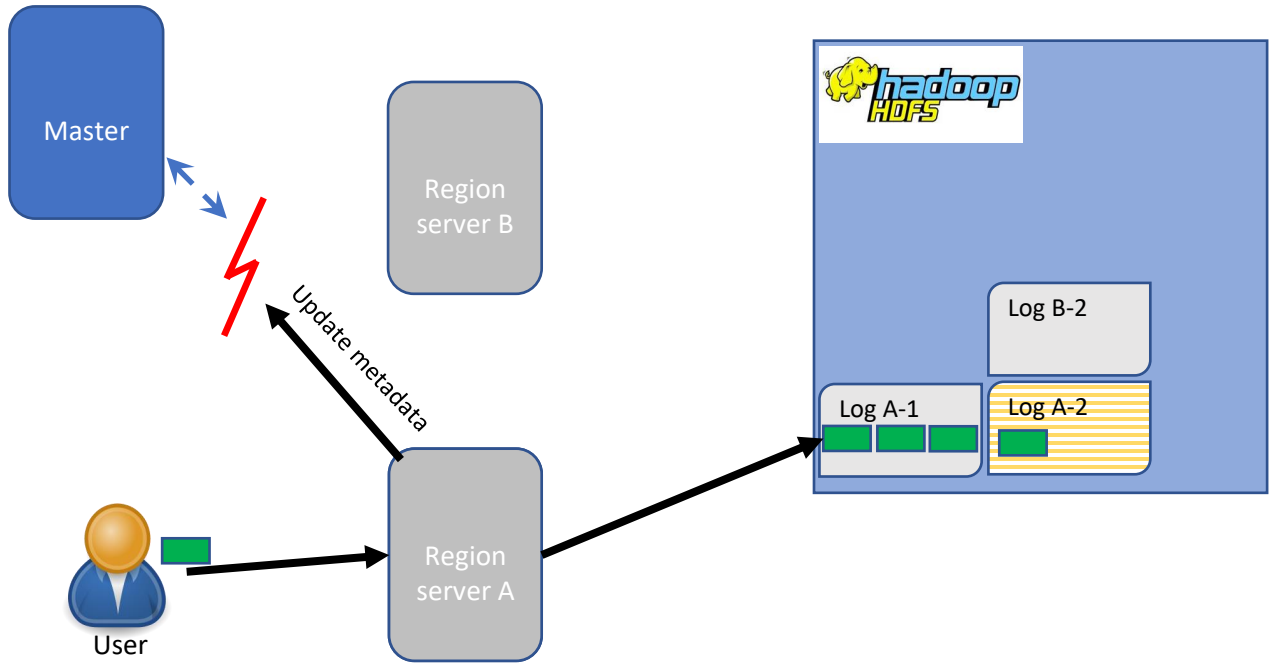


Partial network partition – HBase



Partial network partition – HBase

- Catastrophic: data loss.
- Easy to manifest: deterministic and requires a few events.



What is the impact of partial partitioning?

- Catastrophic: 75% (e.g., data loss or corruption).
- Silent: 84%.
- Permanent: 24% have lasting impact.

How easy are they to manifest?

- Partition only one node.
- No client access or a client access to one side: 60%
- Three or less events: 69%
- Deterministic

Surprisingly, easy to manifest failures cause catastrophic effects.

Other findings

- Vulnerable mechanisms: leader election, config. change, and replication
- Testability: reproducible on 5 nodes
- Design flaws: majority are due to design flews

Outline

- What causes partial network partitioning?
- How do they impact systems?
- Are there any fault tolerance techniques?
- NIFTY: a generic fault tolerance technique
- Evaluation

Study of fault tolerance techniques

- Study the fault tolerance techniques of 8 popular systems.
- Study code patches of all studied failures.

Raft

RabbitMQ

Current Fault Tolerance Techniques

1. Graph-based connectivity monitoring (VoltDB)
2. Checking with neighbours (Elasticsearch, RabbitMQ)
3. Failure verification (MongoDB, Raft, Elasticsearch)
4. Neutralizing partitioned nodes (Mesos, MapReduce, HBase)

Current Fault Tolerance Techniques

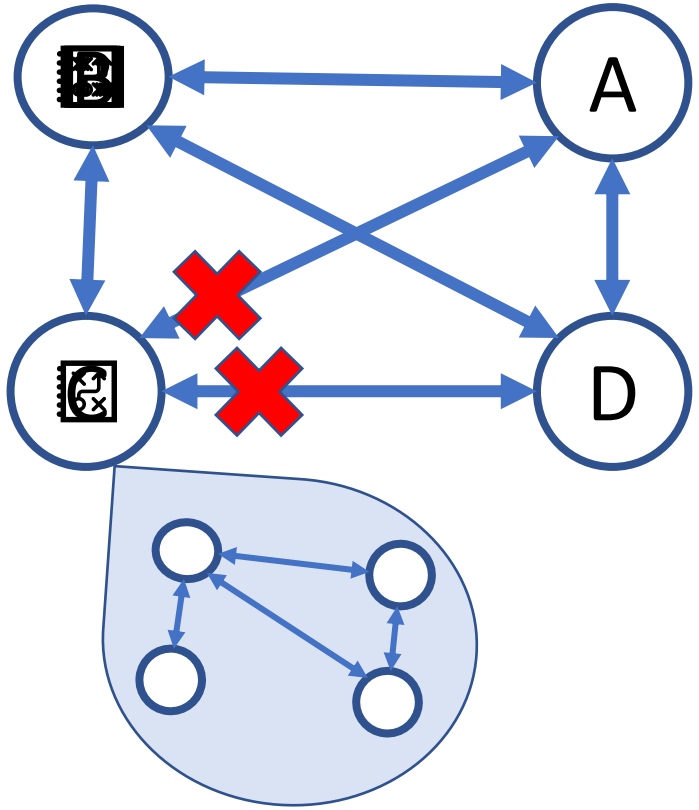
1. Graph-based connectivity monitoring (VoltDB)
2. Checking with neighbours (Elasticsearch, RabbitMQ)
3. Failure verification (MongoDB, Raft, Elasticsearch)
4. Neutralizing partitioned nodes (Mesos, MapReduce, HBase)

Graph-based connectivity monitoring

Idea: Build and analyze a connectivity graph.

How it works:

- All-to-all heart beating
- On a partition: nodes exchange connectivity information
- Each node finds the largest fully-connected sub-graph

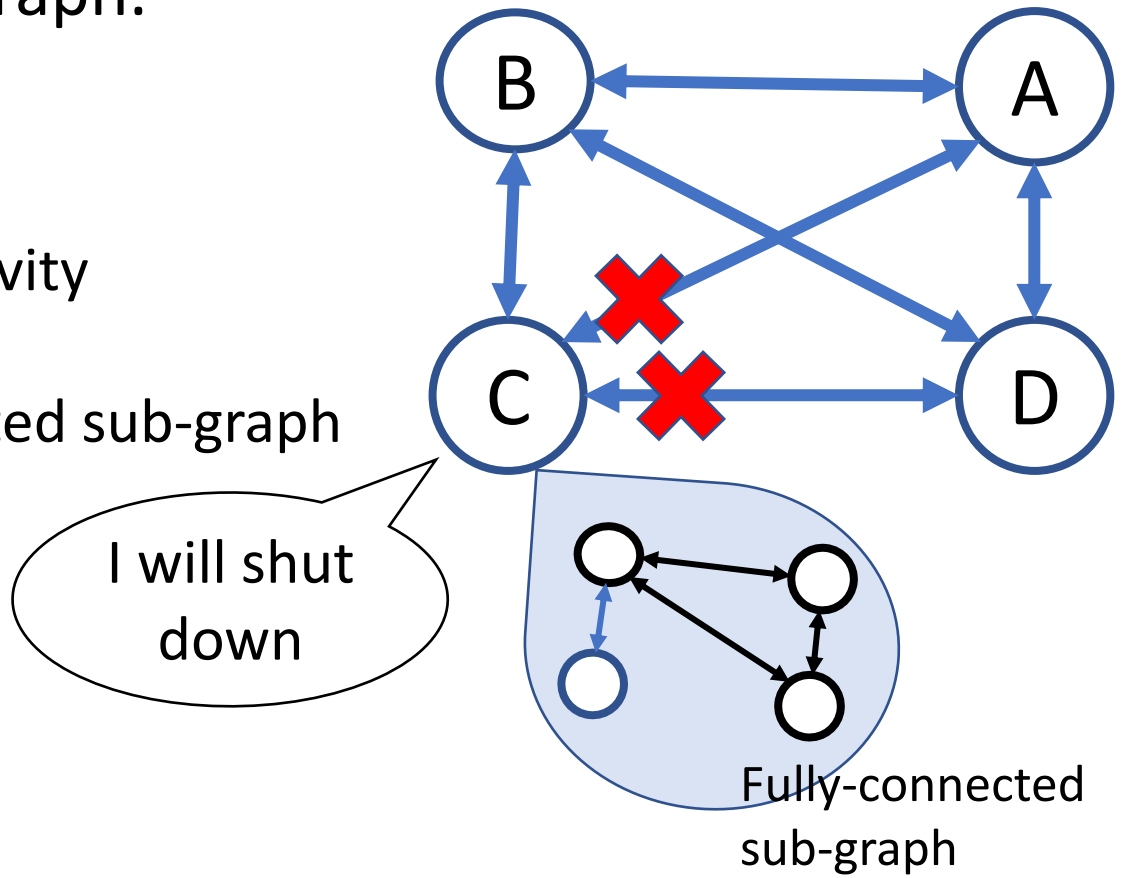


Graph-based connectivity monitoring

Idea: Build and analyze a connectivity graph.

How it works:

- All-to-all heart beating
- On a partition: nodes exchange connectivity information
- Each node finds the largest fully-connected sub-graph
- Nodes out of the sub-graph shut down
- If any data is lost, shut down the cluster



Graph-based Technique Shortcomings

- Unnecessarily shut down nodes.

- High chance of a complete cluster shutdown.

  Partitioning 20% of nodes often leads to complete cluster shutdown.

Shortcomings

	Surviving Clique
	VoltDB
Reduced Availability	X
Complete Unavailability	X
Complete Partition	
Double Execution	
Data Unavailability	
Scope (System/Mechanism)	S

Shortcomings

	Surviving Clique	Checking w/ Neighbors	Failure Verification	Neutralizing Nodes
	VoltDB	Elasticsearch/RabbitMQ	MongoDB/LogCabin	MapReduce/Hbase/Mesos
Reduced Availability	X	X	X	X
Complete Unavailability	X	X		
Complete Partition		X		
Double Execution				X
Data Unavailability		X		
Scope (System/Mechanism)	S	M/S	M	M

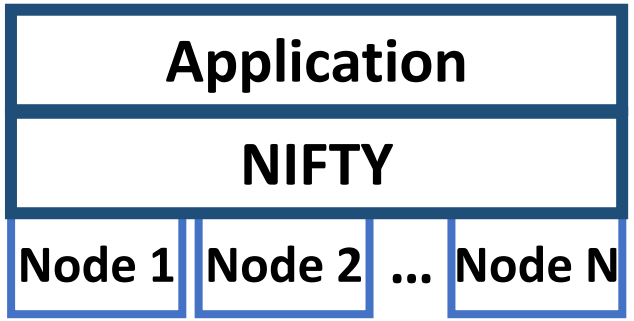
All current fault tolerance techniques have severe shortcomings.

Outline

- What causes partial network partitioning?
- How do they impact systems?
- Are there any fault tolerance techniques?
- NIFTY: a generic fault tolerance technique
- Evaluation

NIFTY

A **N**etwork part**i**tioning **f**ault **t**olerance la**y**er (NIFTY)



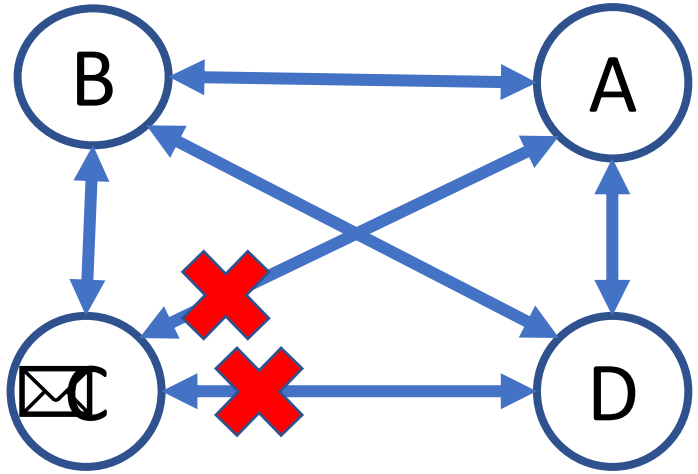
Goals:

- System agnostic
- No changes to existing systems
- Negligible overhead

Insight: leverage existing monitoring techniques to detour traffic around partial partitions.

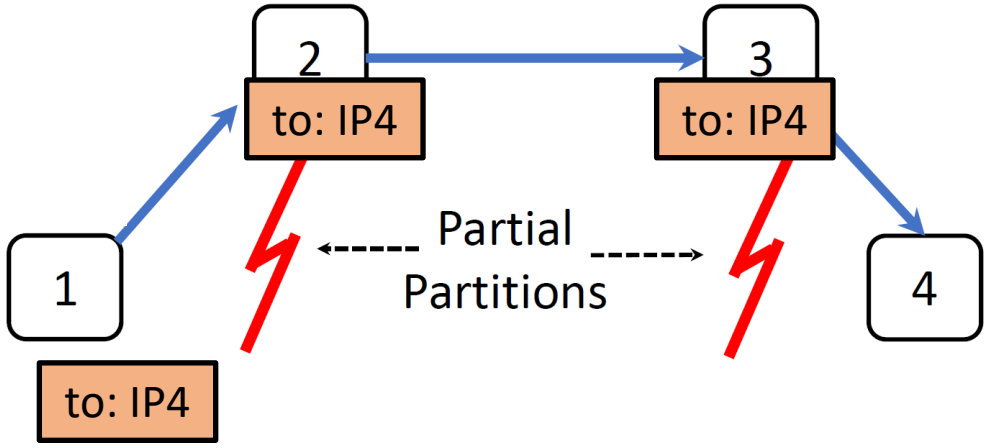
How NIFTY works

- Use heartbeats to detect partial partitions
- On a partial partition: detour packets through intermediate nodes
- Use distance vector routing
- Use OpenVSwitch to deploy routes on end nodes



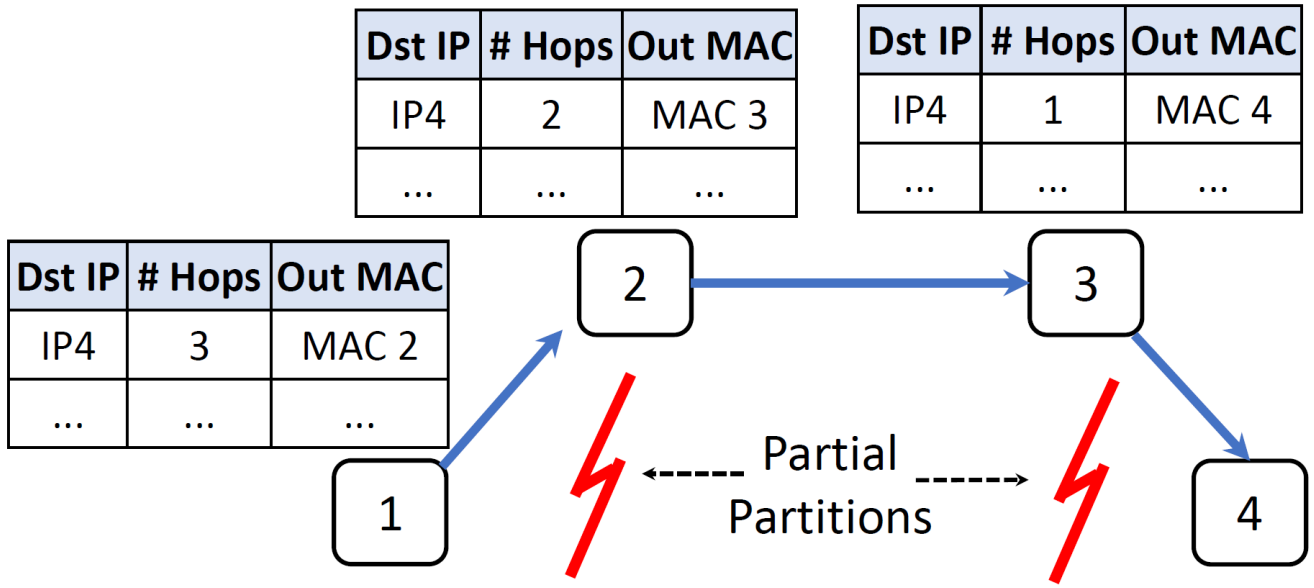
How NIFTY works

Rerouting done through MAC address manipulation



How NIFTY works

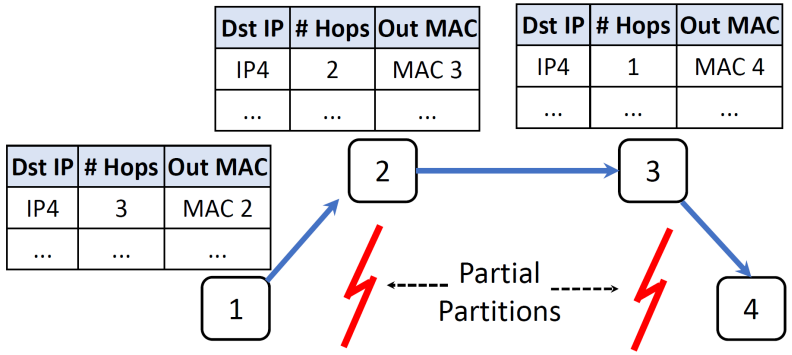
Rerouting done through MAC address manipulation



How NIFTY works

Rerouting done through MAC address manipulation

- Simple
- Agnostic to system running atop of it
- Transparently masks partial partitions



Outline

- What causes partial network partitioning?
- How do they impact systems?
- Are there any fault tolerance techniques?
- NIFTY: a generic fault tolerance technique
- Evaluation

Evaluation

- What is Nifty's overhead?
- How systems perform under a partial partition?
- How does nifty scale for large clusters?
- What is the utility of Nifty's classification API?

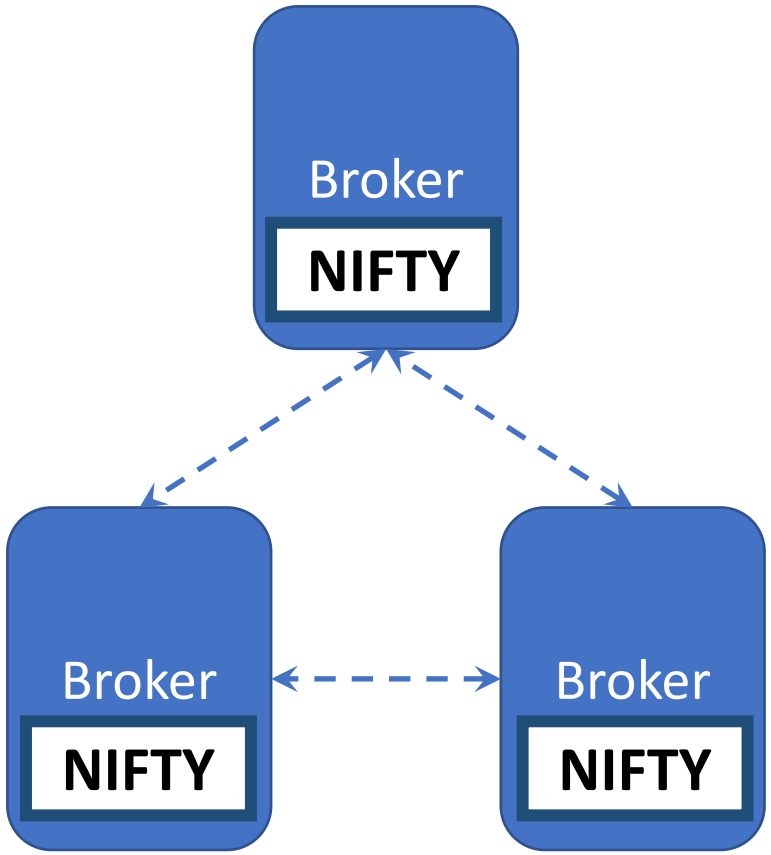
Evaluation

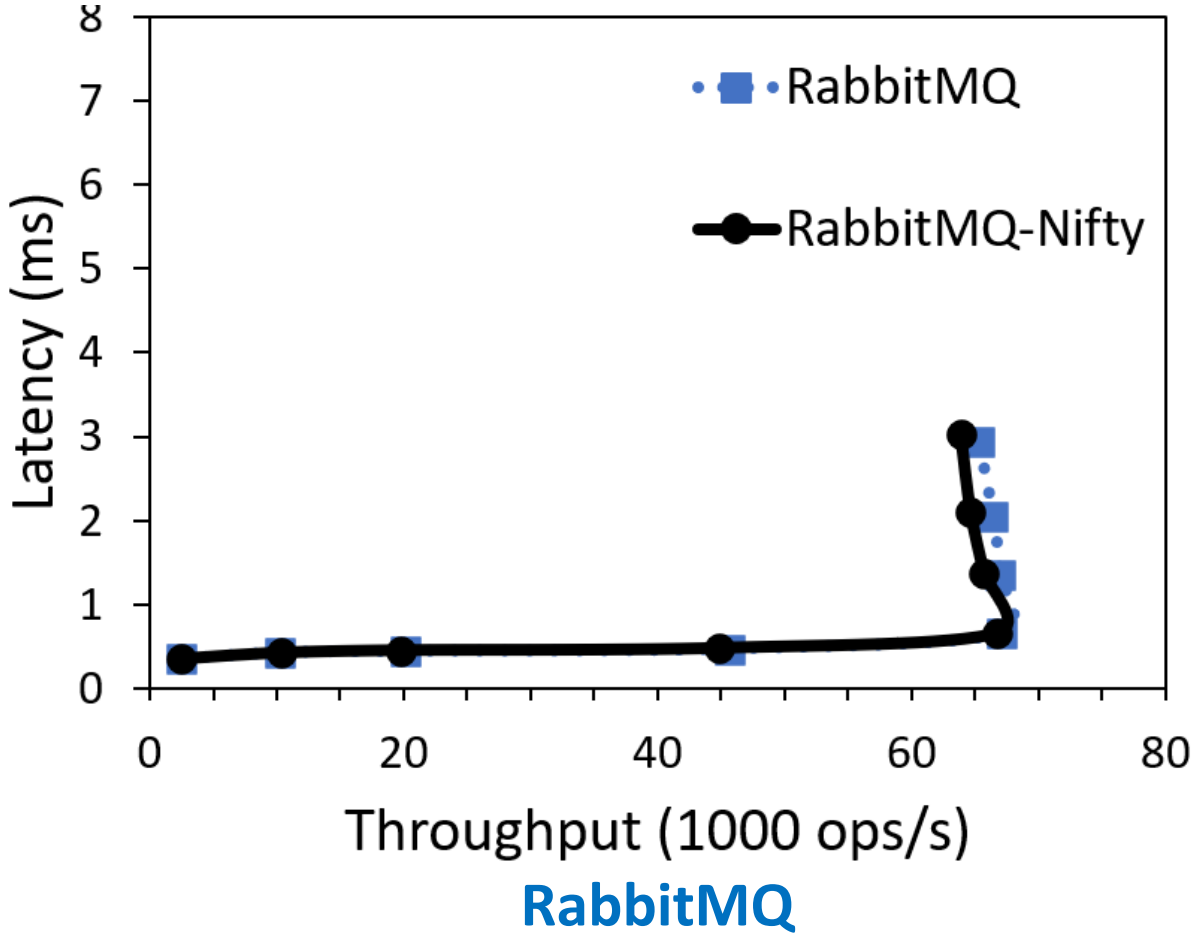
- What is Nifty's overhead?
- How systems perform under a partial partition?
- How does nifty scale for large clusters?
- What is the utility of Nifty's classification API?

Evaluation setup

- Measure the impact of Nifty on 6 systems.
- 40 nodes in Cloudlab Utah cluster.

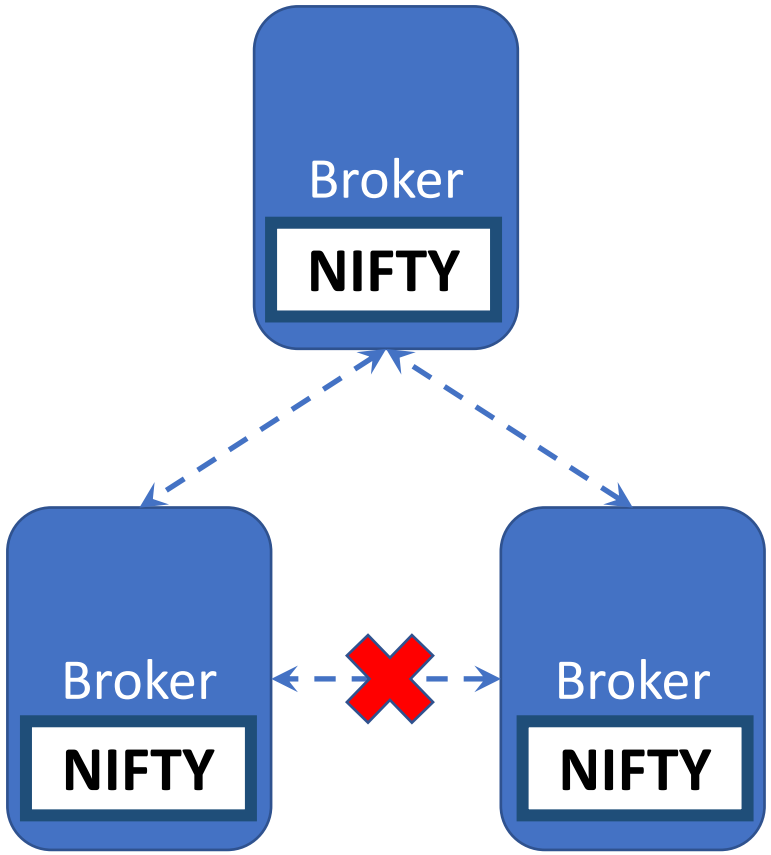
Evaluation: Overhead - RabbitMQ

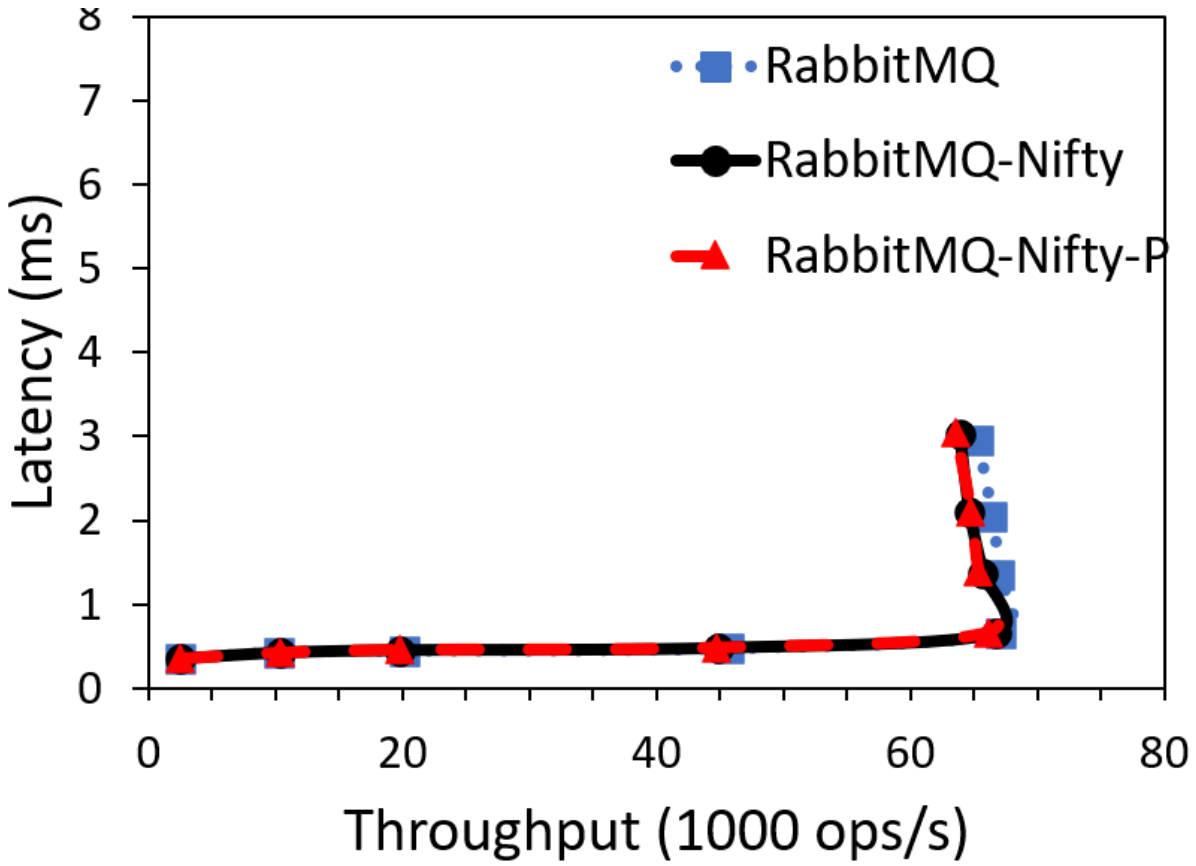




RabbitMQ

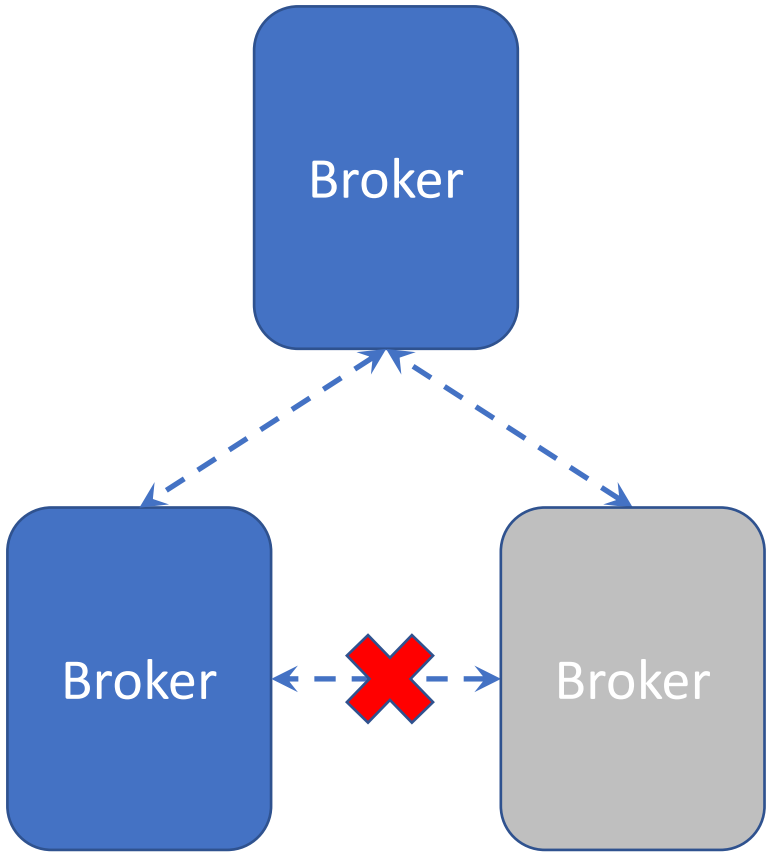
Evaluation: Performance with a Partition

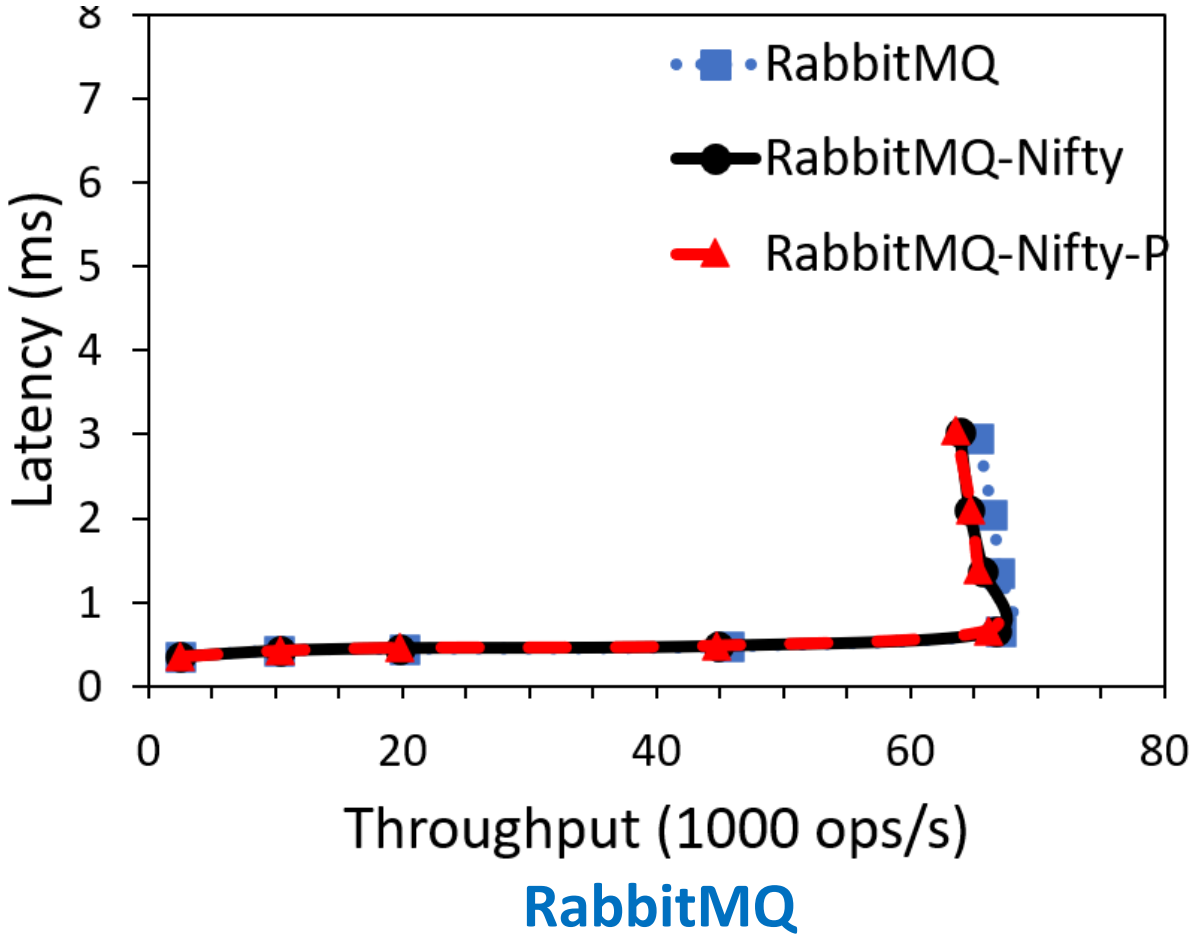




RabbitMQ

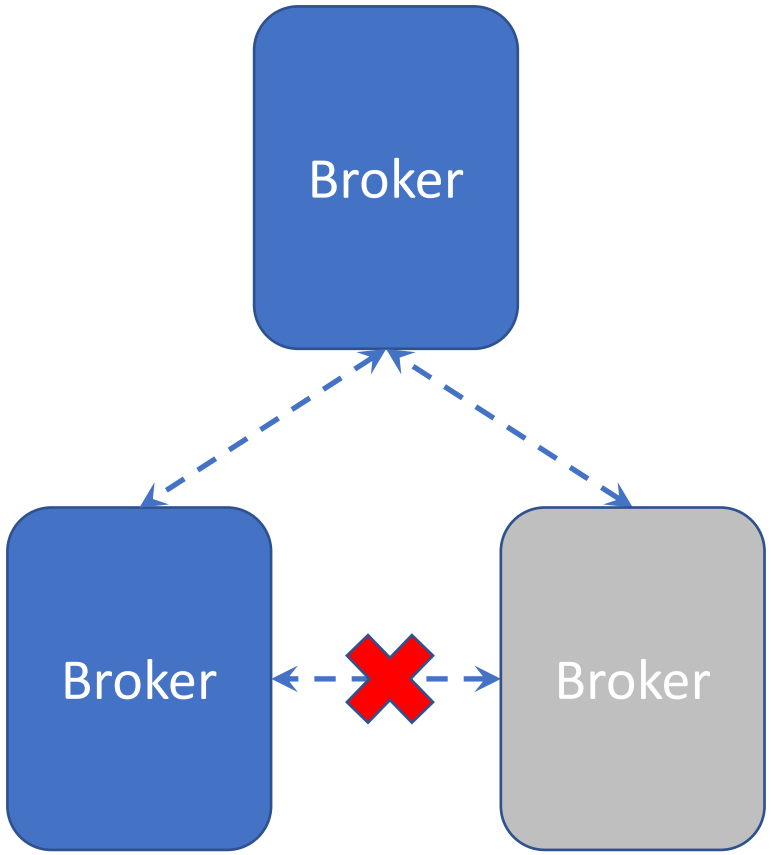
Evaluation: Performance with a Partition

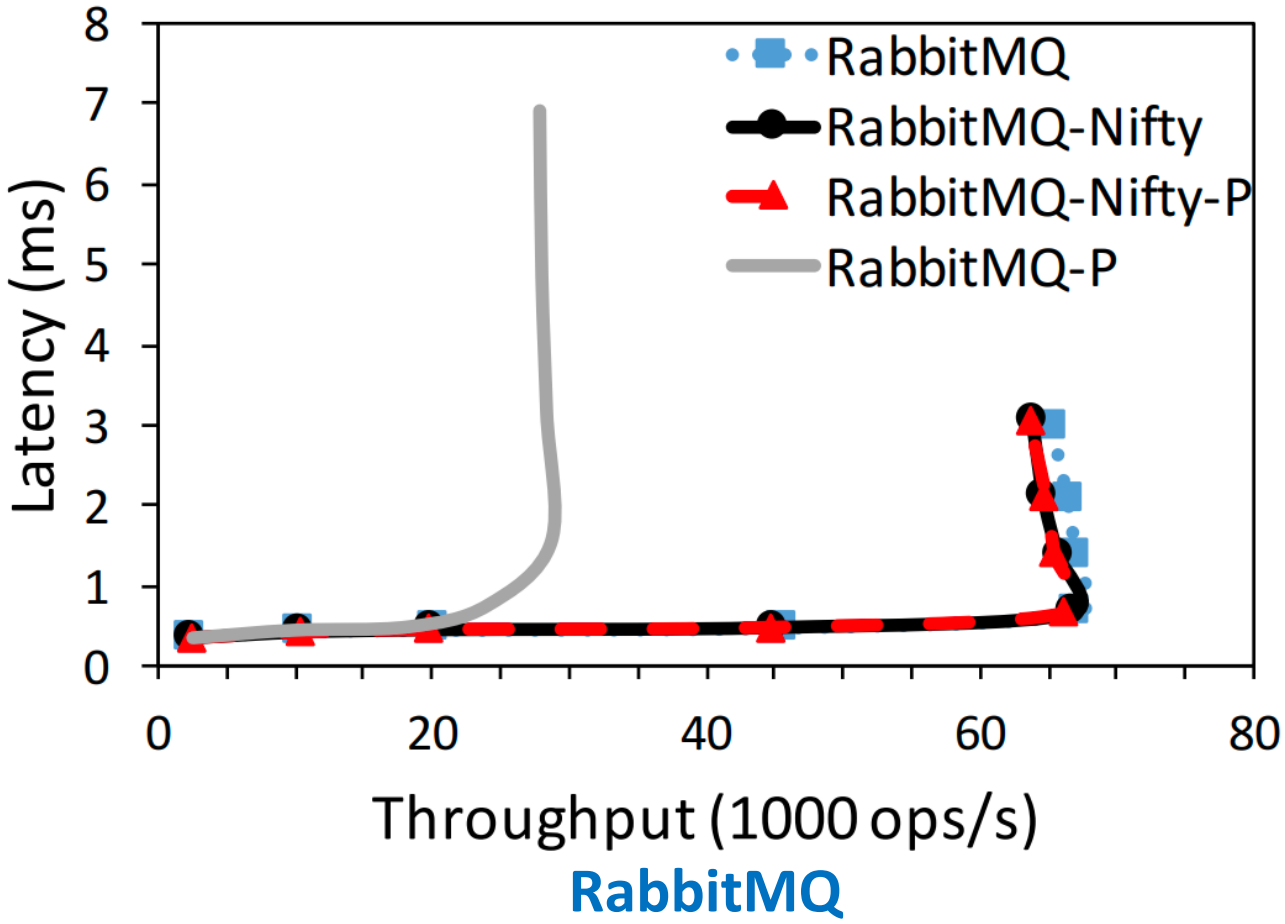




RabbitMQ

Evaluation: Performance with a Partition

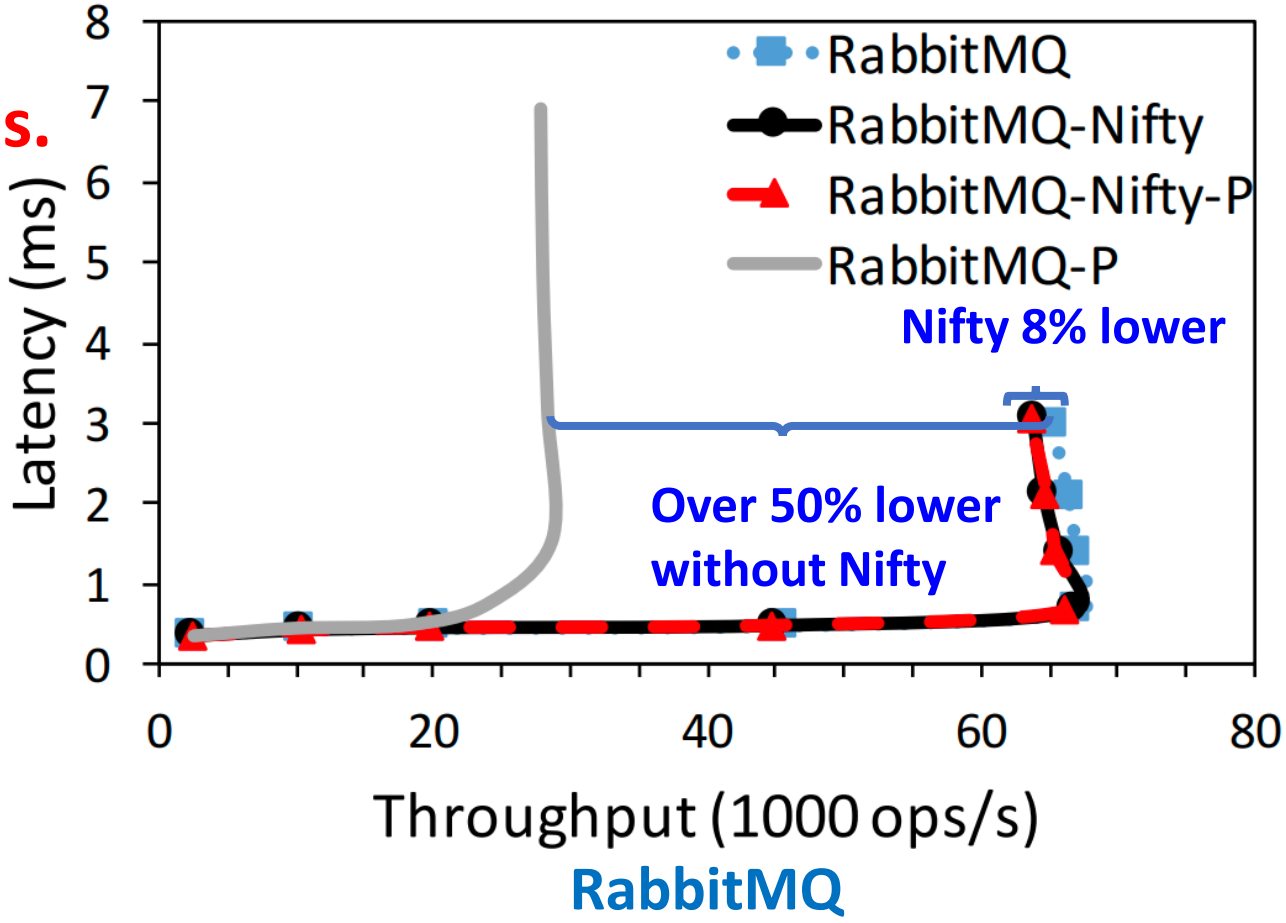




Evaluation: Performance with a Partition

NIFTY has a negligible overhead.

Effectively mask partial partitions.



Conclusion

- First comprehensive study of partial partitioning failures:
  - Failures are catastrophic
  - Failures are easy to manifest
- First study of current fault tolerance techniques:
  - All current techniques have severe shortcomings
- Built Nifty
  - Simple
  - Transparent
  - Low overhead

Thank you!

Source code available at: https://wasl.uwaterloo.ca/projects/nifty/