Lecture #6: Solving SMR with Byzantine Faults in Partial Synchrony: The Essence of Tendermint

COMS 4995-001:
The Science of Blockchains

URL: https://timroughgarden.org/s25/

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Goals for Lecture #6

1. The Tendermint protocol.
   - basis of Cosmos and several other blockchain protocols
   - available more or less off-the-shelf to build on

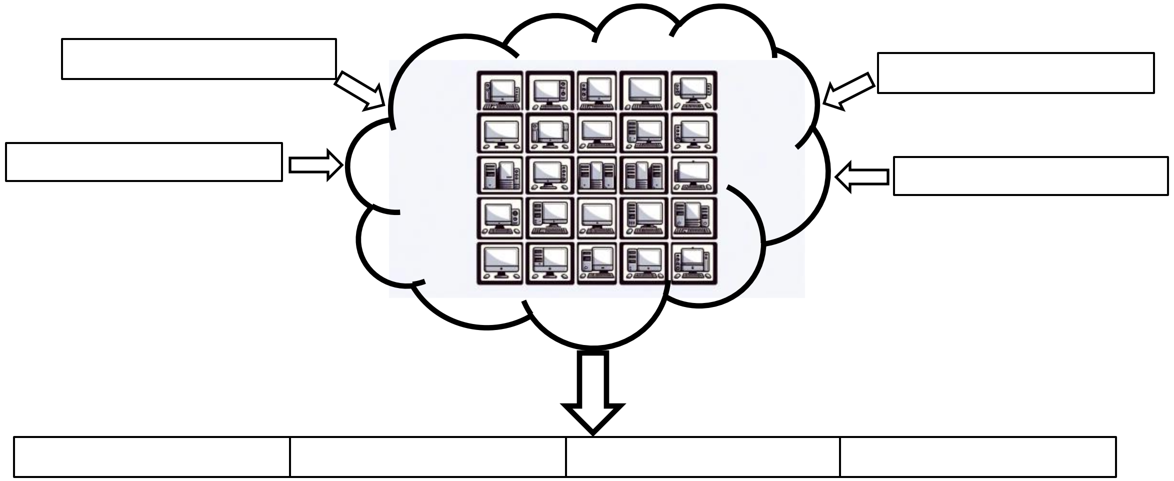
2. Analysis of the Tendermint protocol.
   - achieves optimal Byzantine fault-tolerance in partial synchrony
   - similar structure to Paxos/Raft analysis, but several new ideas

State Machine Replication (SMR)

SMR: version of consensus appropriate for a blockchain protocol.

- “state machine” = for us, current state of virtual machine
- “replication” = all validators perform same state transitions
- “clients” submit transactions (“txs”) to validators
- each validator maintains an append-only list of finalized txs (a.k.a. “log” or “history”)

Goal: a protocol that satisfies consistency and liveness.



A Road Map to Practical SMR Protocols

crash faults + synchrony [security threshold ≈ 100%]	crash faults + partially synchrony [security threshold = 50%]	Byzantine faults + partially synchrony [security threshold ≤ 33%]

easier → harder

Lecture #3: Protocol B solves SMR with crash faults in synchrony.

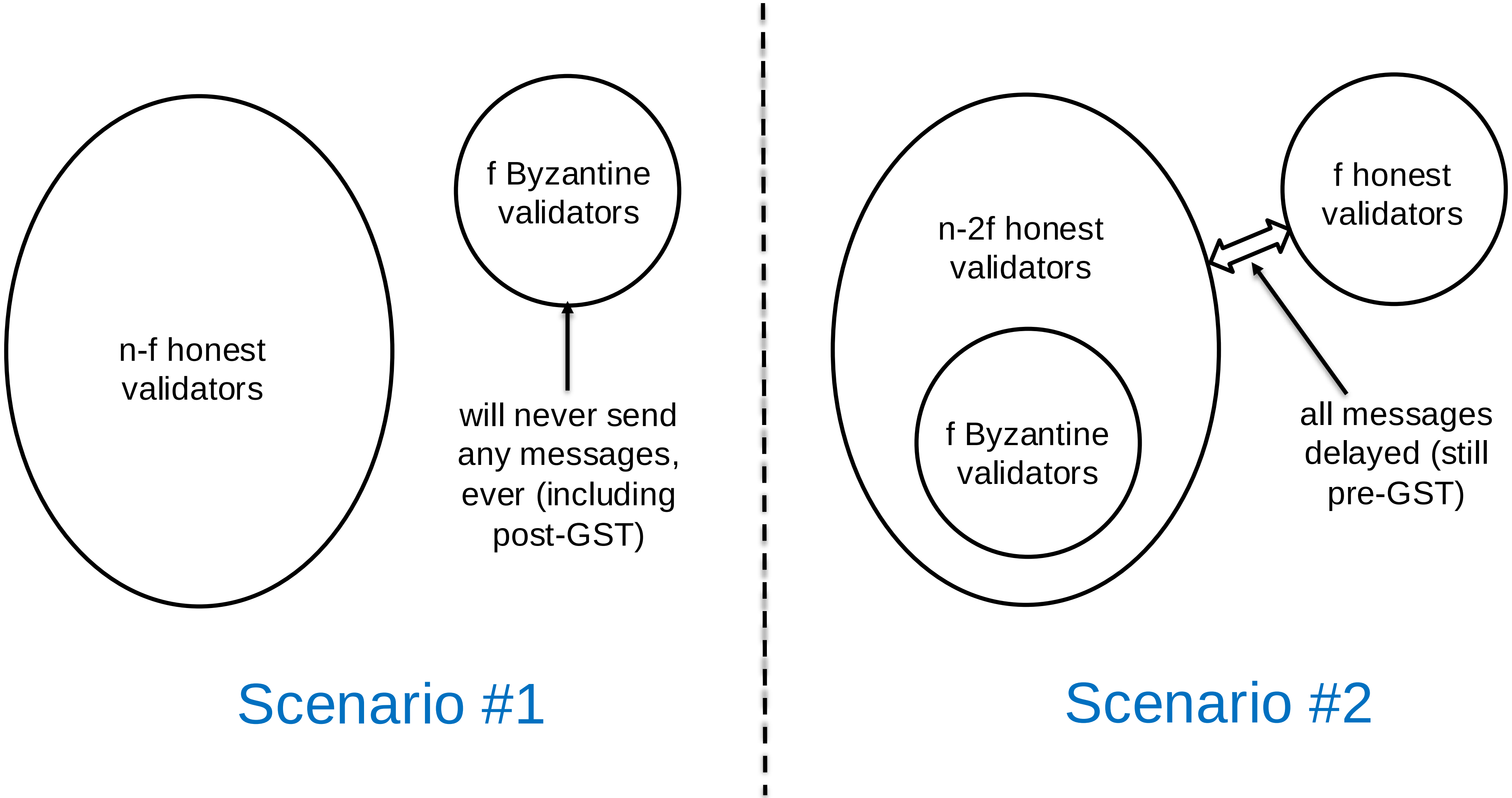
Lecture #4: Paxos/Raft, optimal crash-fault tolerance in partial synchrony.

Lecture #5: can’t achieve >33% Byzantine fault-tolerance in partial synchrony.

Key Ideas in Tendermint

Recall: need to assume < n/3 Byzantine validators.

Post-GST Crashes or Pre-GST Delays?



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Idea #1: every validator signs every message it sends.

- assume all validators know each others public keys (+ IDs + IP addrs)
- called a "public key infrastructure (PKI)" assumption

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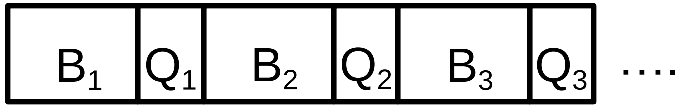

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- QCs included as metadata alongside blocks

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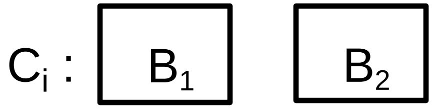

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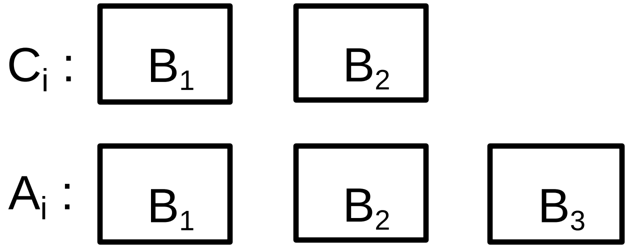

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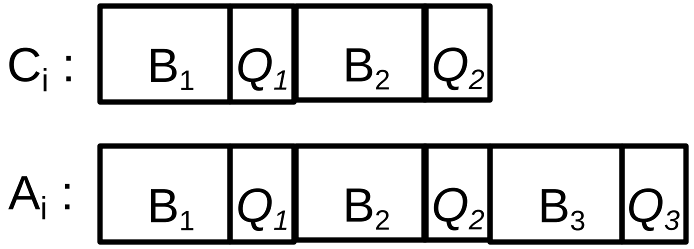

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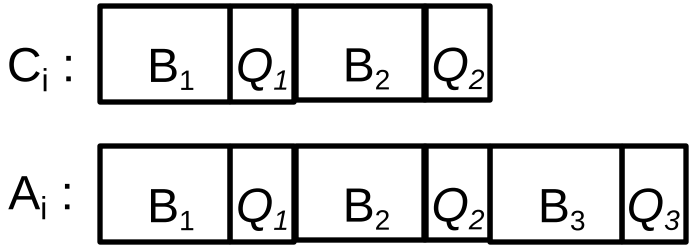

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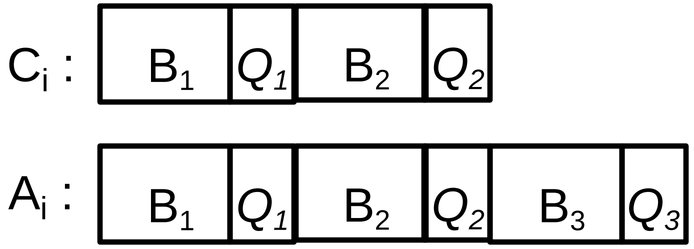

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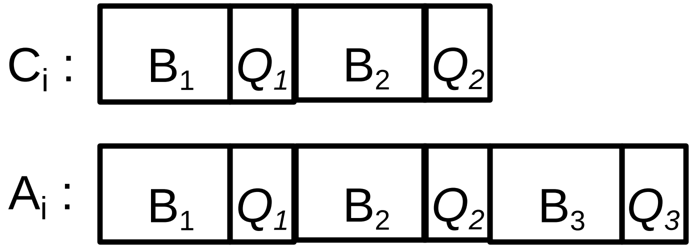

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- all messages annotated with current view number

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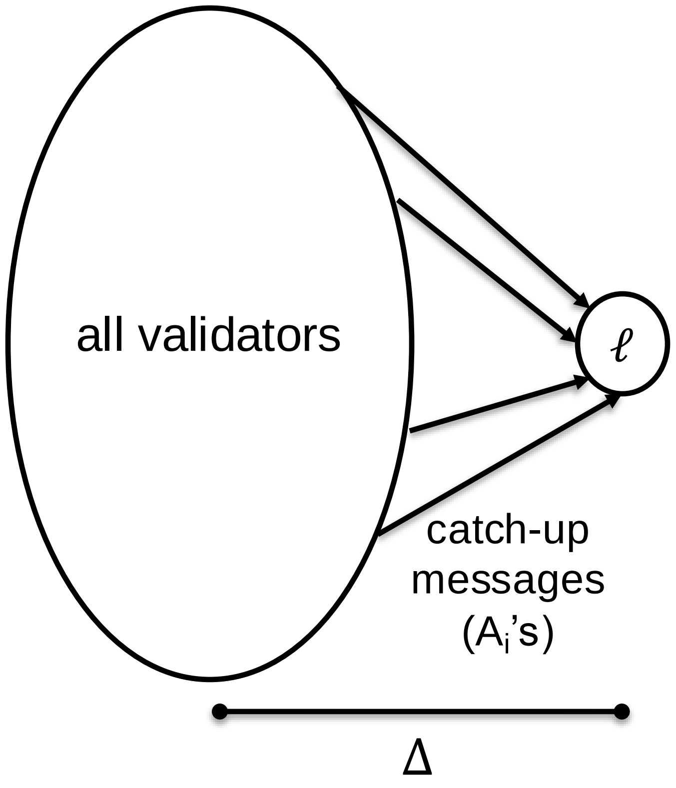

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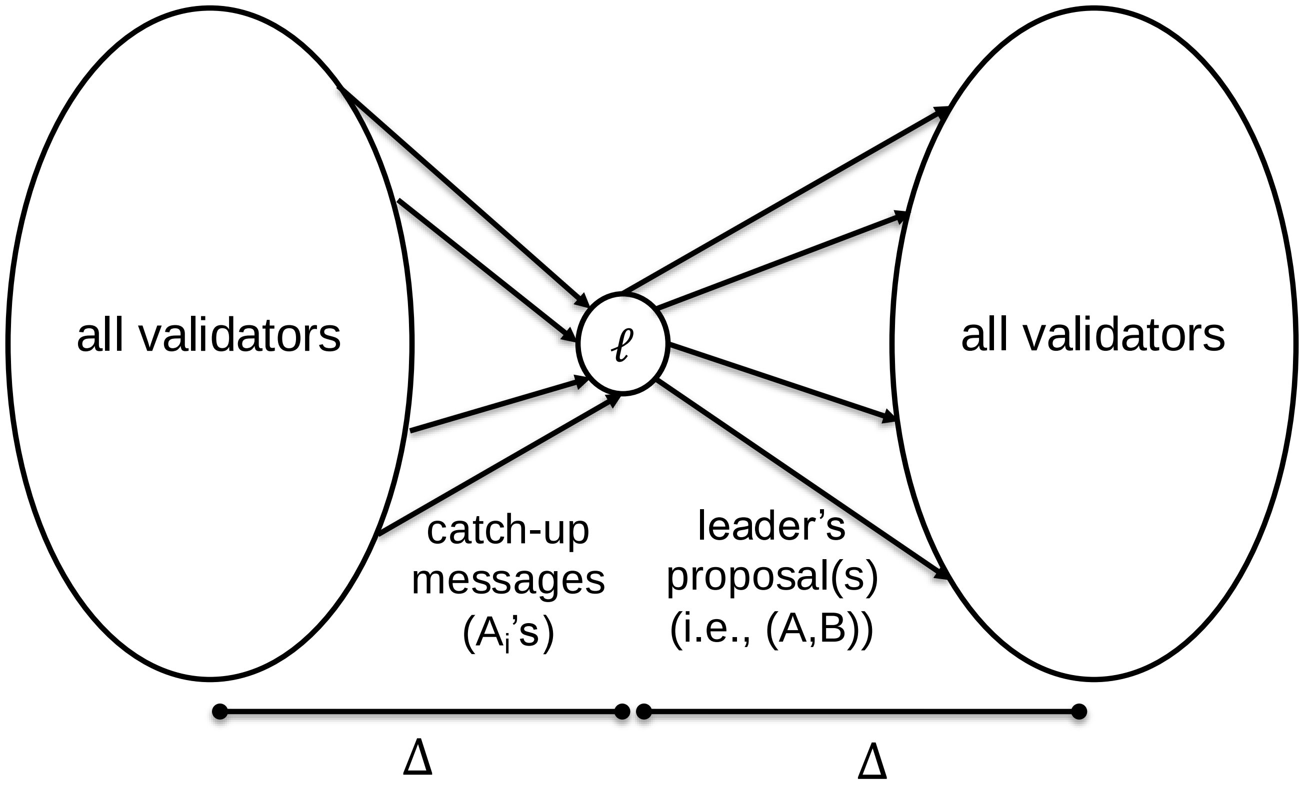

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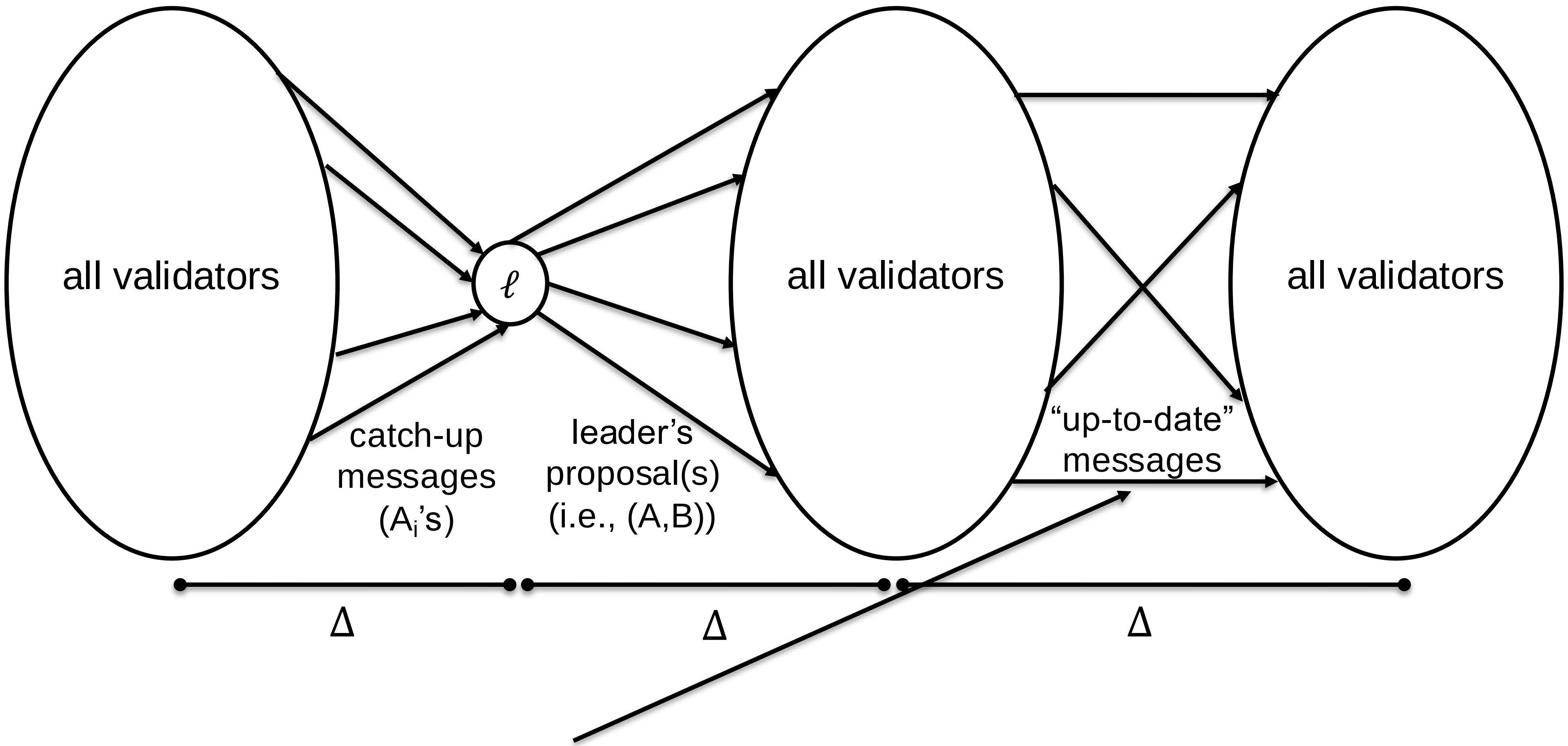

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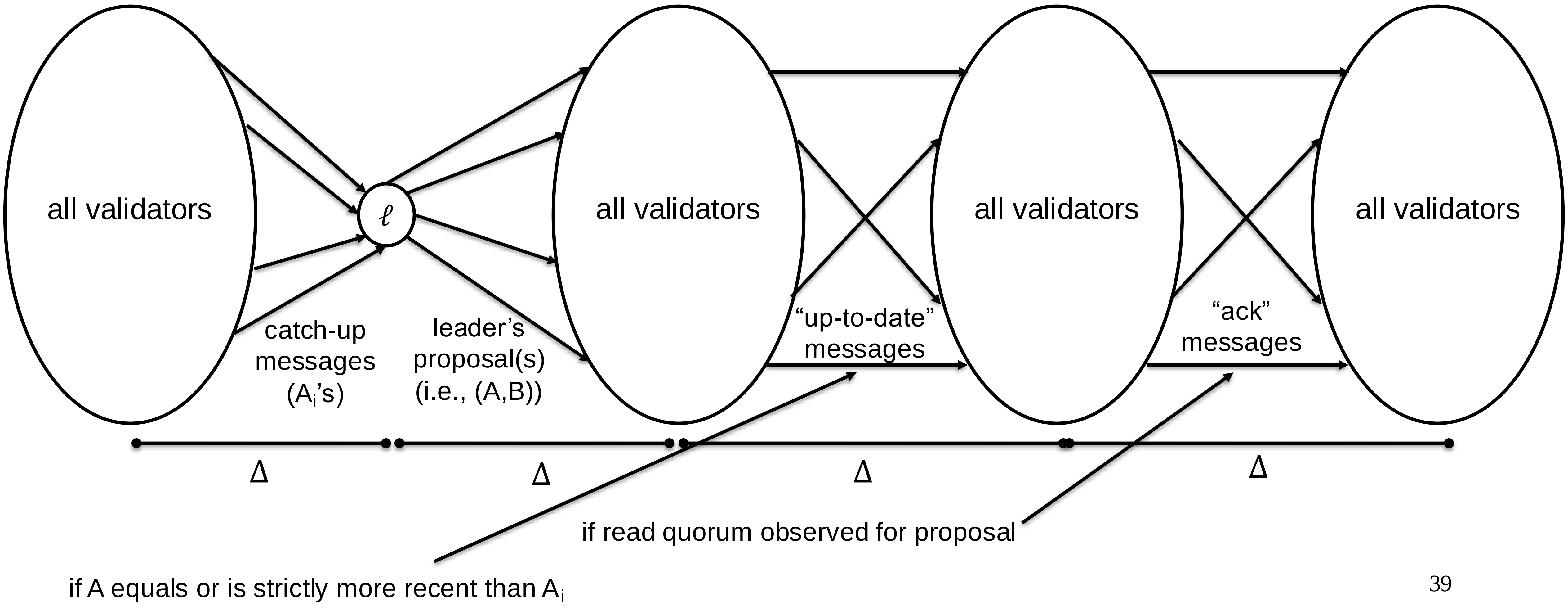

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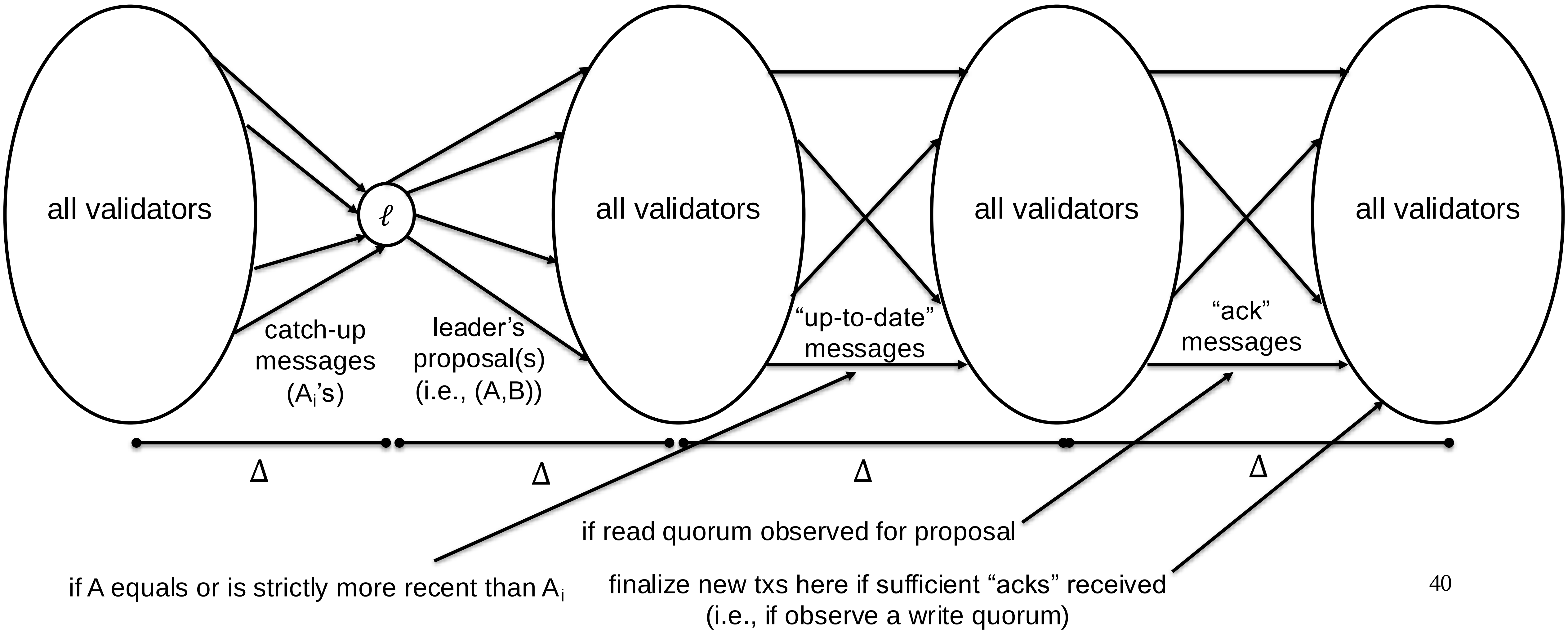

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Recap: The Partially Synchronous Model

- shared global clock (timesteps=0,1,2,…)
- known upper bound Δ on message delays in normal conditions
- unknown transition time GST ("global stabilization time") from asynchrony to synchrony (i.e., end of attack/outage)
  - protocol must work no matter what GST is

Recall goals:

- consistency, always (even pre-GST/"under attack")
- liveness soon after GST (once "normal conditions" resume)
  - FLP ➔ need to give up one of consistency, liveness before GST

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   - consequence: all updates to non-faulty C_i's in views v' > v are to chains that extend A^*. [reason: never update without a QC]

Key Claim Implies Consistency

- consequence (1): if any non-faulty C_i's get updated in this view, all get updated to the same proposal $A^* = (A,B,Q)$.
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- (1) ➔ simultaneous updates (i.e., in same view) are consistent
- (2) ➔ every update extends all updates from all previous views

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- > n/3 validators are in both S and T (<n/3 not in S, <n/3 not in T)

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- some non-faulty validator i is in both Q_1 and Q_2

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- $|S|, |T| > 2n/3$ [due to revised quorum thresholds]
- $> n/3$ validators are in both S and T ($<n/3$ not in S, $<n/3$ not in T)
- some non-faulty validator i is in both Q_1 and Q_2
- since i sent an up-to-date message for only one leader proposal (A,B), Q_1 and Q_2 must both be for (A,B)

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In general (by induction on v' > v): for each j in U, A_j is either A^* or a chain+QC created in a view > v (which, inductively, extends A^*).

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- post-GST ➔ all non-faulty validators j get > 2n/3 "ack (A,B,Q)" messages by time $4\Delta \cdot v + 4\Delta$, set C_j := (A,B,Q) [thereby finalizing tx z]