Lecture #5: Byzantine Faults and Digital Signature Schemes

COMS 4995-001: The Science of Blockchains

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

Tim Roughgarden

Goals for Lecture #5

1. The challenges of Byzantine faults.
   – faulty validators that can behave in arbitrary (worst-case) ways

2. Digital signature schemes.
   – key tool for limiting the space of Byzantine validator strategies

3. Limits on what is achievable.
   – Byzantine faults make the SMR problem harder in partial synchrony

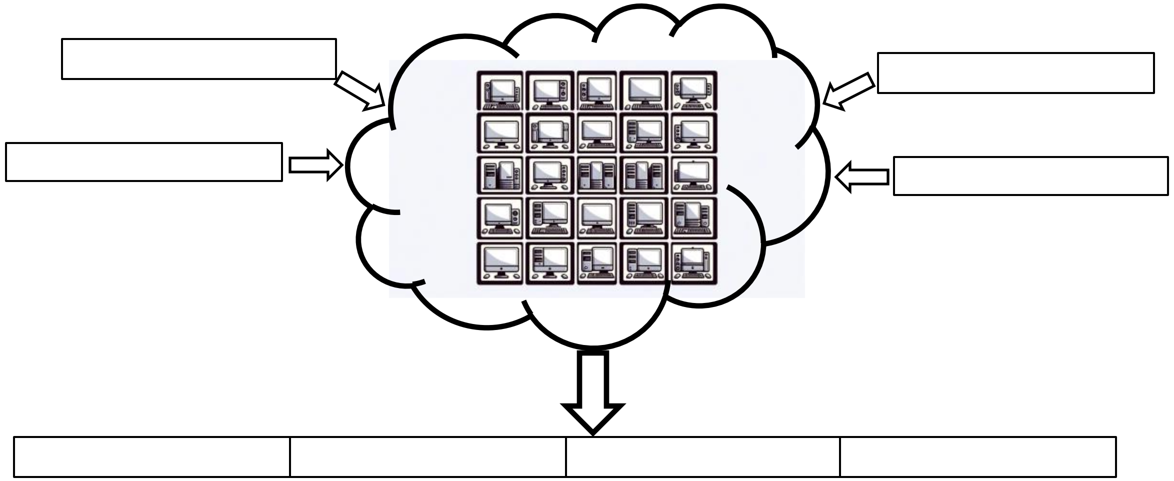
4. Key ideas behind Tendermint.
   – Full protocol description and analysis on Monday.

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 = ?]

easier → harder

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

Lecture #4: if strict majority of validators are non-faulty, Protocol C (≈ Paxos/Raft) solves SMR with crash faults in partial synchrony.

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    - e.g., hacks into validators previously controlled by good actors
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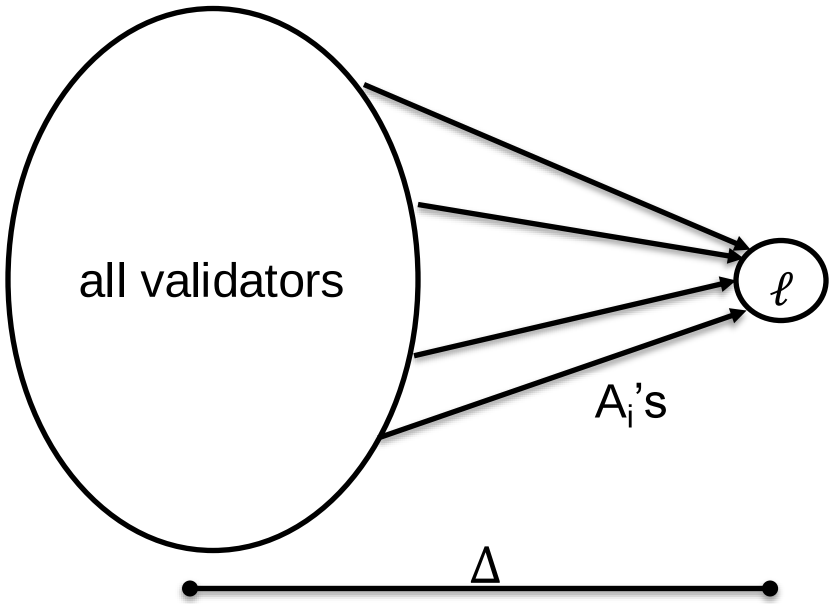

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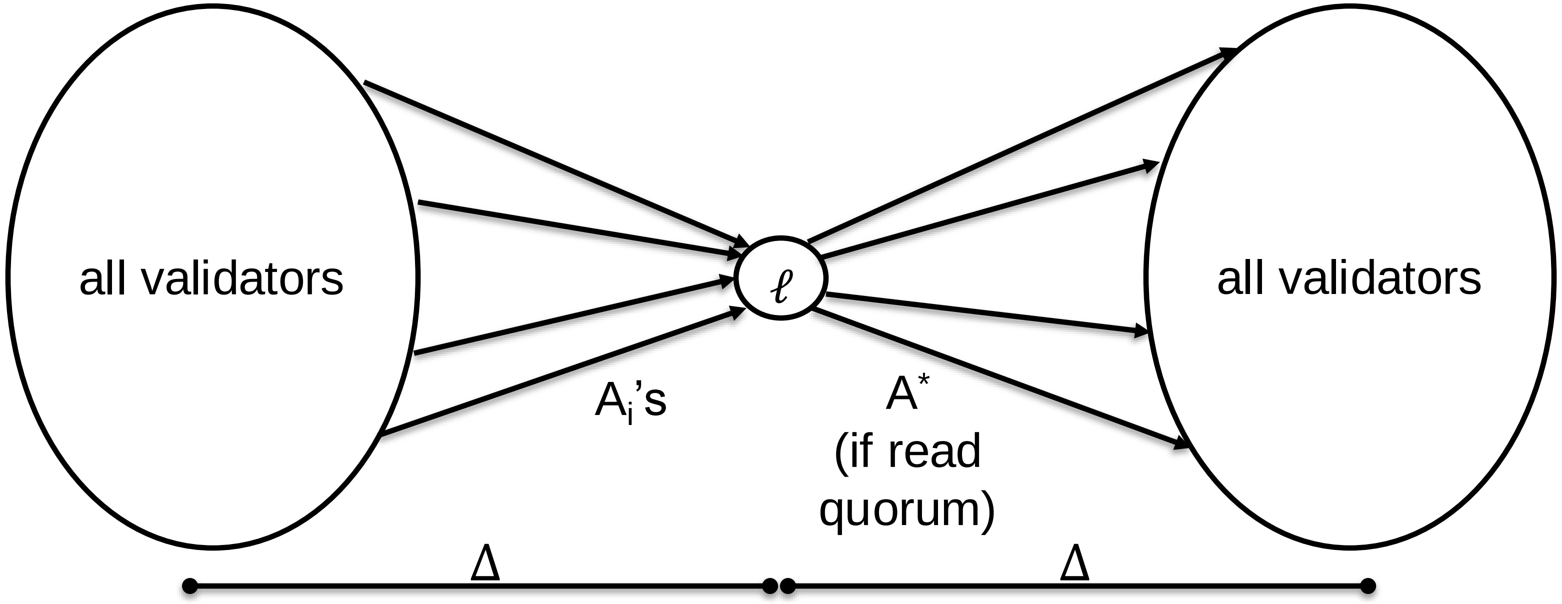

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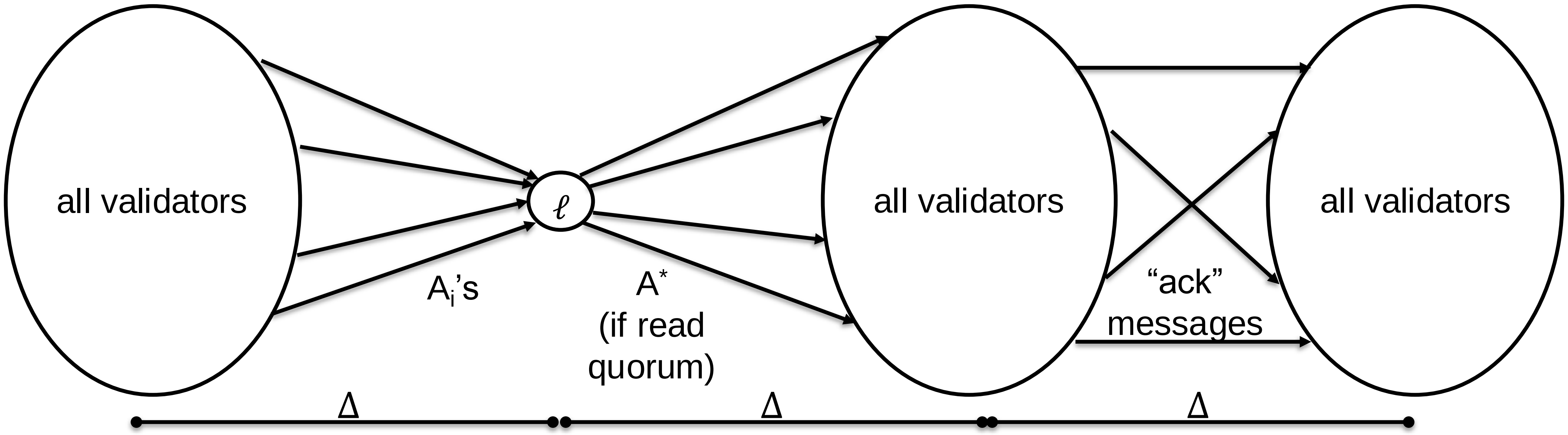

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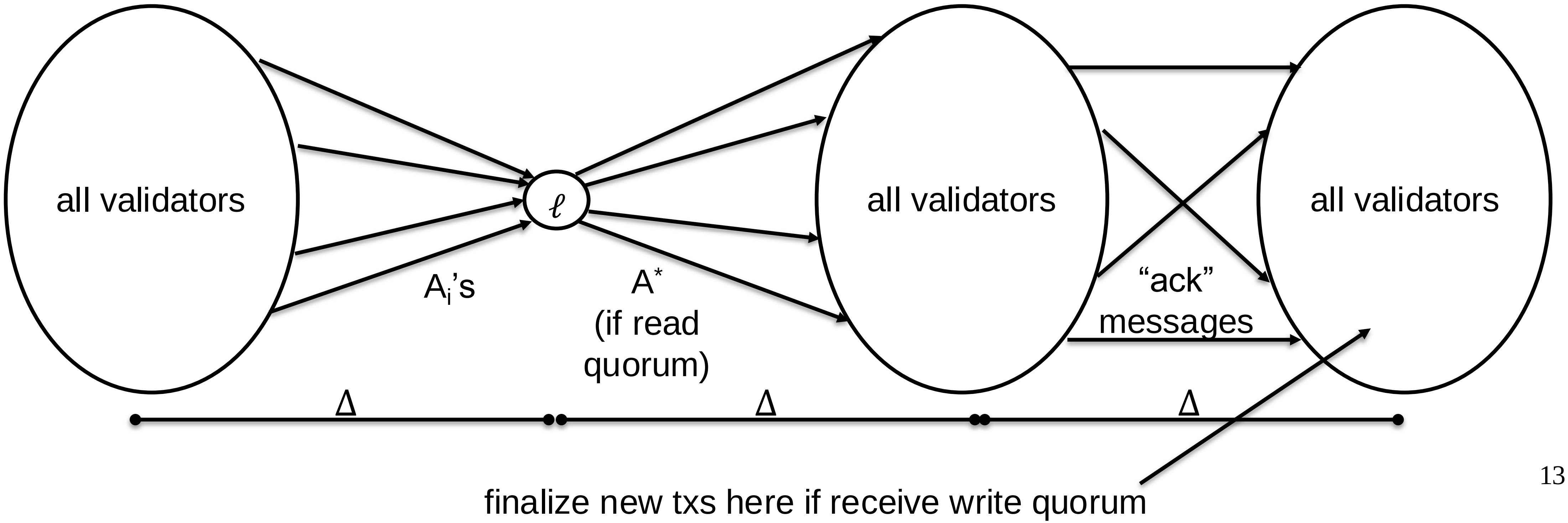

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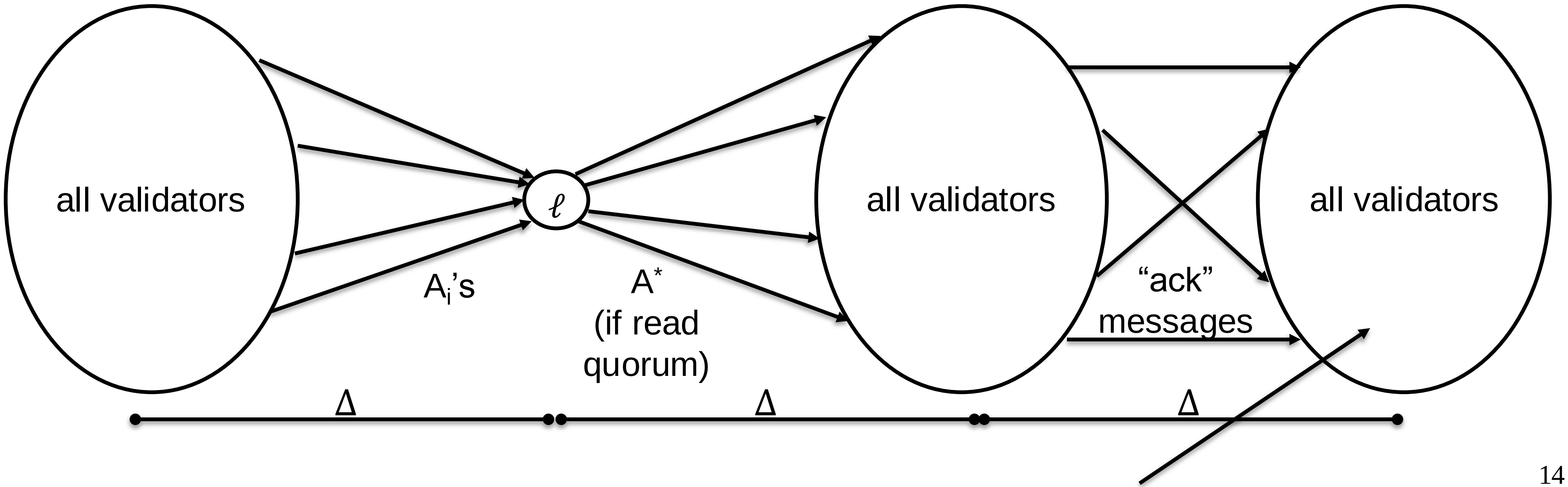
- key property for consistency: read quorum must intersect write quorums from all previous views ➔ if leader makes a proposal, must be up-to-date



finalize new txs here if receive write quorum

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Issue #1: Byzantine leader could ignore read quorum requirement and make an (out-of-date) proposal anyway.

- maybe didn't receive chains from > n/2 validators, or maybe it did and chose to ignore them
- out-of-date proposal (if adopted) ➔ consistency violation

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- no: Byzantine validators can ack multiple proposals
  - non-faulty validators might simultaneous finalize inconsistent chains

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Issue #3: Byzantine validators could lie about messages received from other validators.

- e.g., frame a non-faulty validator for its own misbehavior
- will tackle this issue with cryptography (next)

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Application #2: under the hood, allows validators of a blockchain protocol to sign their messages.

- used in most blockchain protocols for this purpose
  - with Bitcoin a notable exception

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(Semi-)formal DSS security statement: under suitable complexity assumptions, no randomized poly-time (in key length) algorithm with access to a bunch of signed messages can produce a valid signature for an unseen message with non-negligible probability.

What Signatures Can and Can’t Do

Issues:

- Byzantine leader could ignore read quorum requirement and make a proposal anyway. (➔ consistency violation)
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Bad news: even with signatures, SMR strictly harder with Byzantine faults than with crash faults.

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Recall goals:

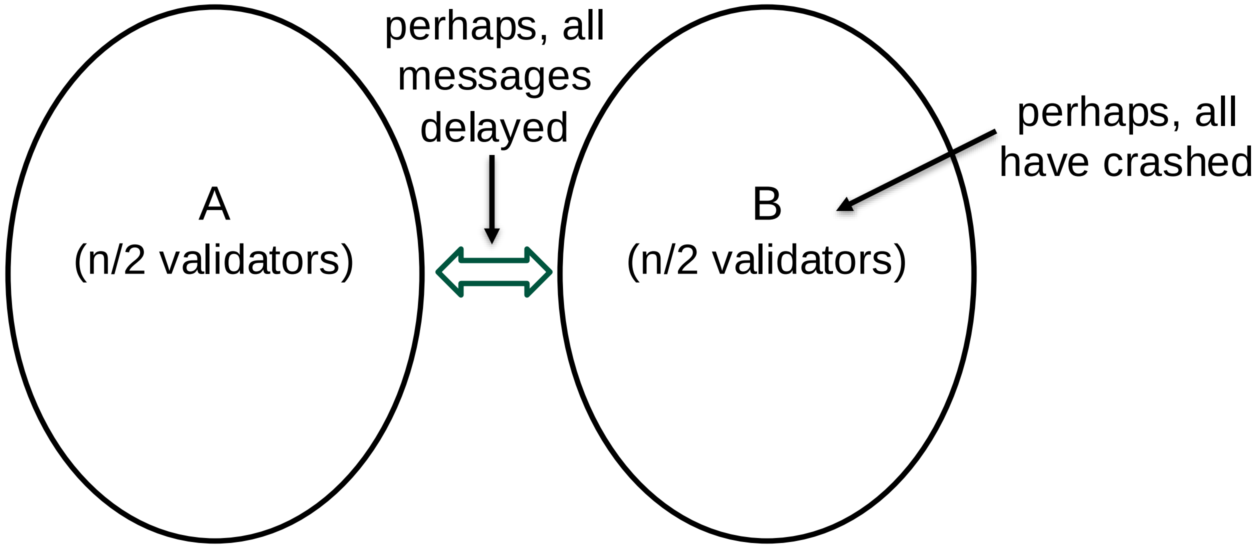
- consistency, always (even pre-GST/"under attack")
- liveness soon after GST (once "normal conditions" resume)
  - FLP ➔ need to give up one of consistency, liveness before GST

Recap: Partial Synchrony + Crash Faults

Fact: crash faults + partial synchrony ➔ security threshold < 50%.

Suppose: validators in A don't hear from any validators in B for a long time.

- should they finalize any new txs?



Catch-22:

- if validators in A wait ➔ possible liveness violation
  - if post-GST and all validators in B have crashed (will wait forever)
- if validators in A proceed ➔ possible consistency violation
  - if pre-GST and all messages A ⇔ B have been delayed

What Is Possible with Byzantine Faults?

Fact: Byzantine faults + partial synch ➔ security threshold < 33%.

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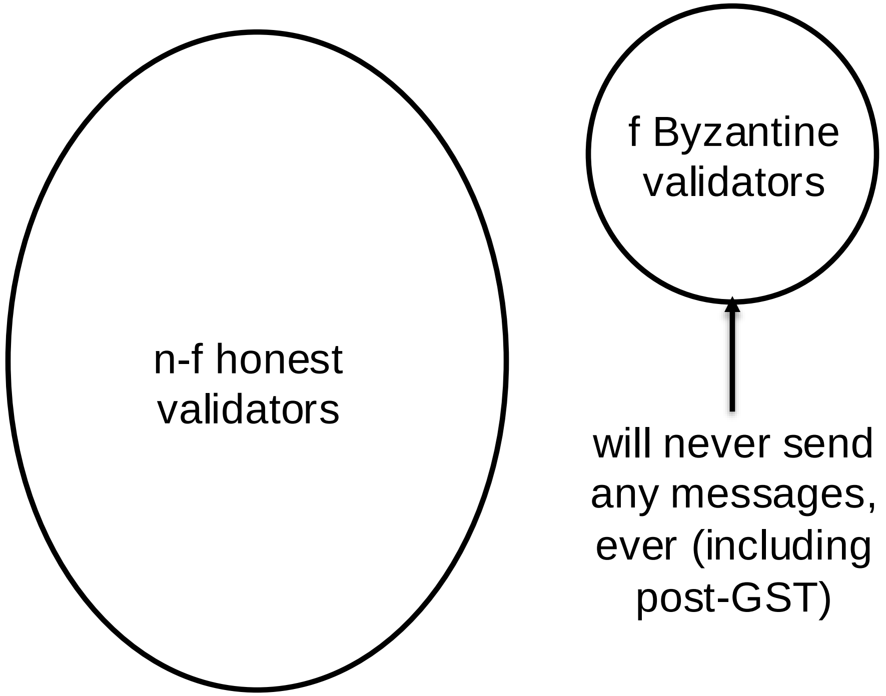

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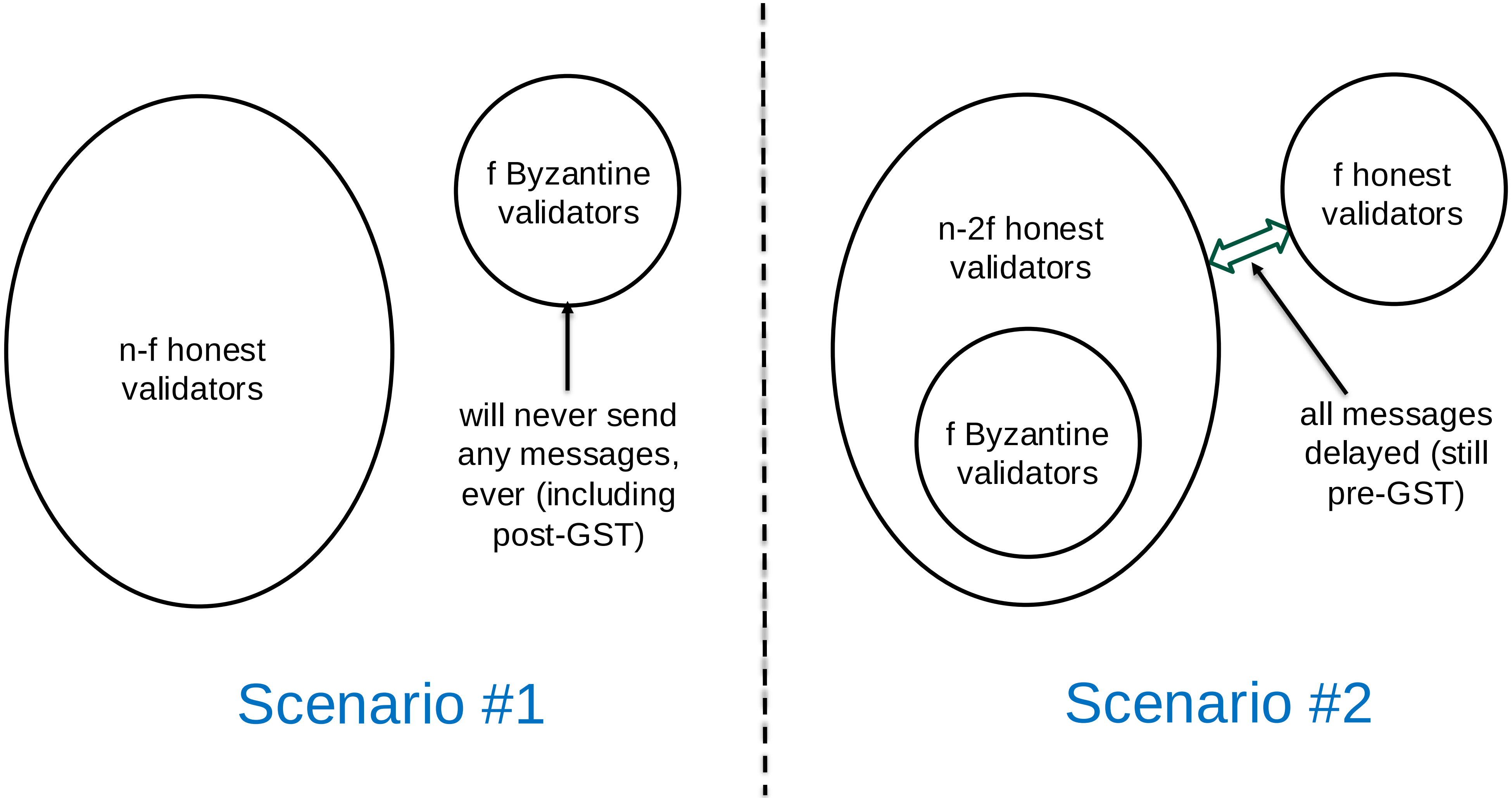

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(n-f)-f: honest; f: Byzantine

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Bonus: can’t have write quorums for two different chains in the same view (despite equivocating leader, Byzantine acks).

- will ensure that simultaneous updates must be consistent

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(ii) increase all quorum sizes to > 2n/3 validators

- consequence: any two quorums have non-faulty validator in common

Bonus: can’t have write quorums for two different chains in the same view (despite equivocating leader, Byzantine acks).

- will ensure that simultaneous updates must be consistent
- reason: non-faulty validators will ack only one proposal per view
  - two write quorums ➔ have a non-faulty validator in common ➔ validator only acked one proposal ➔ both WQs support same proposal

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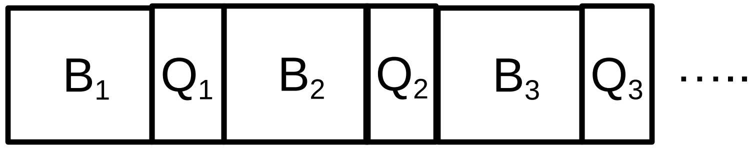

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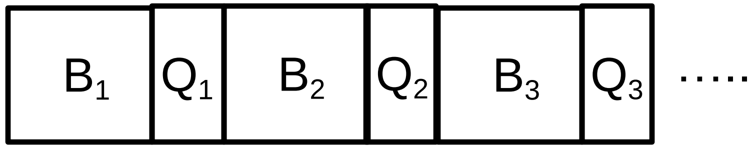

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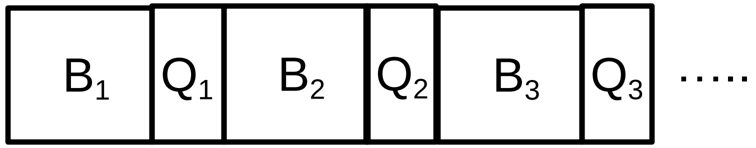

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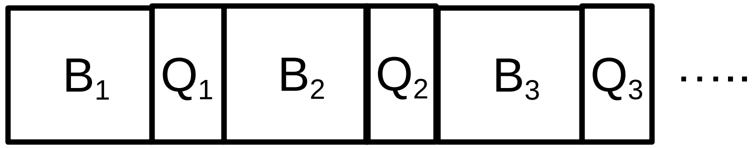

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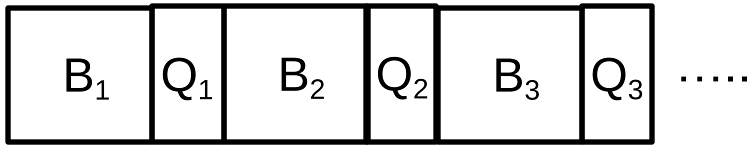

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  - good news: idea #2 ➔ impossible to have QCs for two different proposals in the same view (effectively, equivocation not possible)