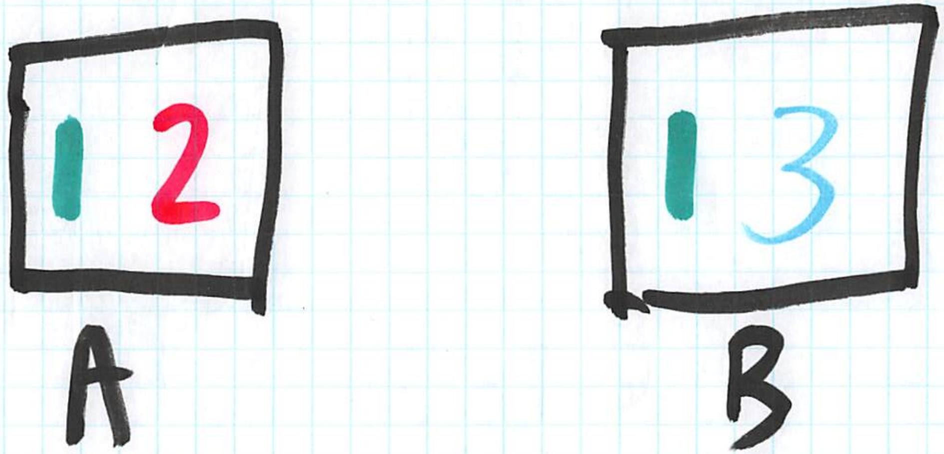
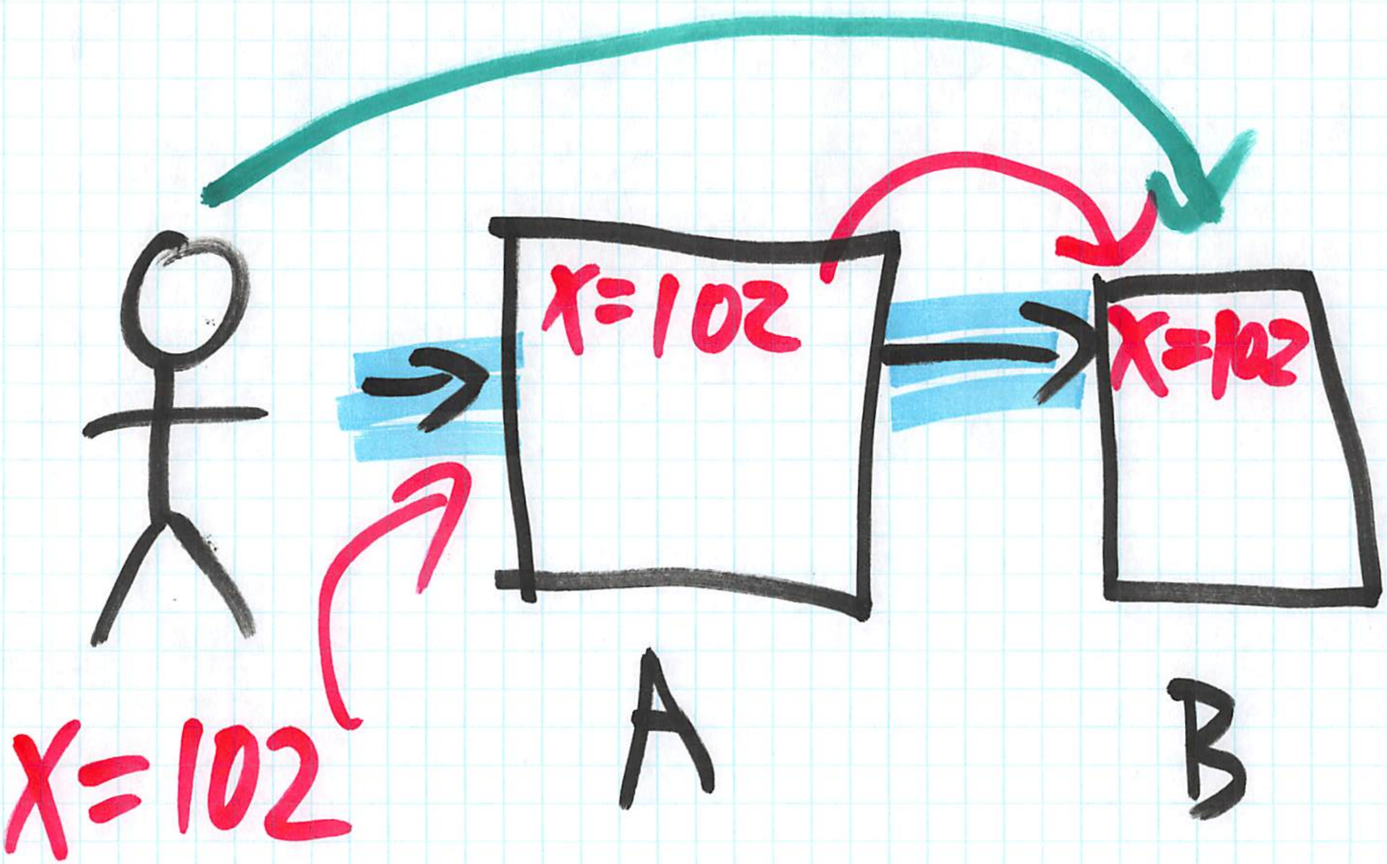
Parrallel Updates (&Queries Continued)


1 2
A
1 3
B



B fails

Nothing Happens

- B is restarted
- B catches up to A's state

Yay!

A fails

Everything fails

Option 1 (consistency)
- A is restarted

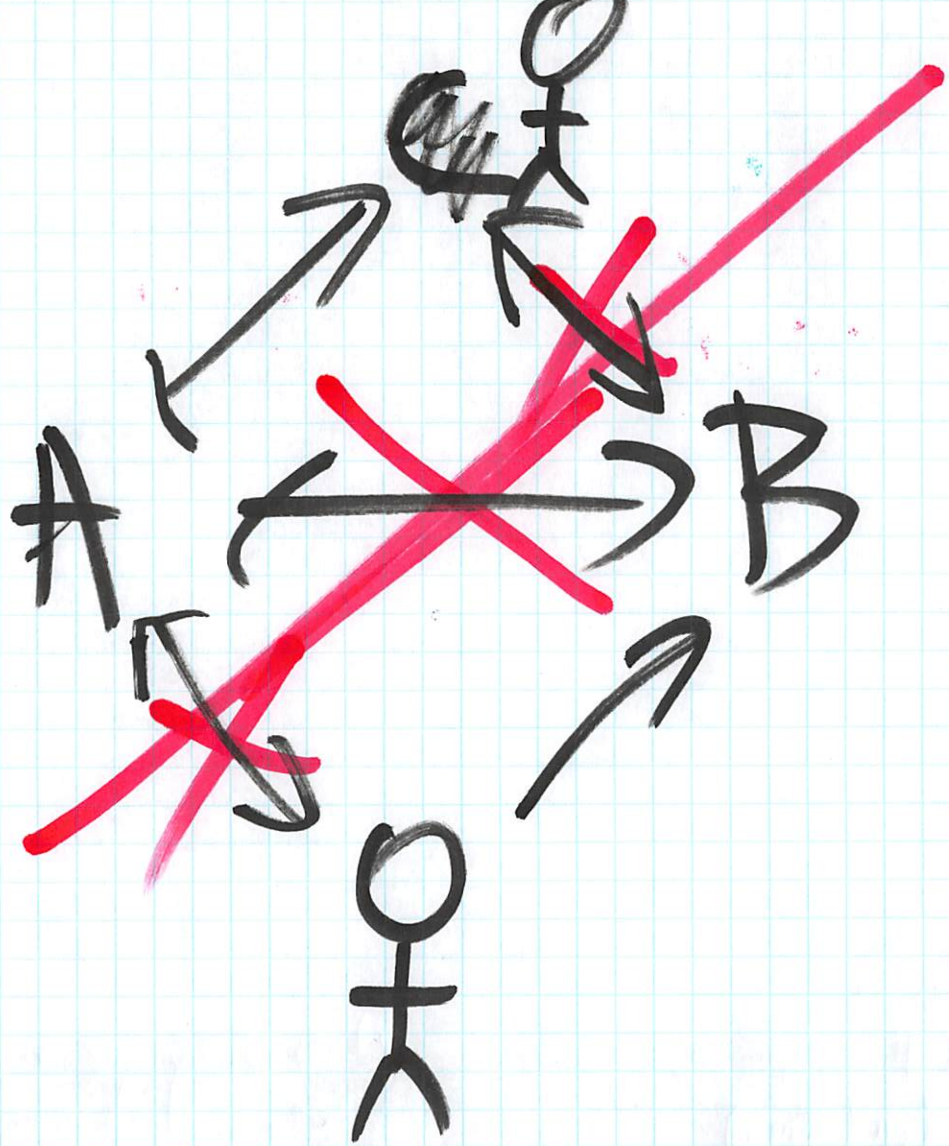
→ Option 2 (Availability)
- Switch over to B as primary
- A reconnects as a follower

Why not option 2?

- B doesn't have an up to date view of the data

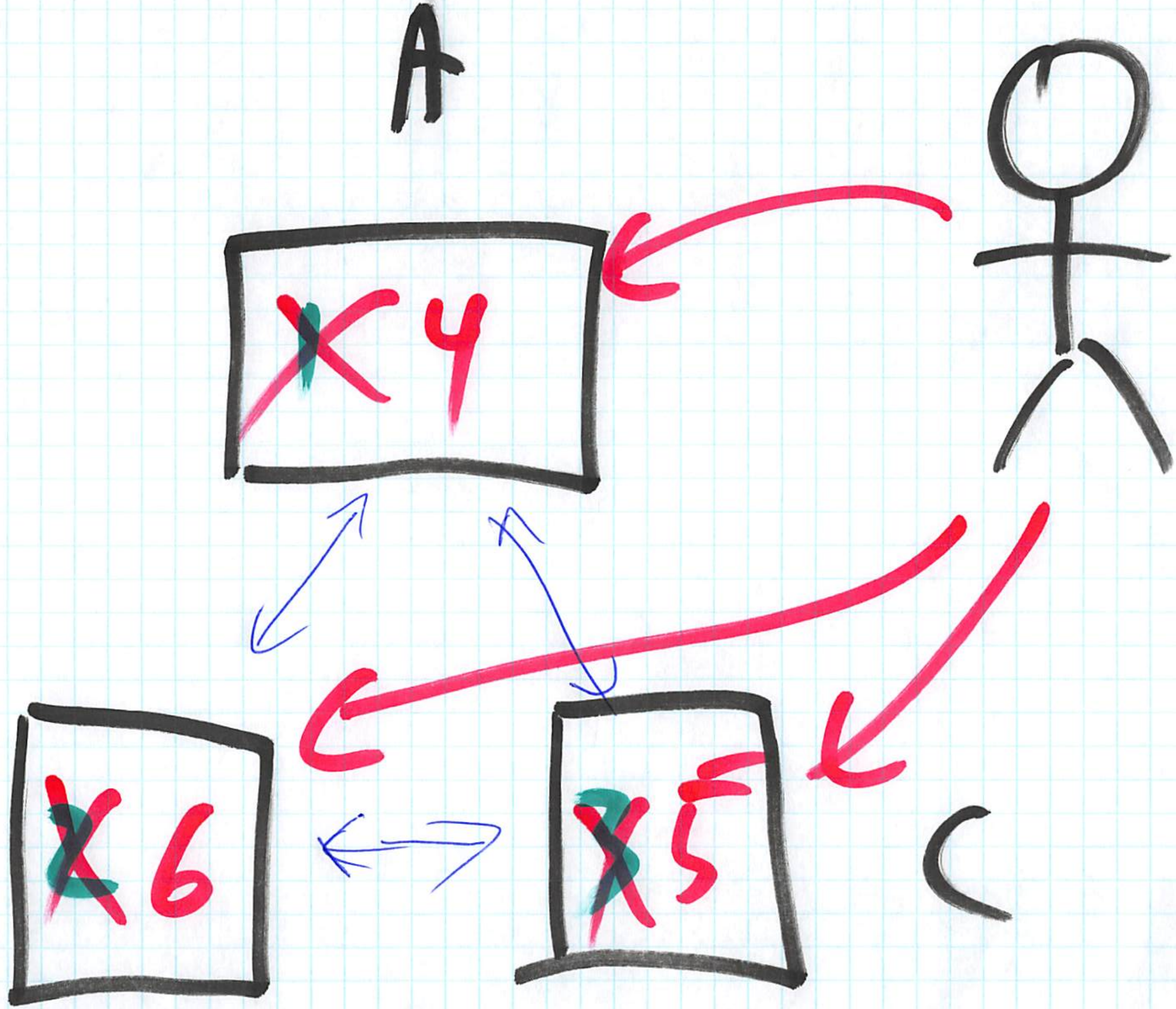
Network Fails

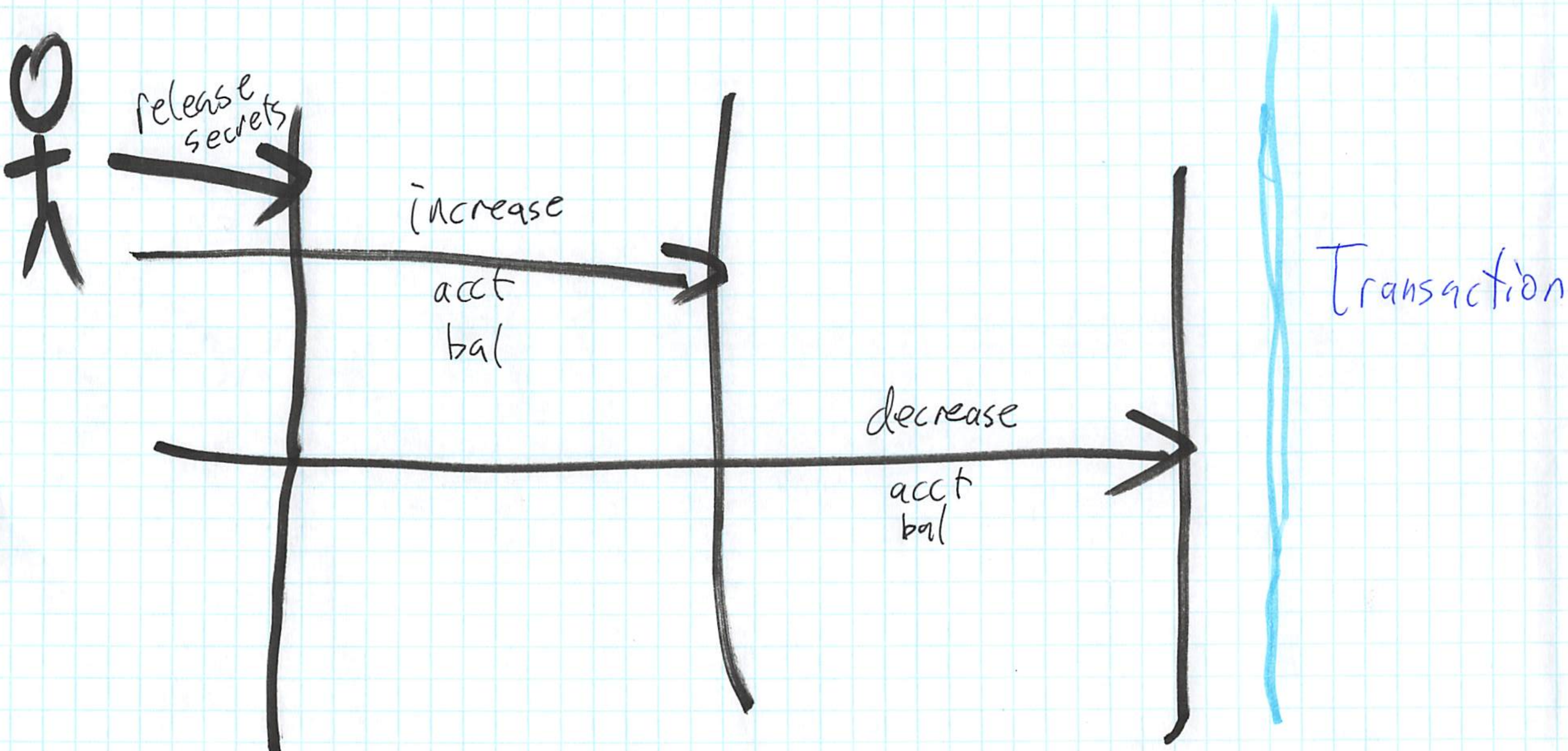
???


A
B

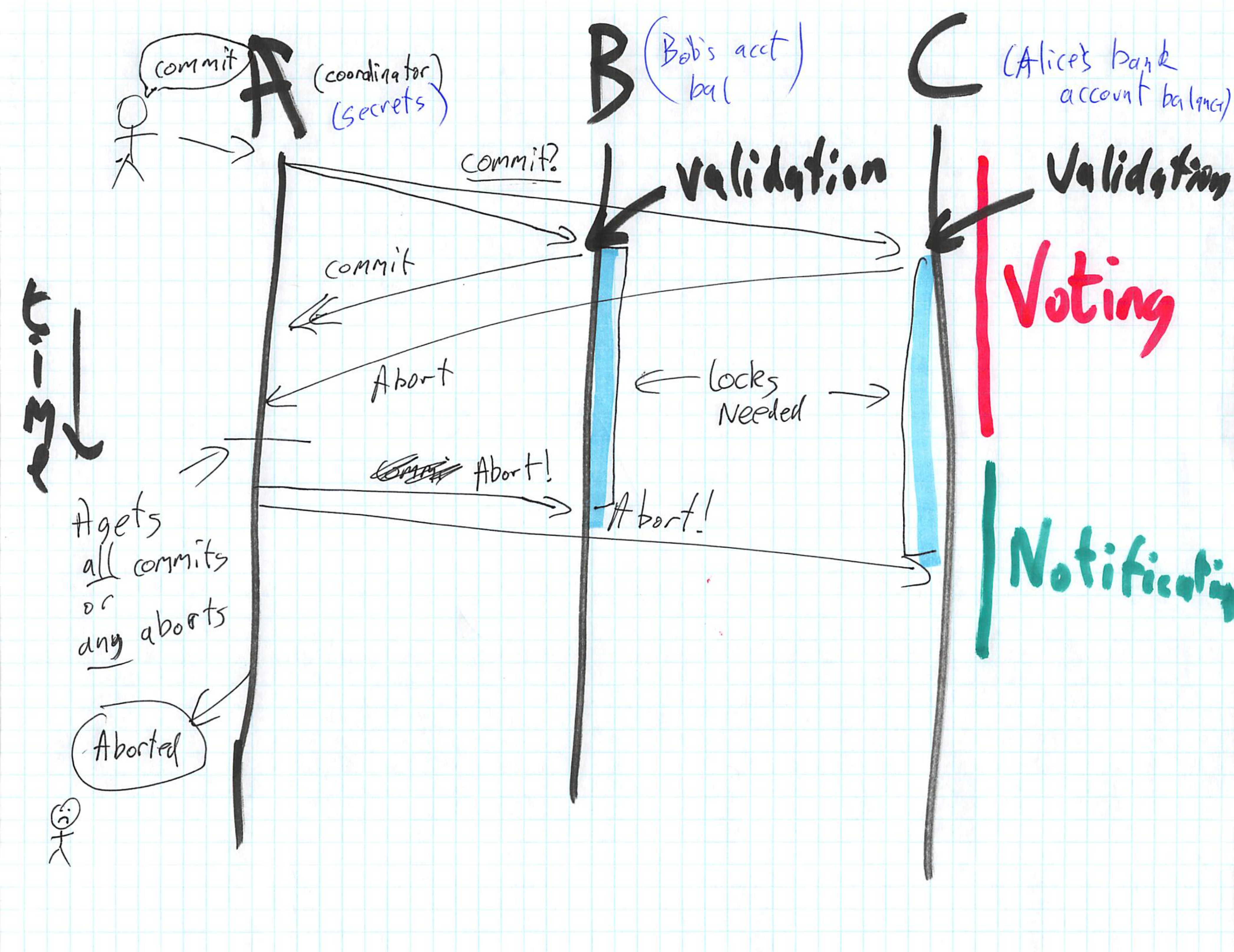
CAP Theorem

Consistency or Availability during Partition

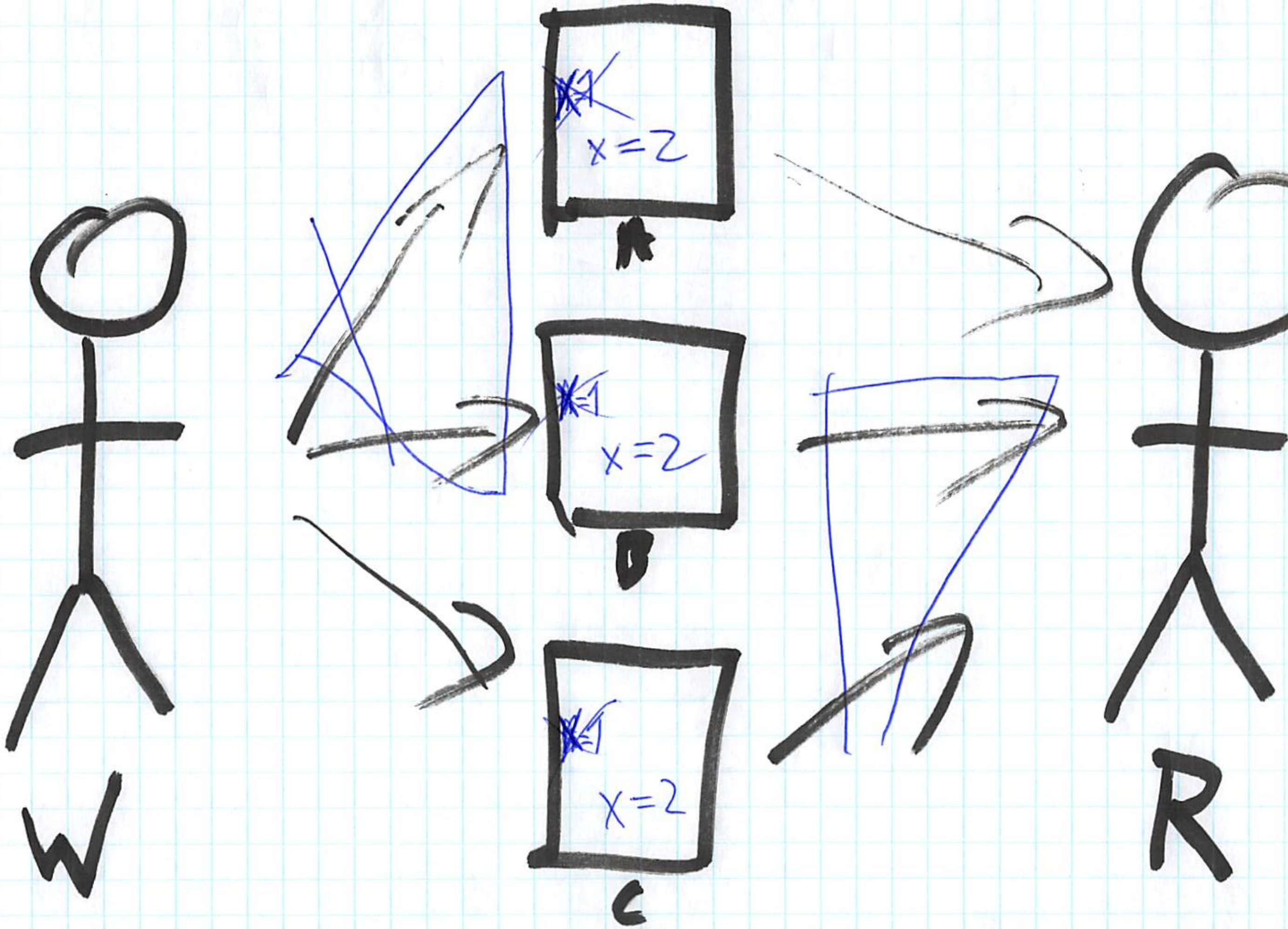

A
4
B
6
5
C



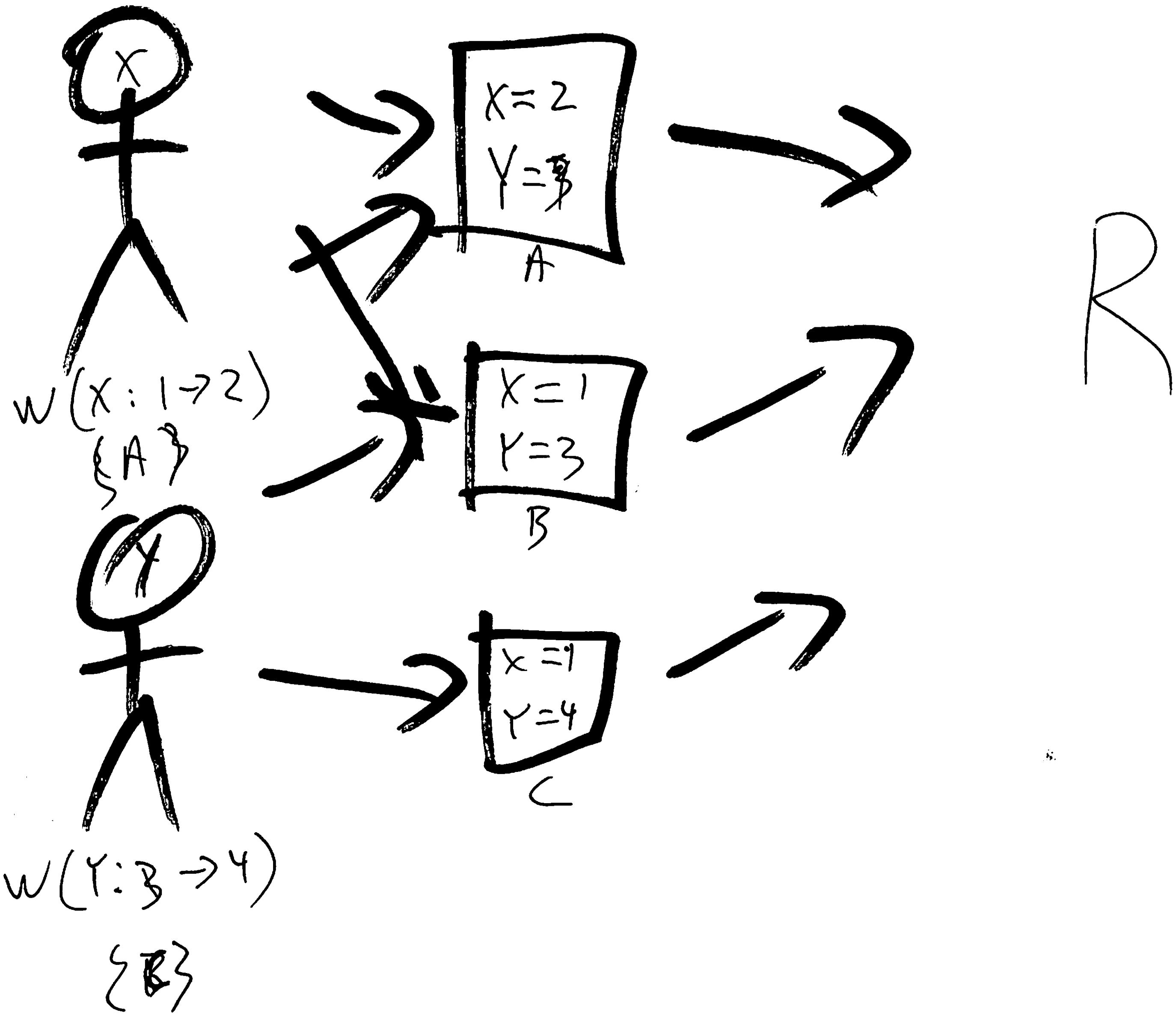
release secrets
increase
acct bal
decrease
acct bal
Transaction



commit
A
(coordinator)
(secrets)
B
(Bob's acct bal)
C
(Alice's bank account balance)
commit?
Validation
Validation
Voting
commit
time
Abort
locks Needed
Abort!
Abort!
A gets all commits or any aborts
Notificatio
Aborted



W(x=2) → tell R "ready" → be told "ready" → R(x) -> 2


X
W(X: 1→2)
{A}
Y
W(Y: 3→4)
{B}
X=2
Y=3
A
X=1
Y=3
B
X=1
Y=4
C
R

w	r
N	1
$\lceil \frac{N}{2} \rceil$	$\lceil \frac{N}{2} \rceil$
1	N

N nodes

w #nodes the writer waits for

r #nodes the reader waits for

$r + w > N$

$N - w > r$

Parallel Data

Types of Parallelism

- **Replication (Multiple copies of the same data)**
  - Better throughput for read-only computations
  - Data safety
- **Partitioning (Different data at different sites**
  - More space
  - Better throughput for writes
  - Sometimes better throughput for read-only computations

Challenges

- **Replication**
  - Reading the same value from each site.
- **Partitioning**
  - Transactions (Update A and B atomically)

Consensus

Getting everyone to agree on something

- **Did a transaction commit?**
- **In which order were the transactions applied?**
- **What is the current value of object A?**

Techniques

- **Primary/Secondary (aka Leader/Follower, aka Master/Slave)**
  - Pick one node as the primary
    - Deterministic property (lowest IP, etc...)
    - Additional consensus protocol for leader selection
  - Primary is the authoritative version
    - All writes go to the primary first.
    - Writes are replicated to the secondary(ies) if any exist.
    - Secondaries can handle (potentially stale) reads, but not writes
- **2-Phase Commit**
  - Every time something happens, everyone communicates with everyone else.
  - All participants signal readiness to participate in consensus
  - A temporary, per-consensus task 'leader' signals all other participants to vote
  - All participants communicate their vote to the leader.
  - Leader tallies votes based on goal requirements

        - k-Data stability requires k replicas to acknowledge
        - Commit/Abort requires unanimous acknowledgement
    - The leader notifies everyone of the vote result.
- **Log Consensus**
    - Sometimes possible. Nodes log messages in an agreed-upon order. Nodes agree to any message they receive in the correct, agreed-upon order.

Failure Modes

- **Fail-Fast / Fail-Stop**
    - Software/Hardware failure that causes the node to crash (although it can eventually be restarted)
    - The node stops functioning outright — no signs of life at all
- **Non-Fail-Stop**
    - Software/Hardware failure that causes the node to behave incorrectly
    - The node keeps responding, but does not respond according to the programmer's expectations
- **Byzantine Faults**
    - Software/Hardware failure that causes the node to behave as incorrectly as possible.
    - The node responds in the most harmful way possible.

Failures

- **What can fail?**
    - The node itself
    - The network connecting the nodes
    - Part of the network connecting the nodes (partition)
- **Does it matter which?**
    - If the node crashes, it loses its local state and has to be restarted from scratch
    - If the network fails… both nodes continue to be active but are unaware of each other's existence… but may be aware of the existence of other nodes.
- **Can a node tell which is which?**
    - No. If Nodes A and B are trying to reach consensus, and B stops responding, A has no clue why.
    - So, what happens when the failure condition ends?

Recovery in Primary/Secondary Replicas

- **Secondary Node Failure**
    - No Harm. Secondary reboots and rejoins.
- **Primary Node Failure**
    - A secondary can rise to take its place… Repeat leader selection process
    - Primary reboots as a secondary
- **Network Failure**
    - From the point of view of secondaries… identical to primary node failure.

Partitions in Consensus

- **Option 1: Assume Node Failure**
  - Maximize availability. Promote secondary to primary to ensure that there's always a primary available.
  - Creates risk of inconsistency, as there are now two primaries. Two authoritative versions of the data.
- **Option 2: Assume Connection Failure**
  - Ensure consistency. Wait for network (or primary node) to recover.
  - Affects availability. Can't do anything until the primary recovers.
- **CAP**
  - Consistency, Availability, Partition-Tolerance
  - Pick any 2
  - More precisely, pick a tradeoff between consistency and availability. How much of each are you willing to sacrifice.

Reader/Writer Stability

- **In a system with N nodes, you want to read the 'latest' version that everyone agrees on.**
  - Failure mode:
    - Receive Ack for write
    - Successfully Read an earlier value
- **Naive:**
  - Write to N nodes, wait for everyone to acknowledge write.
  - Read from N nodes, wait for everyone to agree on read.
- **Fault-Tolerant**
  - Write to N nodes, wait for w nodes to acknowledge write
  - Read from N nodes, wait for r nodes to agree on read.
  - If $w+r > N$, there must be one overlapping node. Guaranteed to be reading at least latest acked value.
  - Can tolerate F failures if $w + r - F > N$