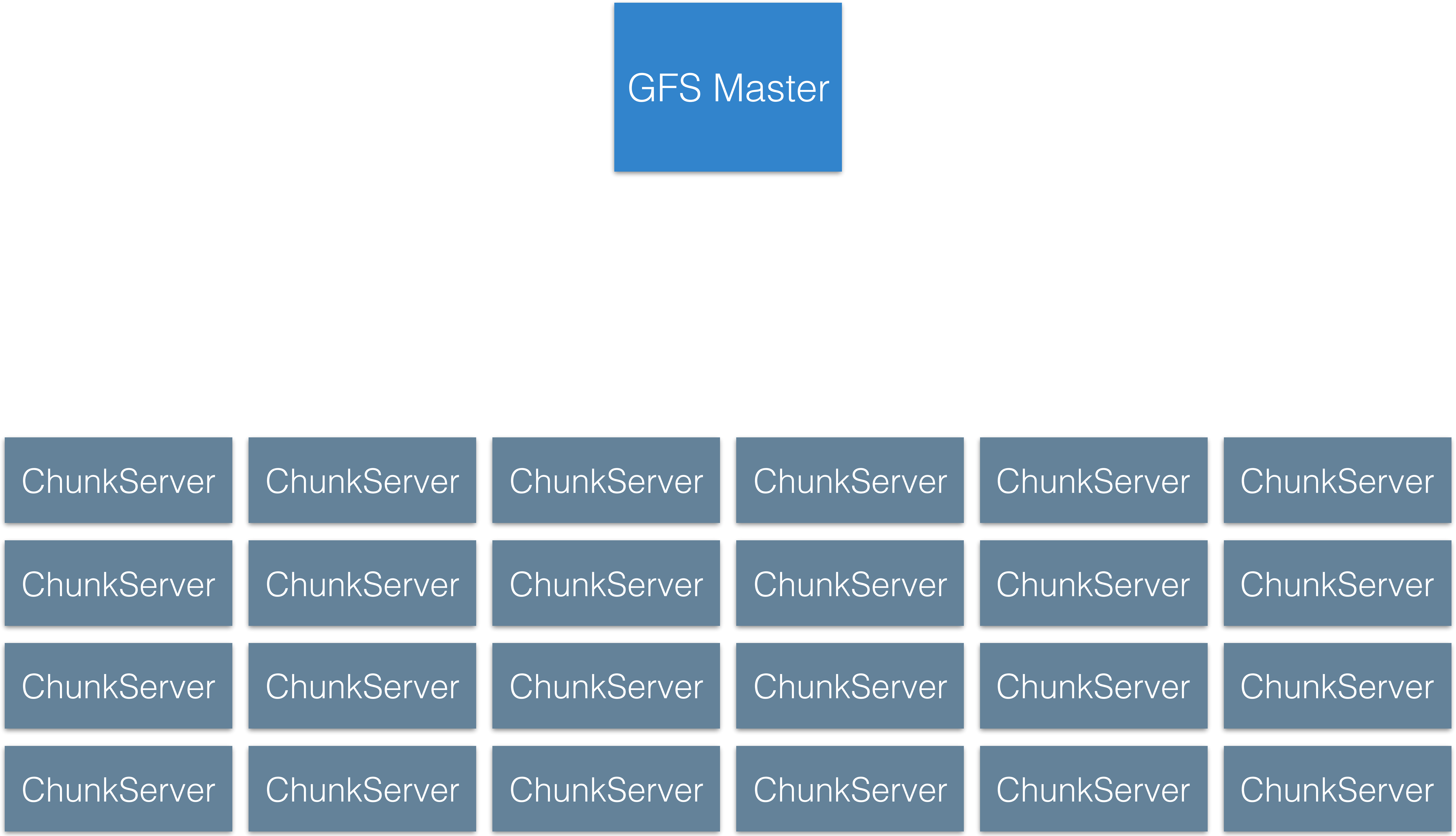
ZooKeeper & Curator

CS 475, Fall 2019
Concurrent & Distributed Systems

GEORGE MASON UNIVERSITY

GFS Architecture



GFS Master

ChunkServer ChunkServer ChunkServer ChunkServer ChunkServer ChunkServer

ChunkServer ChunkServer ChunkServer ChunkServer ChunkServer ChunkServer

ChunkServer ChunkServer ChunkServer ChunkServer ChunkServer ChunkServer

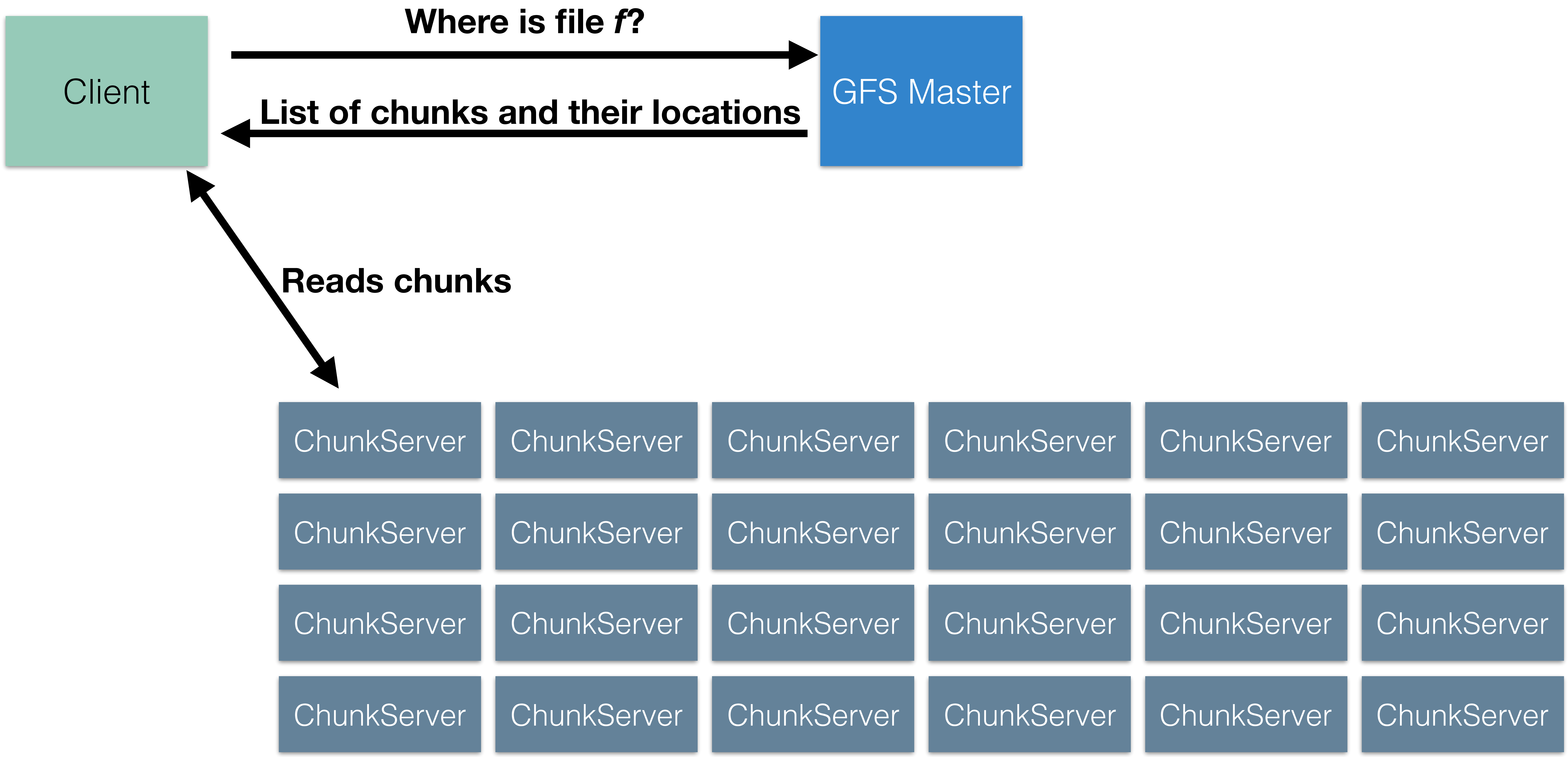
ChunkServer ChunkServer ChunkServer ChunkServer ChunkServer ChunkServer

GFS Metadata Example

Chunk ID	Filename	Part of file	Master Chunk Server	Other Chunk Servers
1	/foo/bar	1 of 1	A, valid for 1 more minute	B, C
2	/another/file	1 of 2	B, valid for 1 more minute	A, C
3	/another/file	2 of 2	D, valid for 1 more minute	C, E

Note - can get very good parallelism by splitting chunks of the same file across different chunk servers

GFS - Reads



Client

Where is file *f*?

GFS Master

List of chunks and their locations

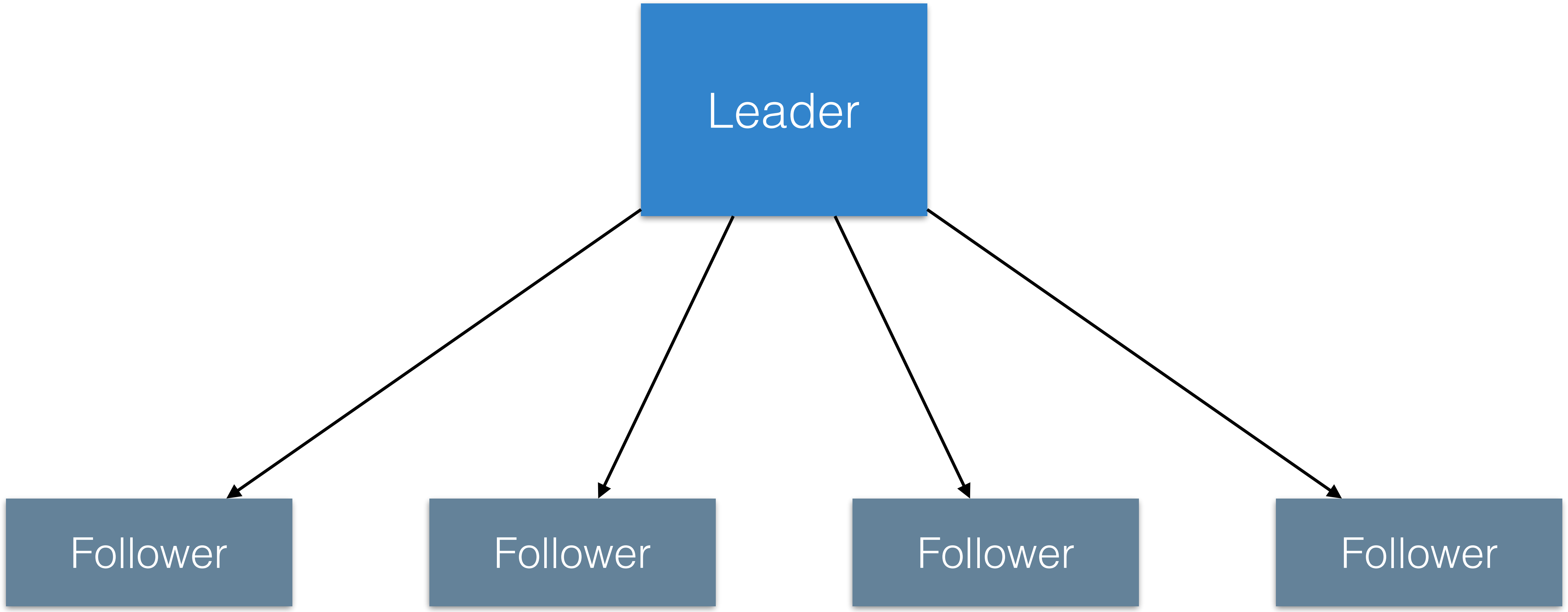
Reads chunks

ChunkServer	ChunkServer	ChunkServer	ChunkServer	ChunkServer	ChunkServer
ChunkServer	ChunkServer	ChunkServer	ChunkServer	ChunkServer	ChunkServer
ChunkServer	ChunkServer	ChunkServer	ChunkServer	ChunkServer	ChunkServer
ChunkServer	ChunkServer	ChunkServer	ChunkServer	ChunkServer	ChunkServer

Today

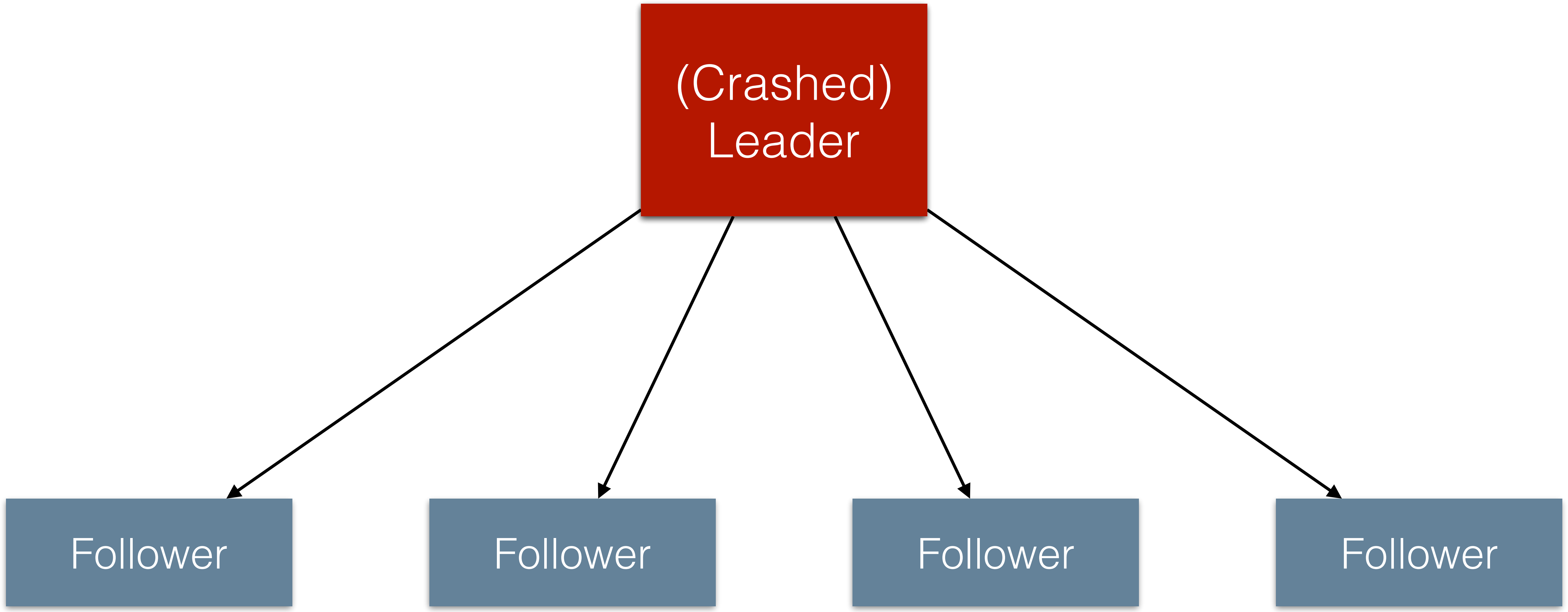
- Reminder - Project is out!
  - Fault-tolerant, sequentially consistent replicated key value store
  - Start thinking of groups (1 to 3 students per group)
- Today:
  - ZooKeeper - what does it give us and how do we use it?

Leader/follower distributed model



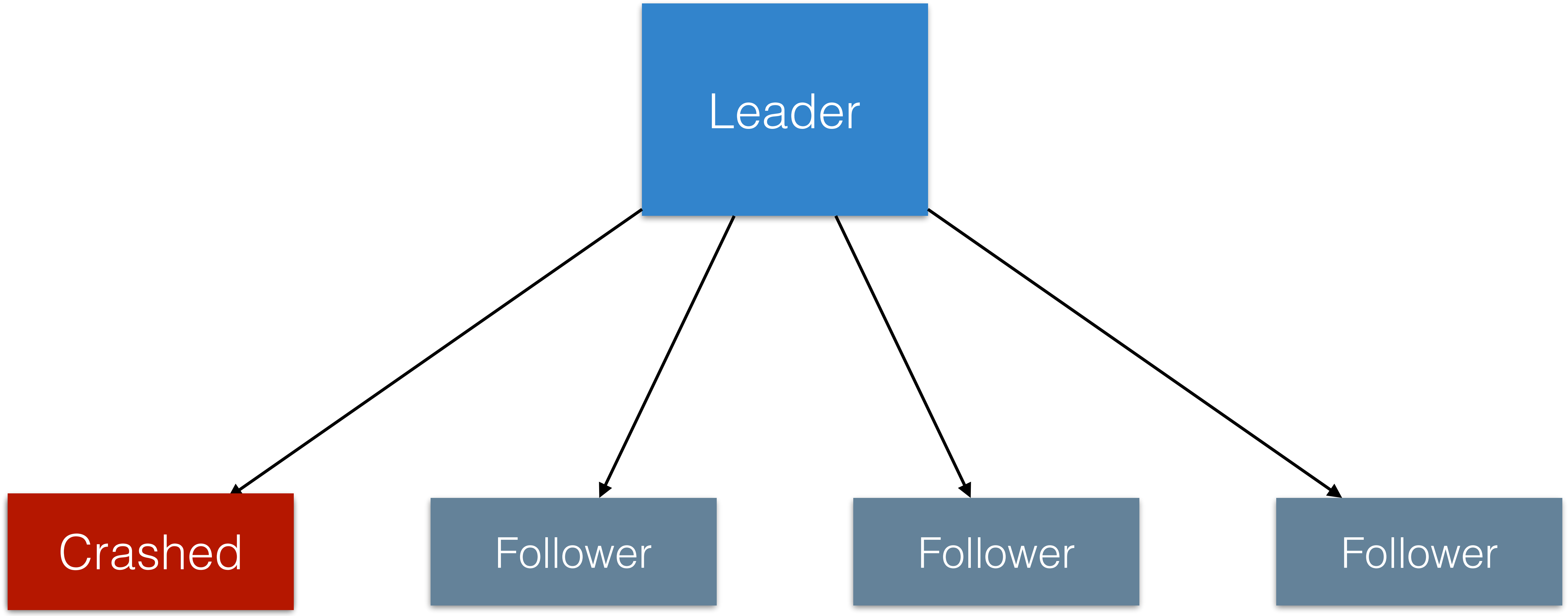
Leader/follower distributed model

- Leader is single point of failure!
- If leader fails, no work is assigned
- Need to select a new leader



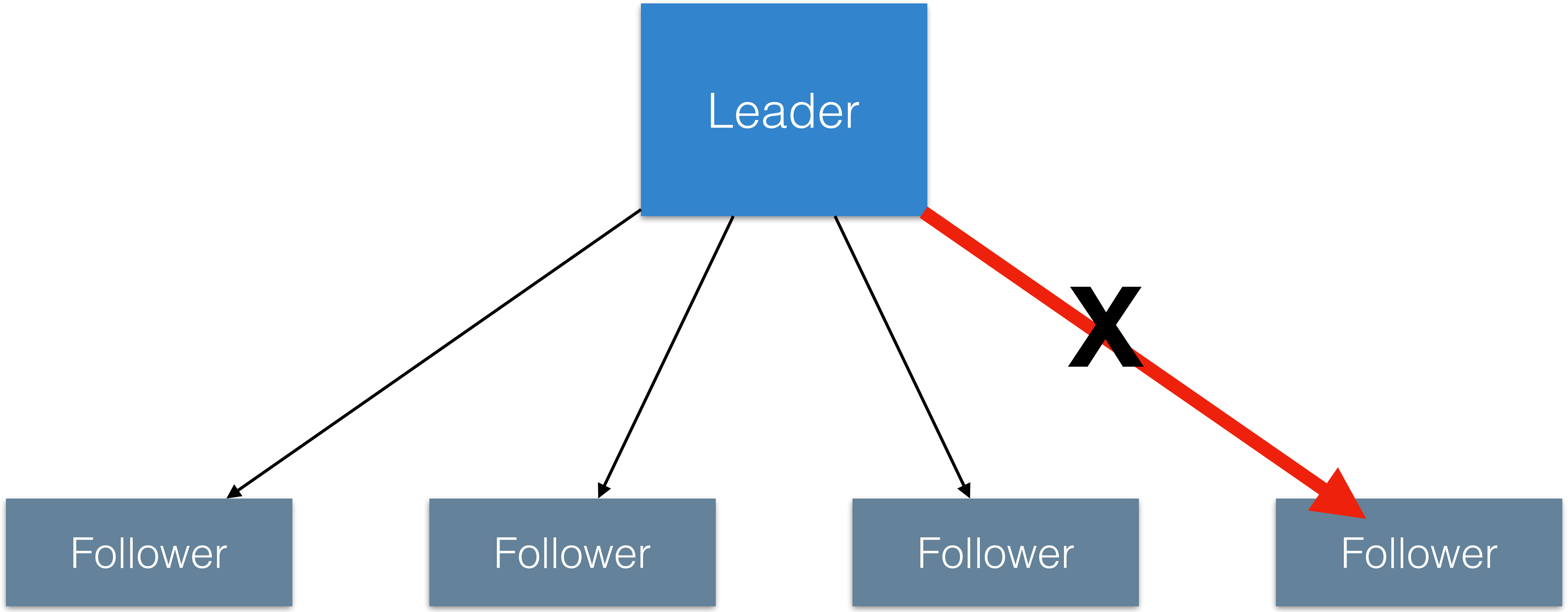
Leader/follower distributed model

- If a follower fails?
- Not as bad, but need to detect its failure
- Some tasks might need to get re-assigned elsewhere



Leader/follower distributed model

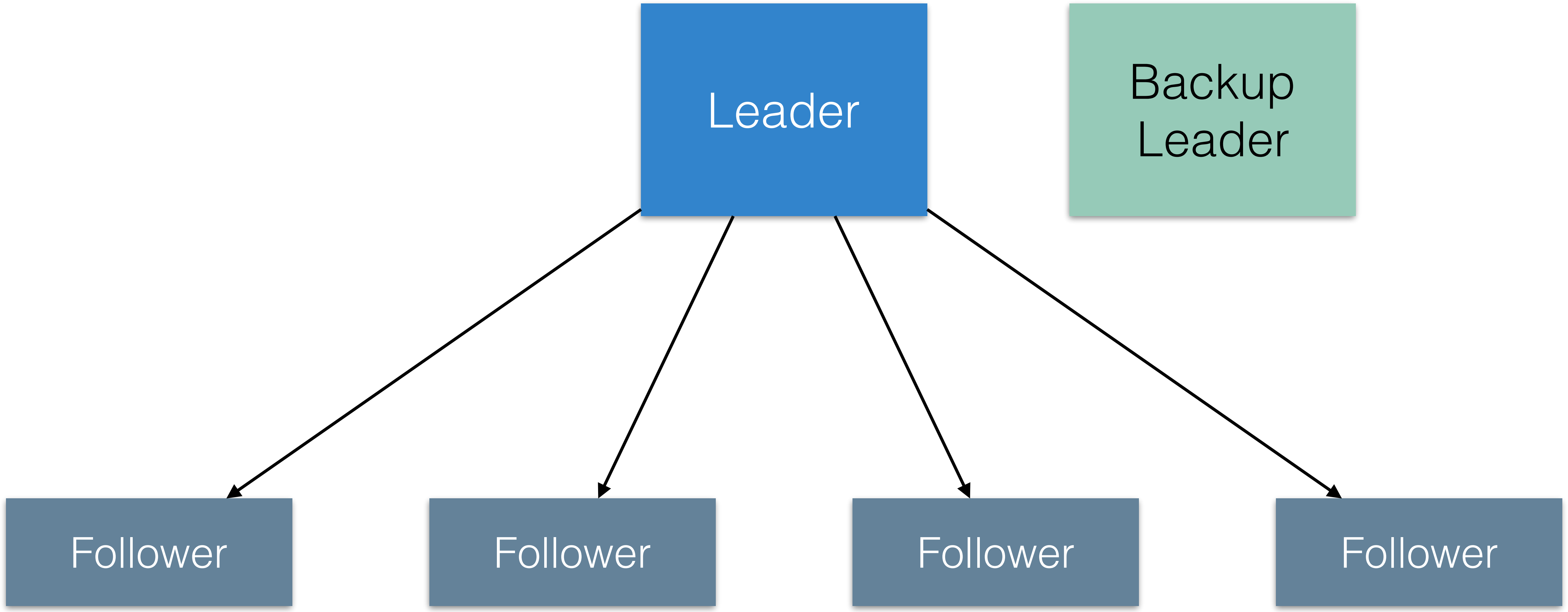
- If a follower doesn't receive a task (network link failure)?
- Again, not as bad, but need to detect
- Will need to try to re-establish link (difference between "there is no work left to do" and "I just didn't hear I needed to do something)



Coordination

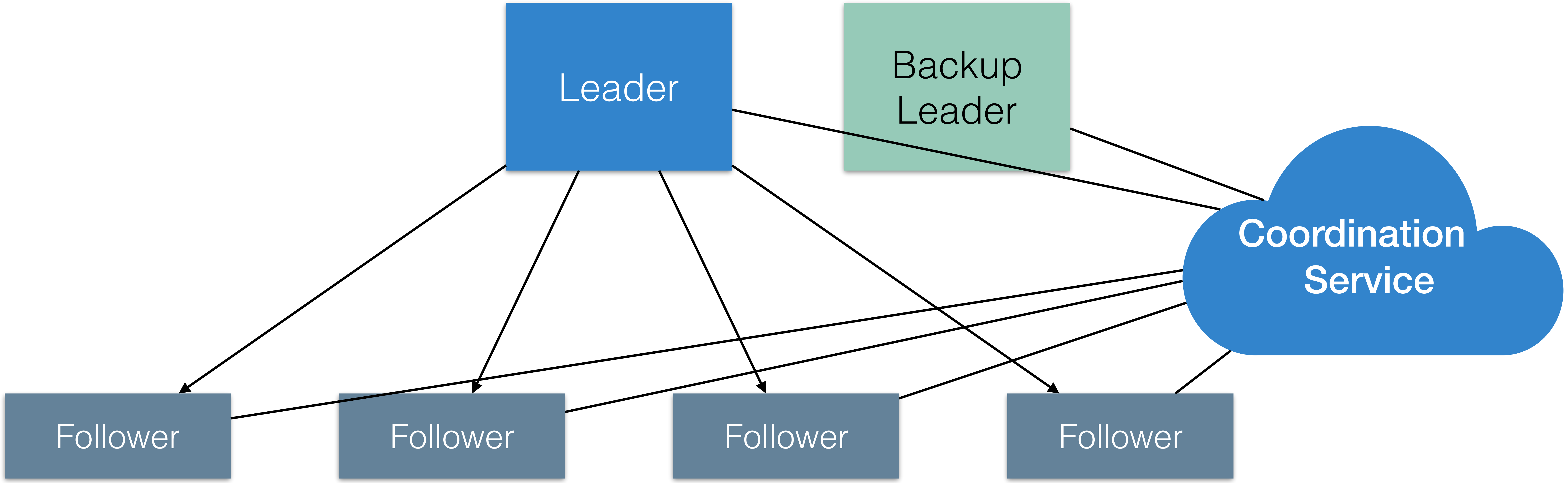
- Semaphores
- Queues
- Transactions
- Locks
- Barriers

Strawman Fault Tolerant Leader/Follower System



How do we know to switch to the backup?
How do we know when followers have crashed, or network has failed?

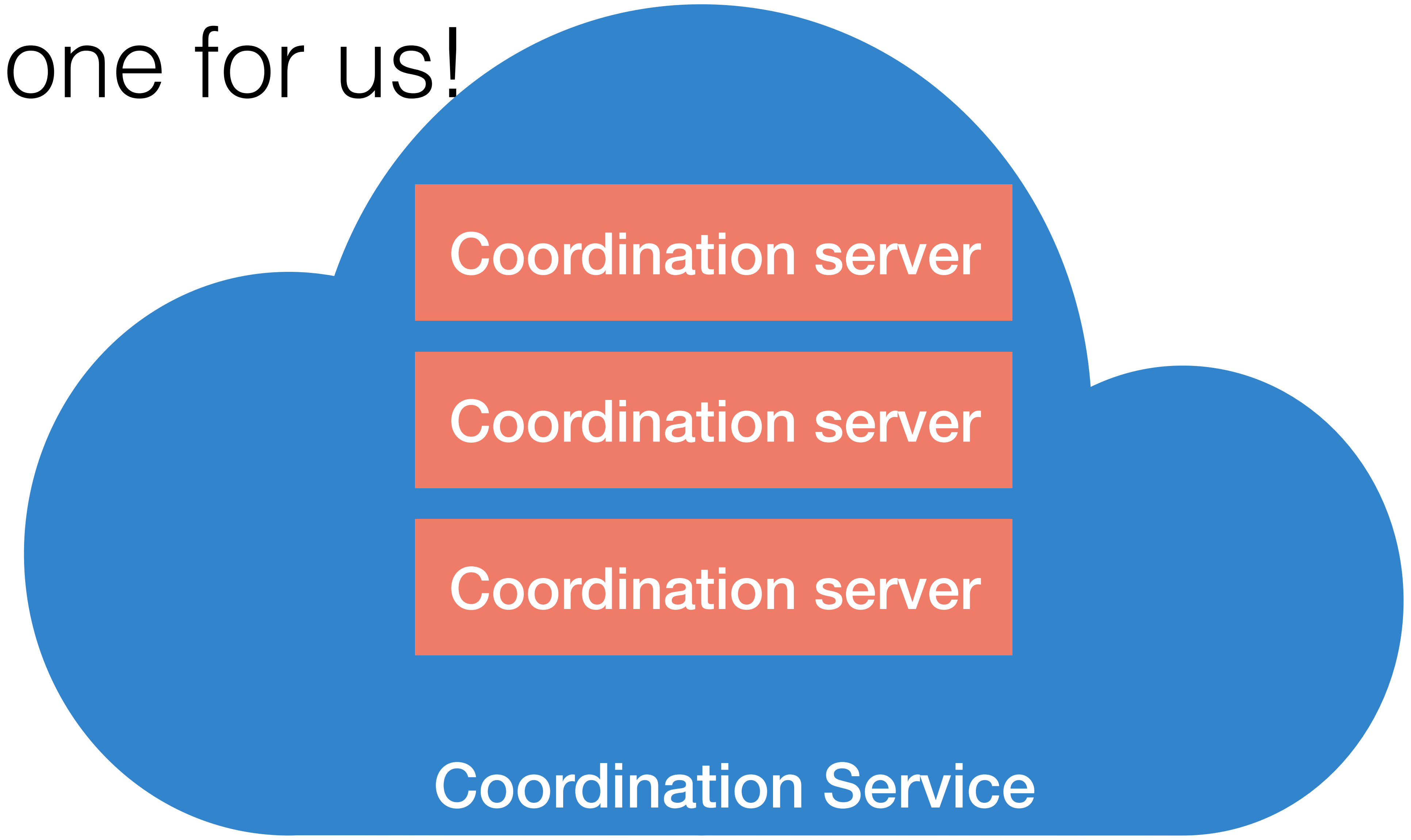
Fault Tolerant Leader/Follower System



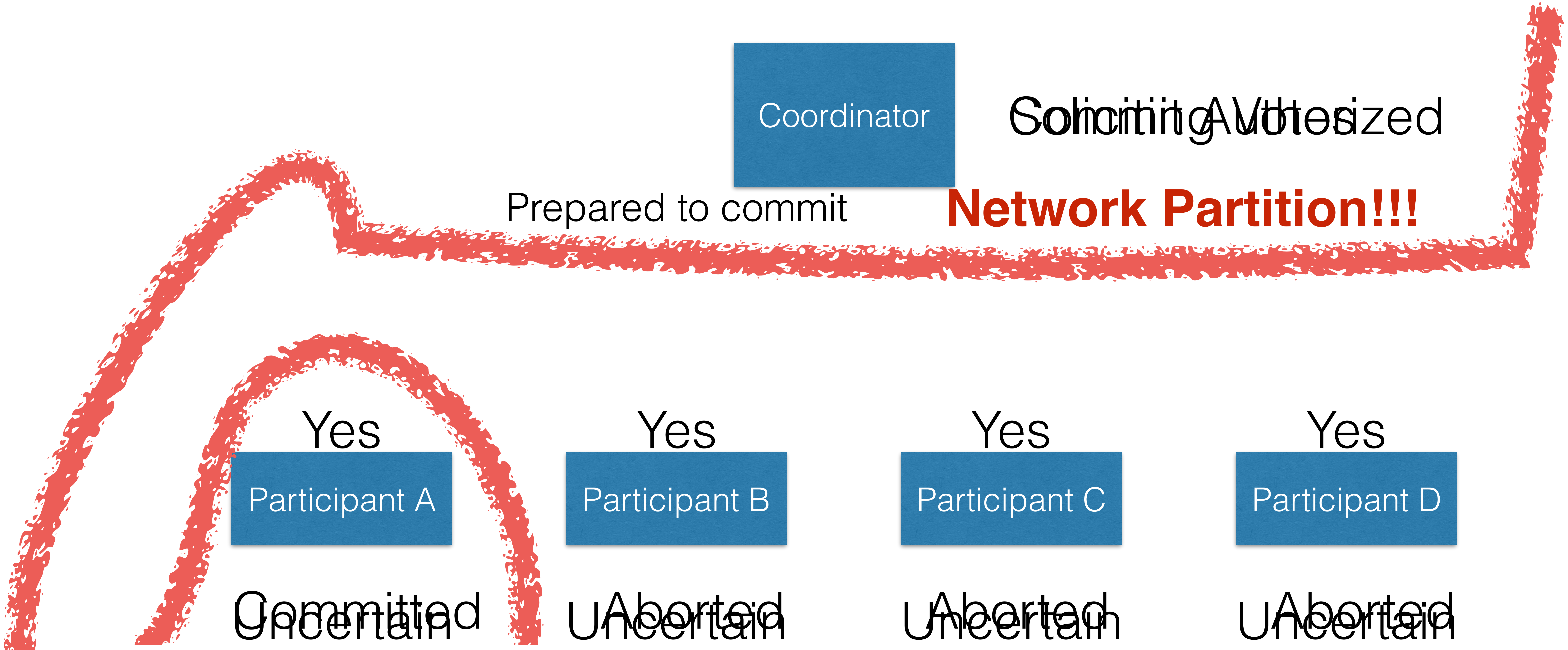
Coordination service handles all of those tricky parts.
But can't the coordination service fail?

Fault-Tolerant Distributed Coordination

- Leave it to the coordination service to be fault-tolerant
- Can solve our leader/follower coordination problem in 2 steps:
  - 1 - Write a fault-tolerant distributed coordination service
  - 2 - Use it
- Thankfully, (1) has been done for us!



Review: Partitions



Timeout behavior: Commit!

Timeout behavior: abort

Review: FLP - Intuition

- Why can’t we make a protocol for consensus/agreement that can tolerate both partitions and node failures?
- To tolerate a partition, you need to assume that **eventually** the partition will heal, and the network will deliver the delayed packages
- But the messages might be delayed **forever**
- Hence, your protocol would not come to a result, until **forever** (it would not have the **liveness** property)

ZooKeeper

- Distributed coordination service from Yahoo! originally, now maintained as Apache project, used widely (key component of Hadoop etc)
- Highly available, fault tolerant, performant
- Designed so that YOU don’t have to implement Paxos for:
  - Maintaining group membership, distributed data structures, distributed locks, distributed protocol state, etc

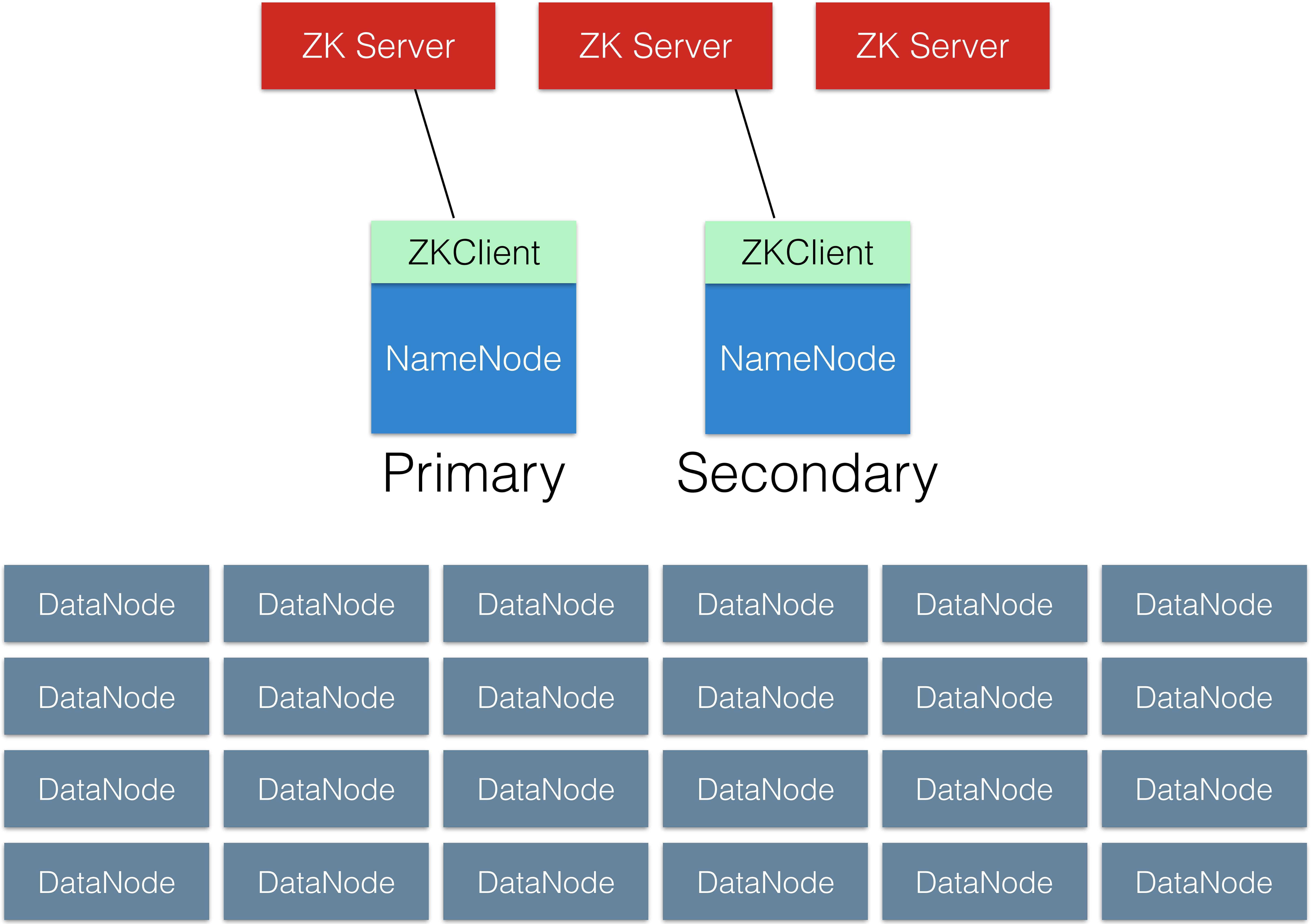
ZooKeeper - Guarantees

- **Liveness**: if a majority of ZooKeeper servers are active and communicating the service will be available
- **Atomic updates**: A write is either entirely successful, or entirely failed
- **Durability**: if the ZooKeeper service responds successfully to a change request, that change persists across any number of failures as long as a quorum of servers is eventually able to recover

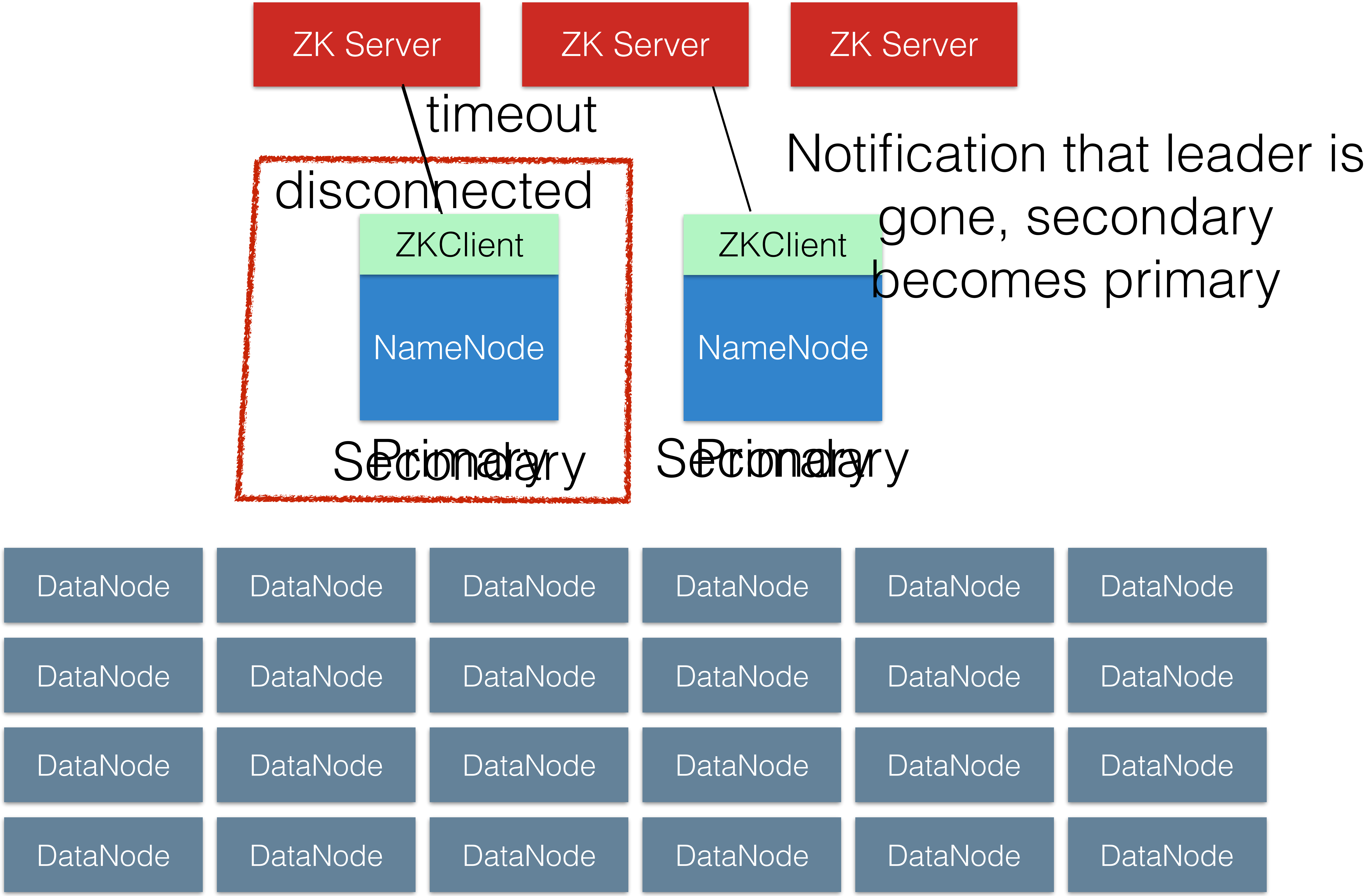
Example use-cases

- Configuration management (which servers are doing what role?)
- Synchronization primitives
- Anti-use cases:
    - Storing large amounts of data
    - Sharing messages and data that don’t require liveness/durability guarantees

Hadoop + ZooKeeper



Hadoop + ZooKeeper



ZK Server

ZK Server

ZK Server

timeout

disconnected

ZKClient

NameNode

Secondary

Primary

ZKClient

NameNode

Secondary

Primary

Notification that leader is gone, secondary becomes primary

DataNode

DataNode

DataNode

DataNode

DataNode

DataNode

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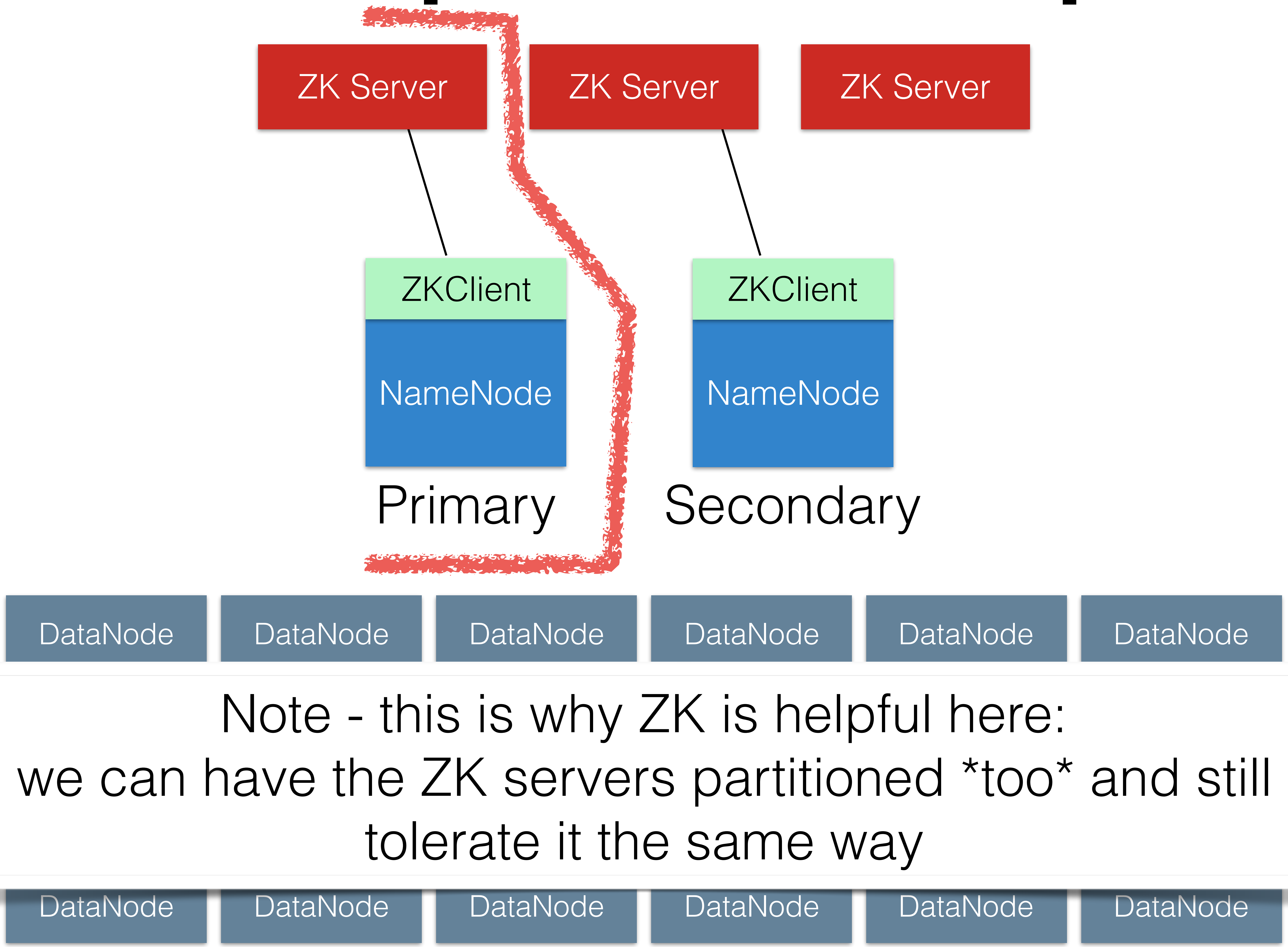
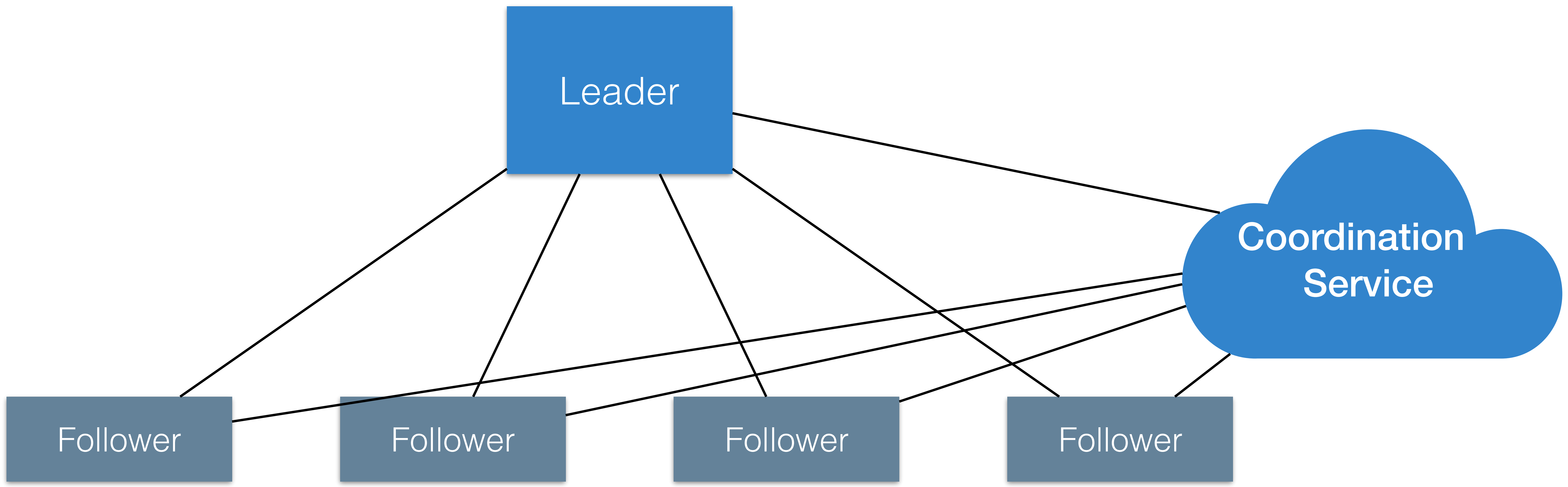
Hadoop + ZooKeeper



Note - this is why ZK is helpful here:
we can have the ZK servers partitioned *too* and still tolerate it the same way

ZooKeeper in Final Project



All writes go to leader

Who is the leader? Once we hit the leader, is it sure that it still is the leader?

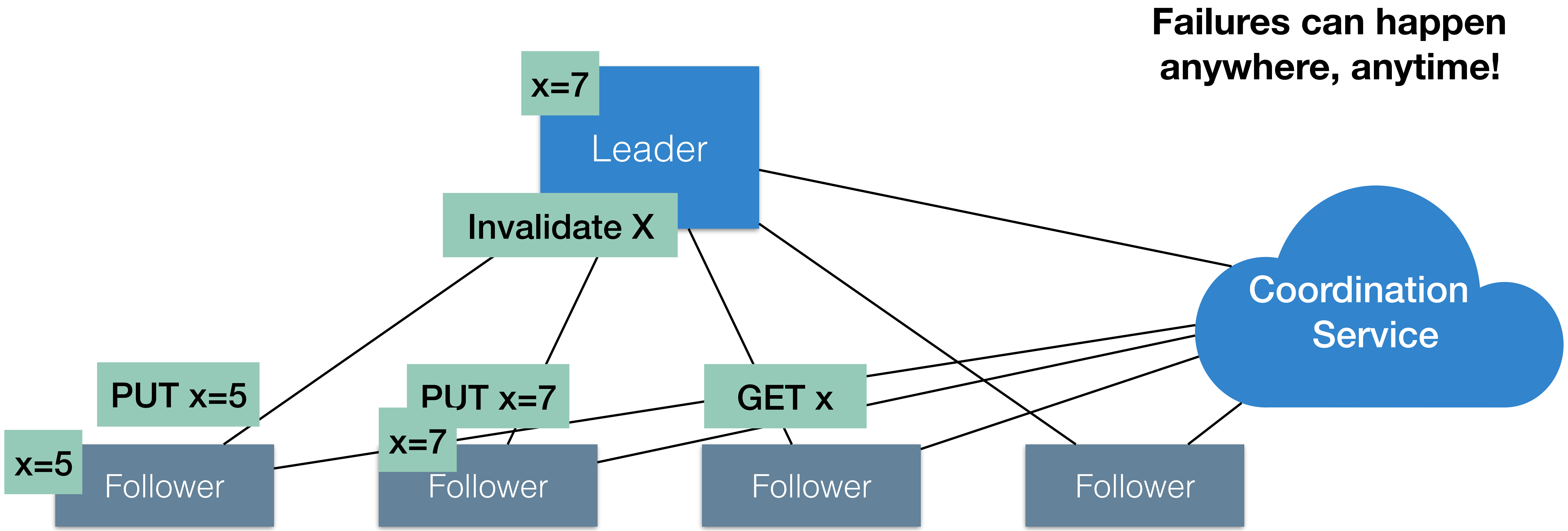
Leader broadcasts read-invalidates to clients

Who is still alive?

Reads processed on each client

If don’t have data cached, contact leader - who is leader?

ZooKeeper in Final Project



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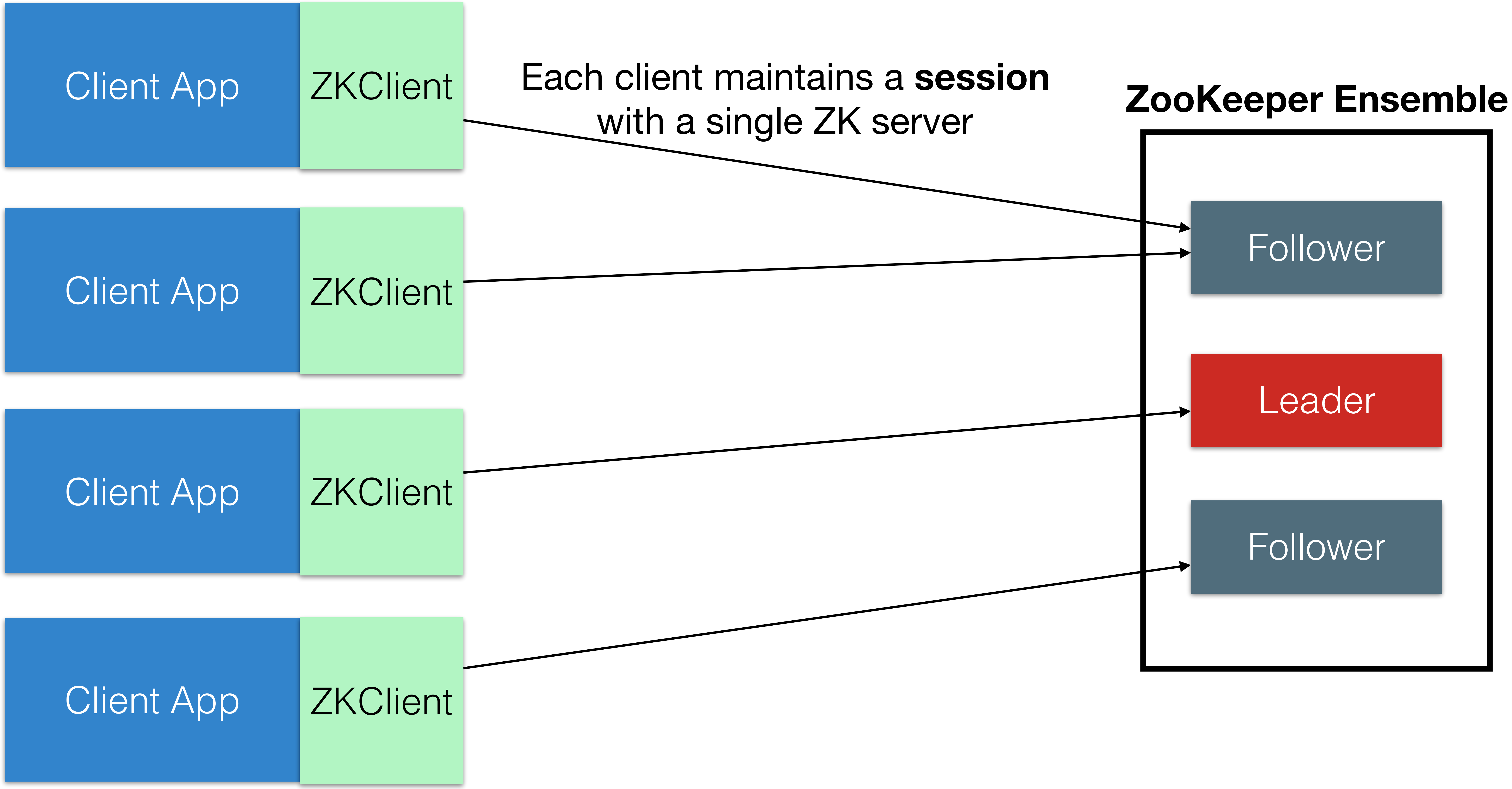
ZooKeeper - Overview

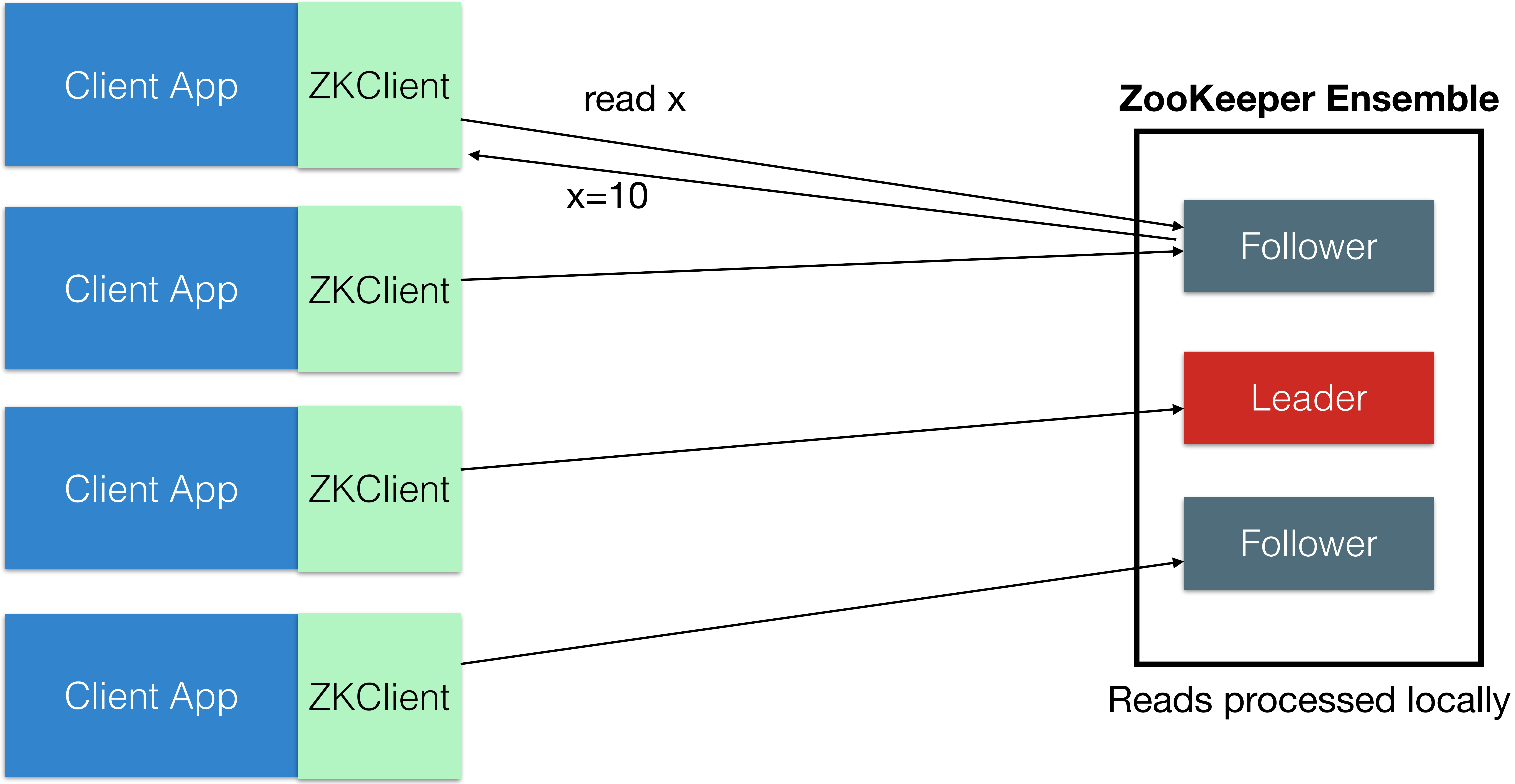


Each client maintains a **session** with a single ZK server

ZooKeeper - Sessions

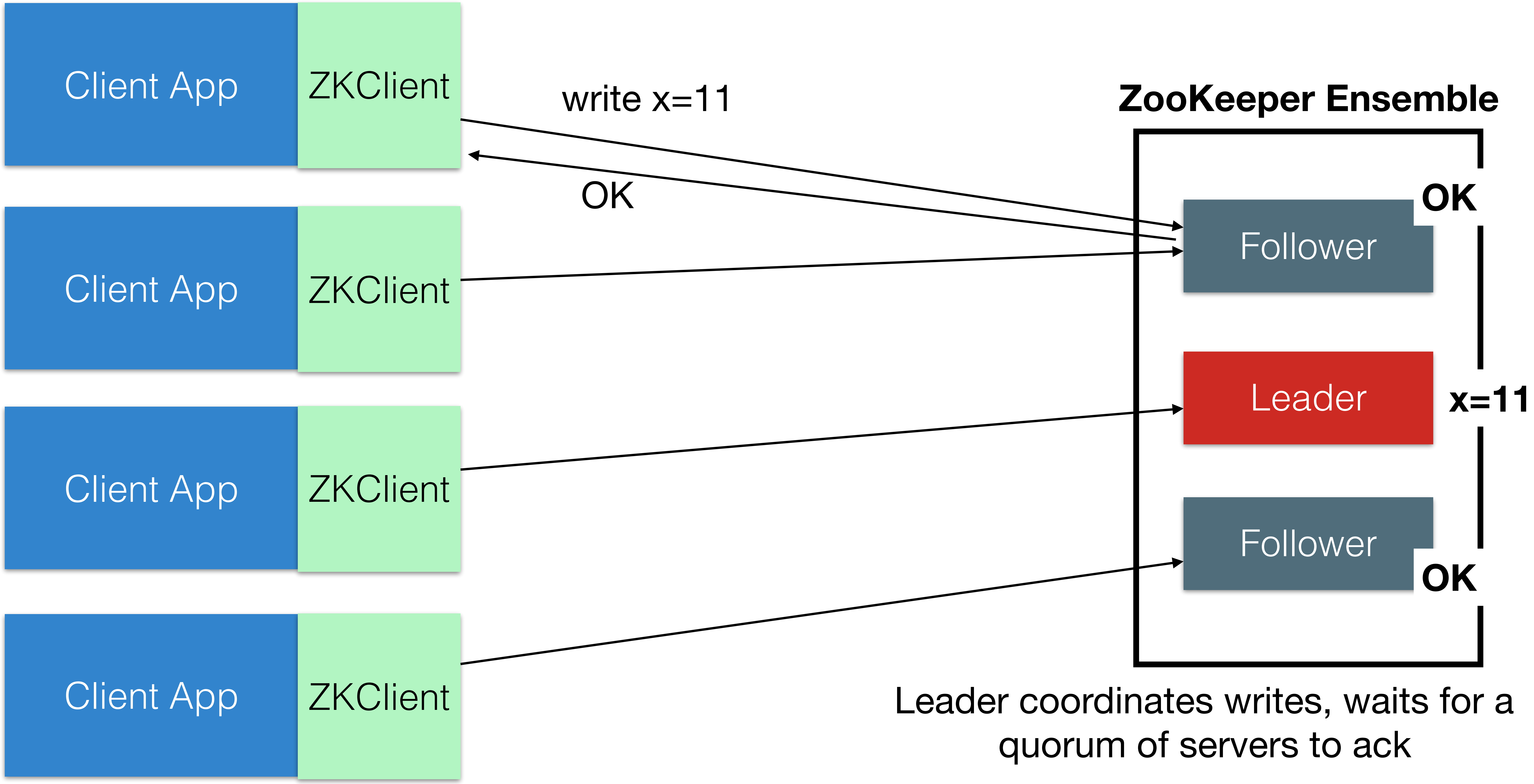
- Each client maintains a session with a single ZK server
- Sessions are valid for some time window
- If client discovers its disconnected from ZK server, attempts to reconnect to a different server before session expires

ZooKeeper - Overview



Reads processed locally

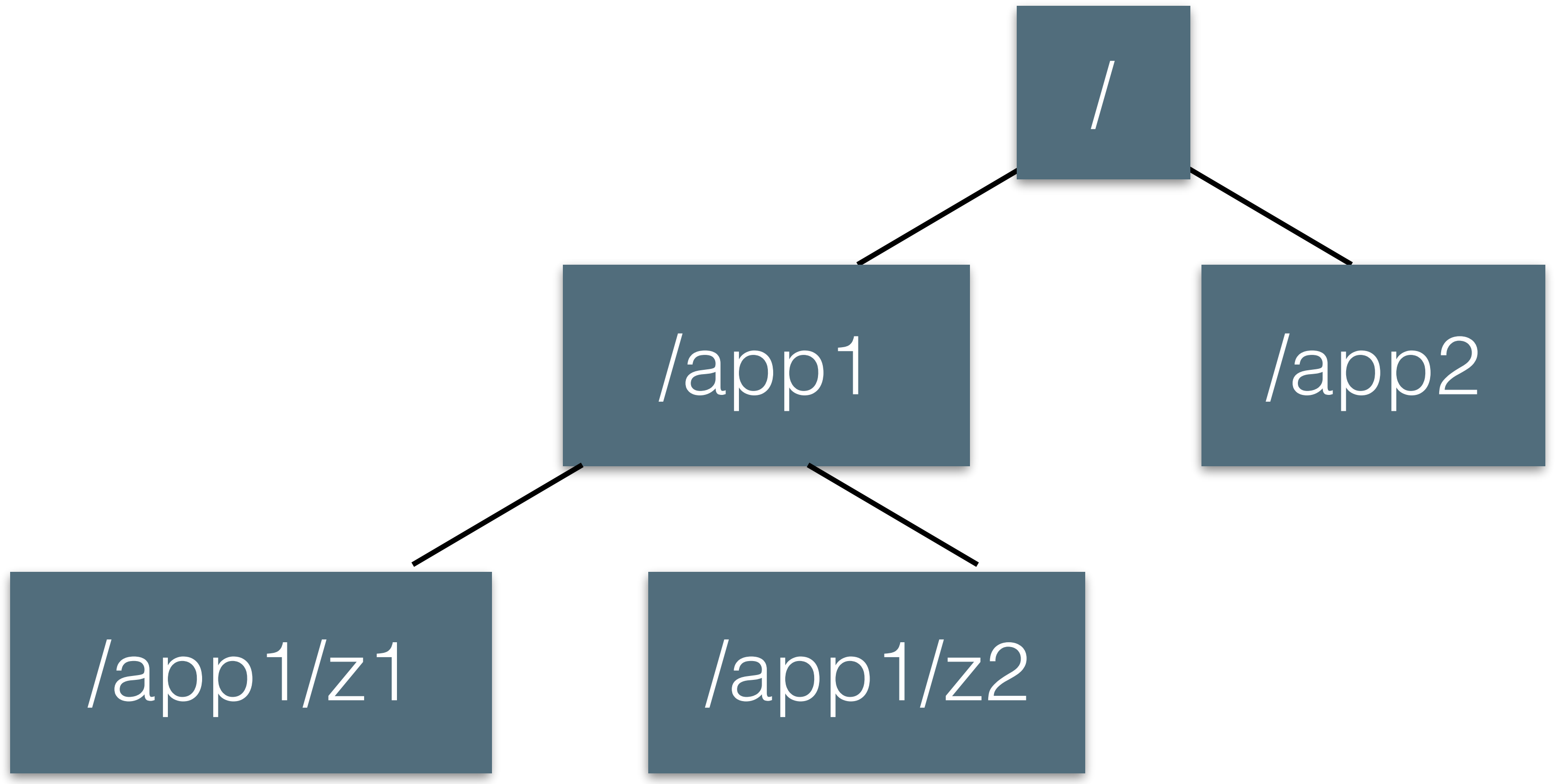
ZooKeeper - Overview



Leader coordinates writes, waits for a quorum of servers to ack

ZooKeeper - Data Model

- Provides a hierarchical namespace
- Each node is called a znode
- ZooKeeper provides an API to manipulate these nodes



ZooKeeper - ZNodes

- In-memory data
- NOT for storing general data - just metadata (they are replicated and generally stored in memory)
- Map to some client abstraction, for instance - locks
- Znodes maintain counters and timestamps as metadata

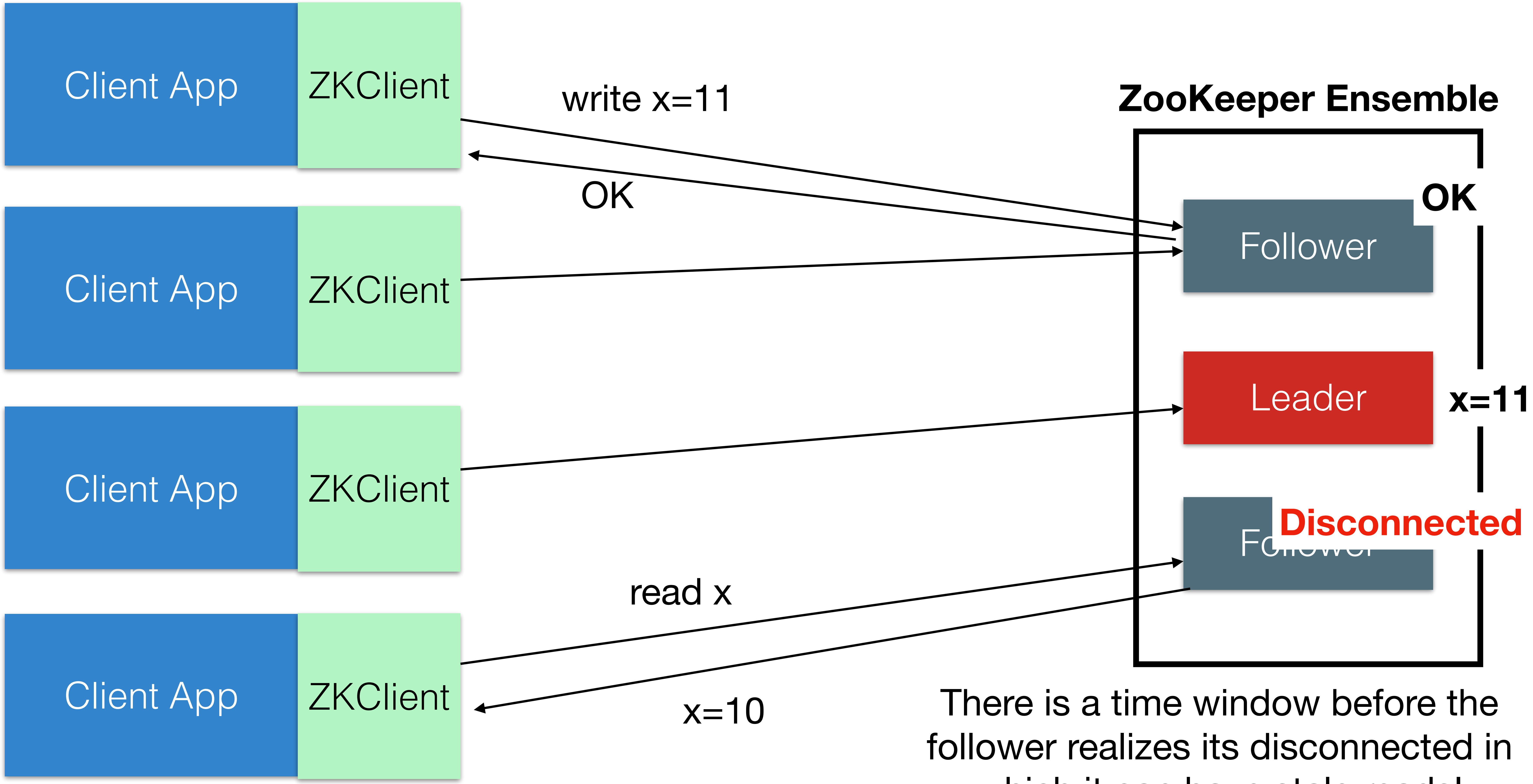
ZooKeeper - Znode Types

- Regular znodes
  - Can have children znodes
  - Created and deleted by clients explicitly through API
- Ephemeral znodes
  - Cannot have children
  - Created by clients explicitly
  - Deleted by clients OR removed automatically when client session that created them disconnects

ZooKeeper - API

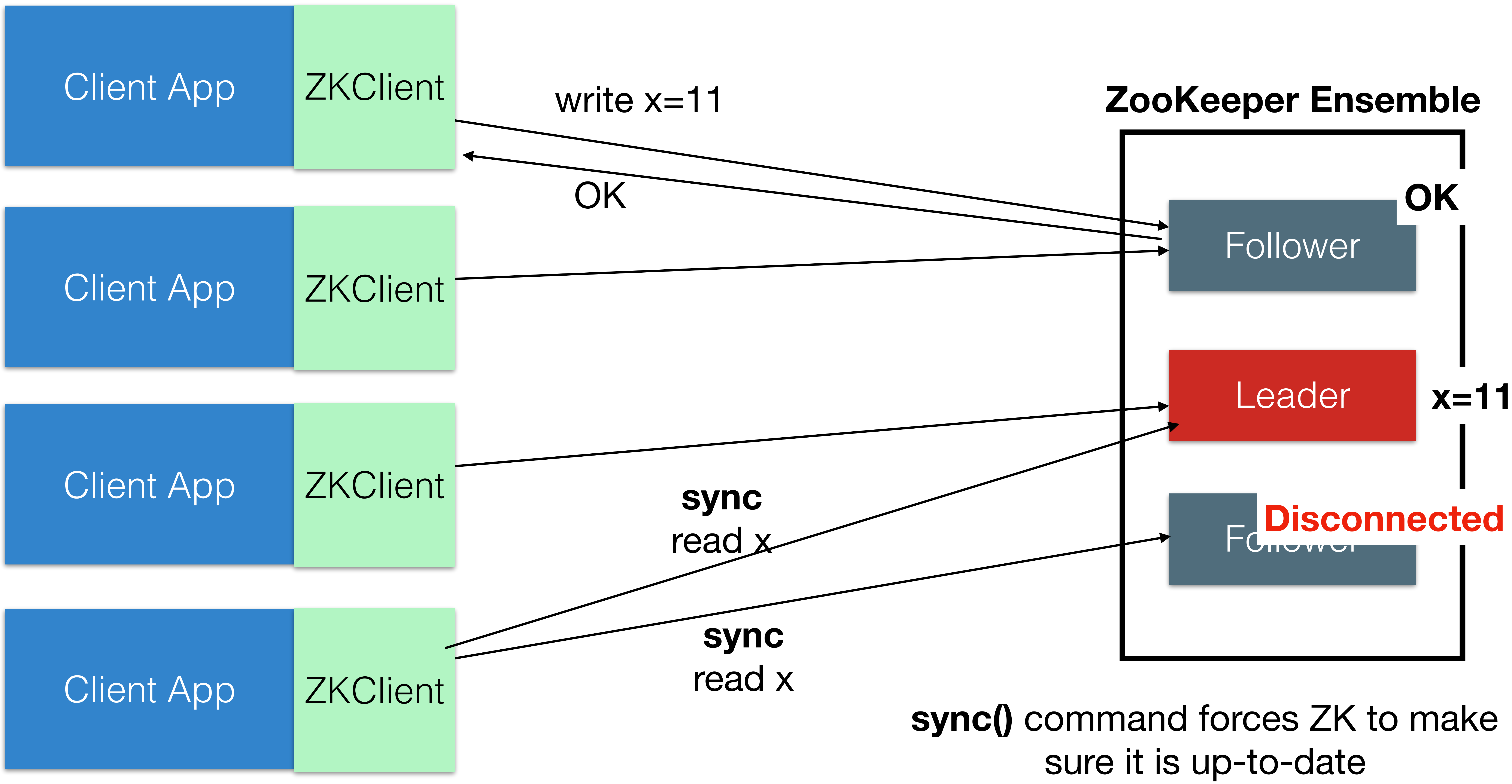
- Clients track changes to znodes by registering a **watch**
- Create(path, data, flags)
  Delete(path, version)
  Exists(path, watch)
  getData(path, watch)
  setData(path, data, version)
  getChildren(path, watch)
  Sync(path)

ZooKeeper - Consistency



There is a time window before the follower realizes its disconnected in which it can have stale reads!

ZooKeeper - Consistency



sync() command forces ZK to make sure it is up-to-date

ZooKeeper - Consistency

- Sequential consistency of writes
  - All updates are applied in the order they are sent, linearized into a total order by the leader
- Atomicity of writes
  - Updates either succeed or fail
- Reliability
  - Once a write has been applied, it will persist until its overwritten, as long as a majority of servers don't crash
- Timeliness
  - Clients are guaranteed to be up-to-date for reads **within a time bound** - after which you either see newest data or are disconnected

ZooKeeper - Lock Example

- To acquire a lock called **foo**
- Try to create an ephemeral znode called **/locks/foo**
- If you succeeded:
  - You have the lock
- If you failed:
  - Set a watch on that node. When you are notified that the node is deleted, try to create it again.
- Note - no issue with consistency, since there is no read (just an atomic write)

ZooKeeper - Recipes

- Why figure out how to re-implement this low level stuff (like locks)?
- Recipes: https://zookeeper.apache.org/doc/r3.3.6/recipes.html
  - And in Java: http://curator.apache.org
- Examples:
  - Locks
  - Group Membership

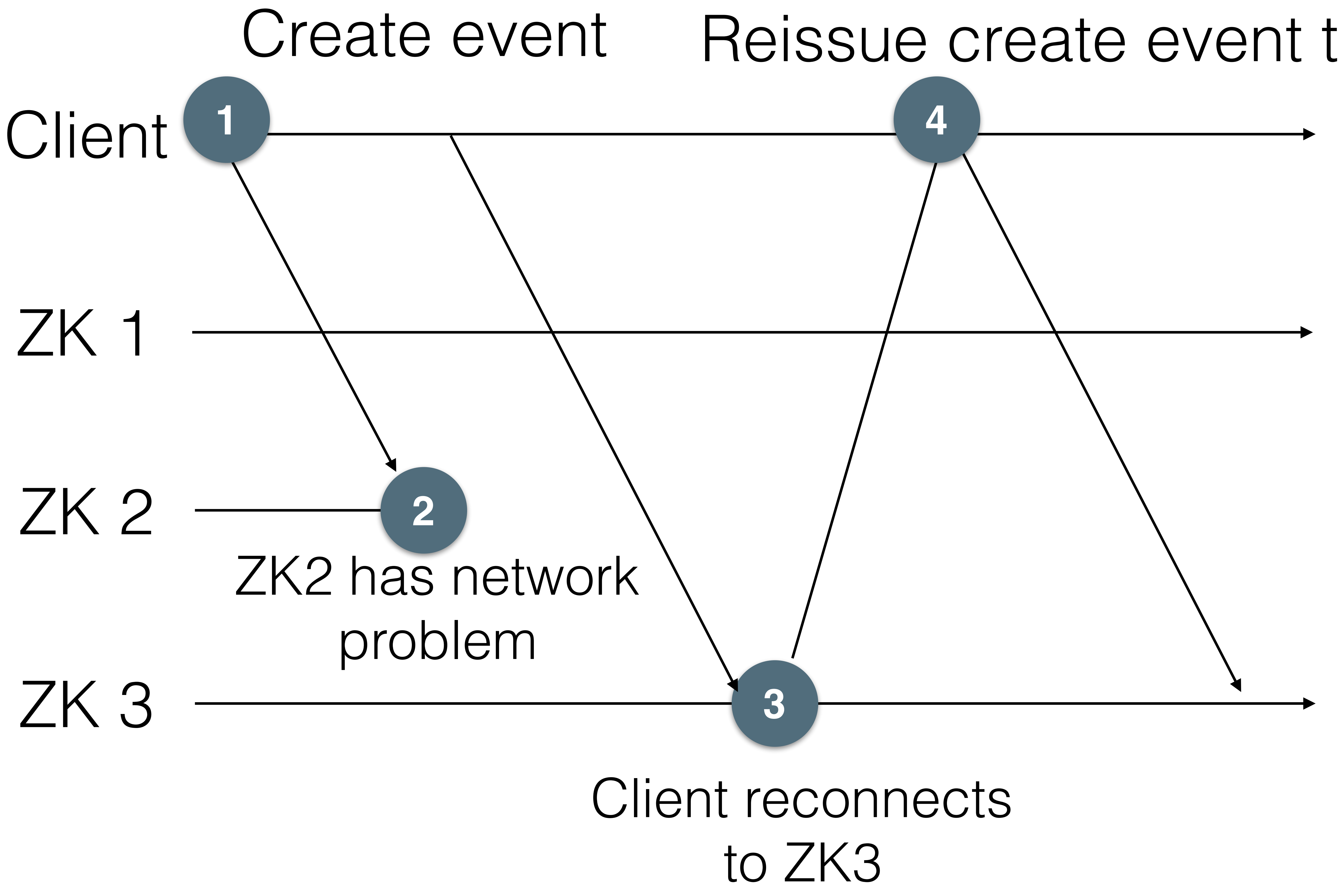
How Many ZooKeepers?

- How many ZooKeepers do you want?
  - An odd number
  - 3-7 is typical
  - Too many and you pay a LOT for coordination

Failure Handling in ZK

- Just using ZooKeeper does not solve failures
- Apps using ZooKeeper need to be aware of the potential failures that can occur, and act appropriately
- ZK client will guarantee consistency **if it is connected to the server cluster**

Failure Handling in ZK



Create event

Reissue create event to zk3

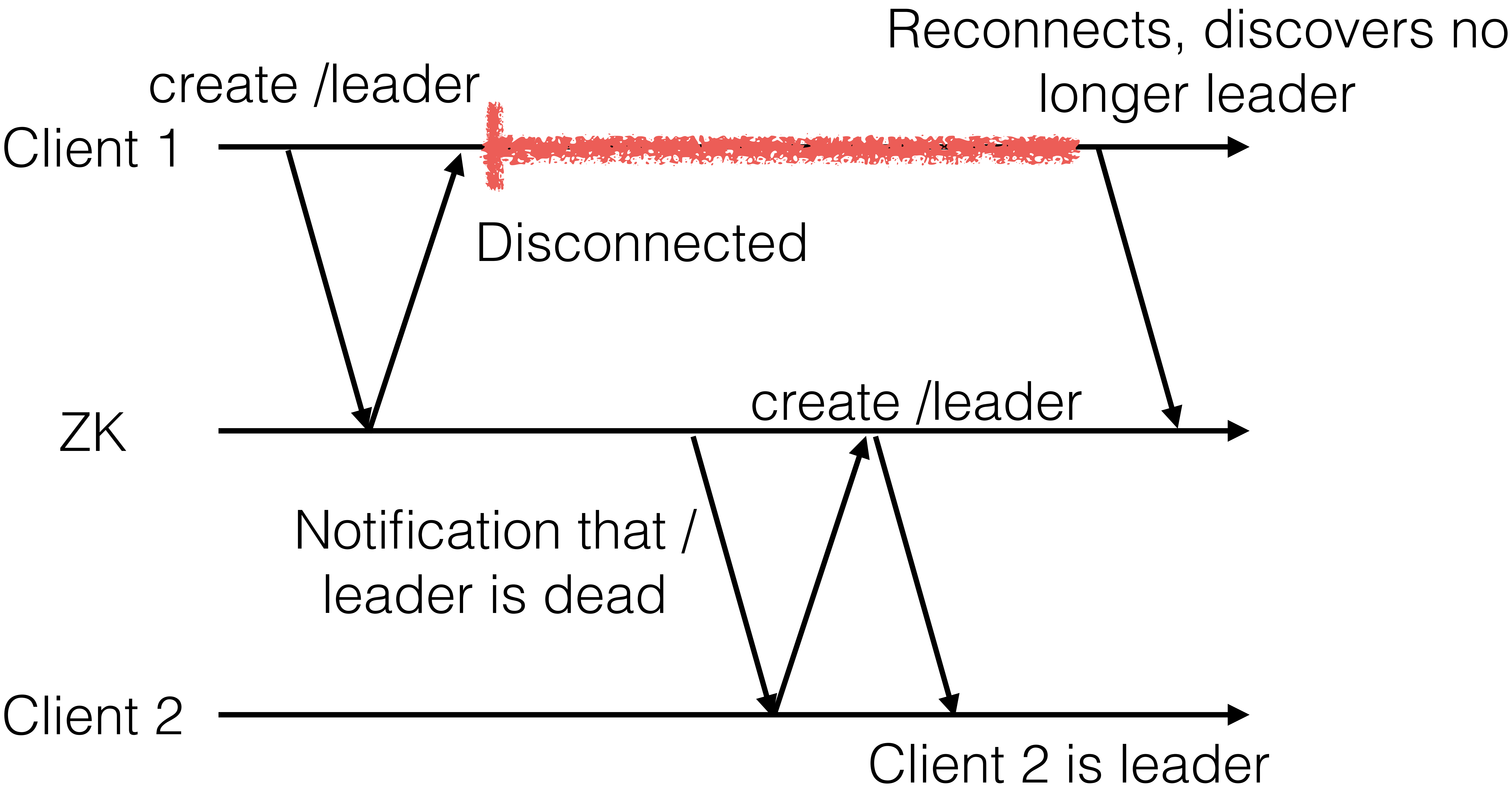
ZK2 has network problem

Client reconnects to ZK3

Failure Handling in ZK

- If in the middle of an operation, client receives a **ConnectionLossException**
- Also, client receives a **disconnected message**
- Clients can't tell whether or not the operation was completed though - perhaps it was completed before the failure
- Clients that are disconnected can not receive any notifications from ZK

Dangers of ignorance



Dangers of ignorance

- Each client needs to be aware of whether or not its connected: when disconnected, can not assume that it is still included in any way in operations
- By default, ZK client will NOT close the client session because it's disconnected!
  - Assumption that eventually things will reconnect
  - Up to you to decide to close it or not

ZK: Handling Reconnection

- What should we do when we reconnect?
- Re-issue outstanding requests?
  - Can't assume that outstanding requests didn't succeed
  - Example: create /leader (succeed but disconnect), re-issue create /leader and fail to create it because you already did it!
- Need to check what has changed with the world since we were last connected

HW4 Discussion

Go to socrative.com and select “Student Login” Room: CS475; ID is your G-Number

1. How fair do you think this assignment was?
2. How difficult did you think this assignment was?
3. How long did you spend on this assignment?

Reminder: If you are not in class, you may not complete the activity. If you do anyway, this will constitute a violation of the honor code.

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