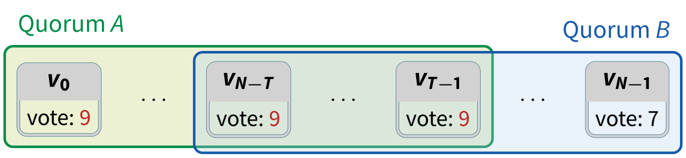
Administrivia

- **If you need access to lecture videos, please email cs244b-staff**
  - Subject: downloadable lecture videos
  - I need the ability to download lecture videos and I promise to delete all downloaded videos at the end of the quarter.
- **Please re-do poll from last class here (or class poll link on class web page)**
  - Contrary to zoom documentation I was unable to get results after last lecture
- **Jim office hours announcement**

Plan for next three lectures

- **Today: PBFT – classic BFT replication algorithm**
  - First practical algorithm, still quite relevant (e.g., hyperledger)
- **Wednesday: Randomized BFT algorithms**
  - Very different BFT techniques with different tools, trade-offs
- **Monday 5/4: Other topics in BFT, HotStuff**
  - Advances since 1999 (when PBFT published)
  - Partial synchrony
- **Then we switch gears and talk about higher-level systems**

Voting safety in fail-stop model



- **Suppose you have N nodes with fail-stop behavior**
- **Pick a quorum size $T > N/2$**
- **If T nodes (a quorum) all vote for a value, output that value**
  - → E.g., Quorum A unanimously votes for 9, okay to output 9
  - Nodes cannot change their vote
  - Any two quorums intersect $\Longrightarrow$ agreement
- **Problem: stuck states**
  - Failure could mean not everyone learns of unanimous quorum
  - Split vote could make unanimous quorum impossible

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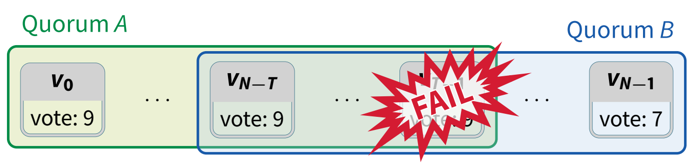

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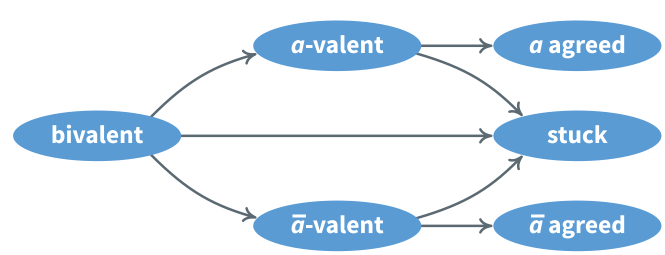
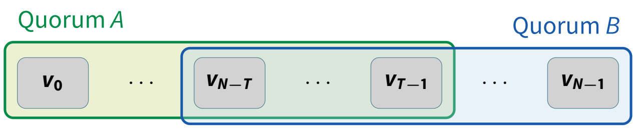
What voting gives us



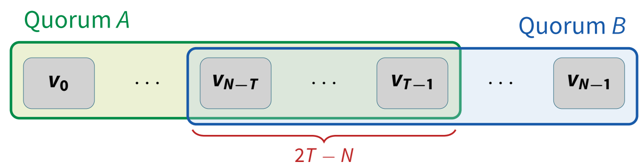
- **You might get system-wide agreement or you might get stuck**
  - Can't vote directly on consensus question (what RSM op to apply)
- **How do you know you agreed?**
  - If more than $f = N - T$ nodes fail, will always get stuck
  - If $f + 1$ nodes see T votes, even if f fail one can spread word

Byzantine agreement



- **What if nodes may experience Byzantine failure?**
  → Byzantine nodes can illegally change their votes
  - In fail-stop case, safety required any two quorums to share a node
  - Now, any two quorums to share a *non-faulty* node
- ***Safety* requires: # failures $\leq f_S = 2T - N - 1$**
- ***Liveness* requires: # failures $\leq f_L = N - T$**
  - At least one entirely non-faulty quorum exists
- **Typically set $N = 3f + 1$ and $T = 2f + 1$ so $f_S = f_L = f$**

Byzantine agreement



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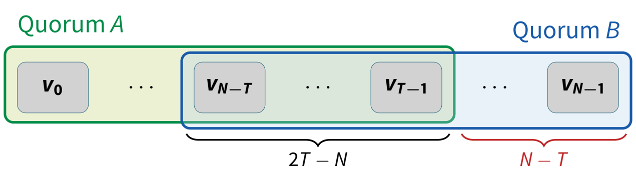

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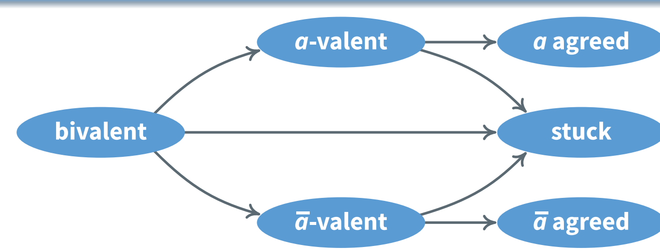

- **If $f_S + 1 = 2T - N$ nodes malicious, system loses safety**
- **Suppose $f_S + 1$ nodes all claim to have seen T votes for a**
  - Can assume system is a-valent with no loss of safety
  - In fact, $f_S + 1$ signed msgs = proof of system state (or unsafety)
- **Now say $f_L + f_S + 1 = T$ nodes all make same assertion**
  - If $> f_L$ fail, system loses liveness (0 correct nodes in whole system)
  - If $\leq f_L$ fail, $\geq f_S + 1$ remaining nodes can notify rest
  - So either catastrophy or all non-faulty nodes will eventually hear it

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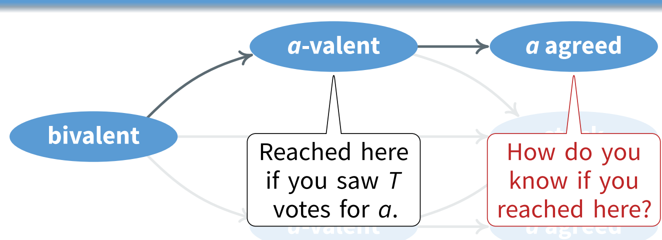

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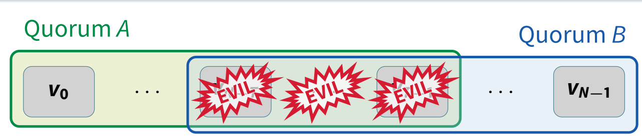

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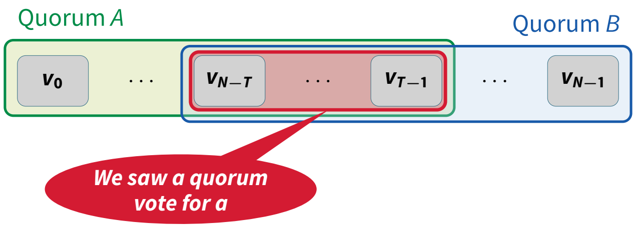

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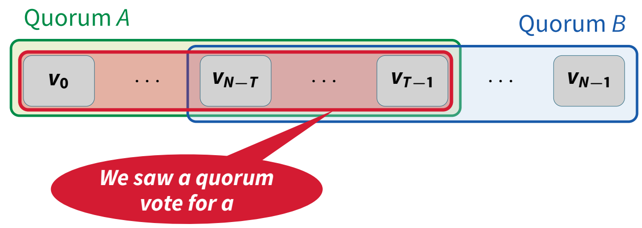

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