EECS 591
Distributed Systems

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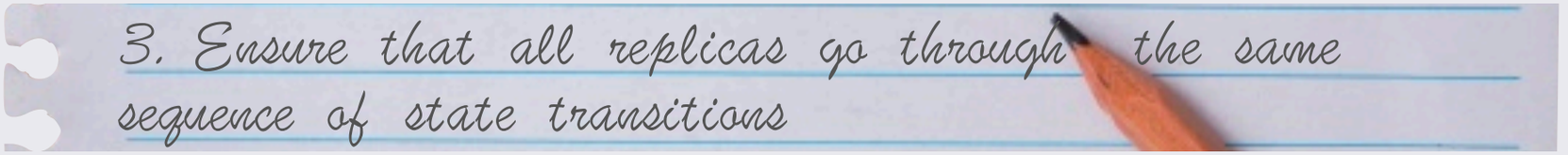
Fall 2021

Using (multi)Paxos to implement State Machine Replication

The original Paxos algorithm achieves agreement on **one** value

SMR required replicas to agree on the **sequence** of commands that will be executed

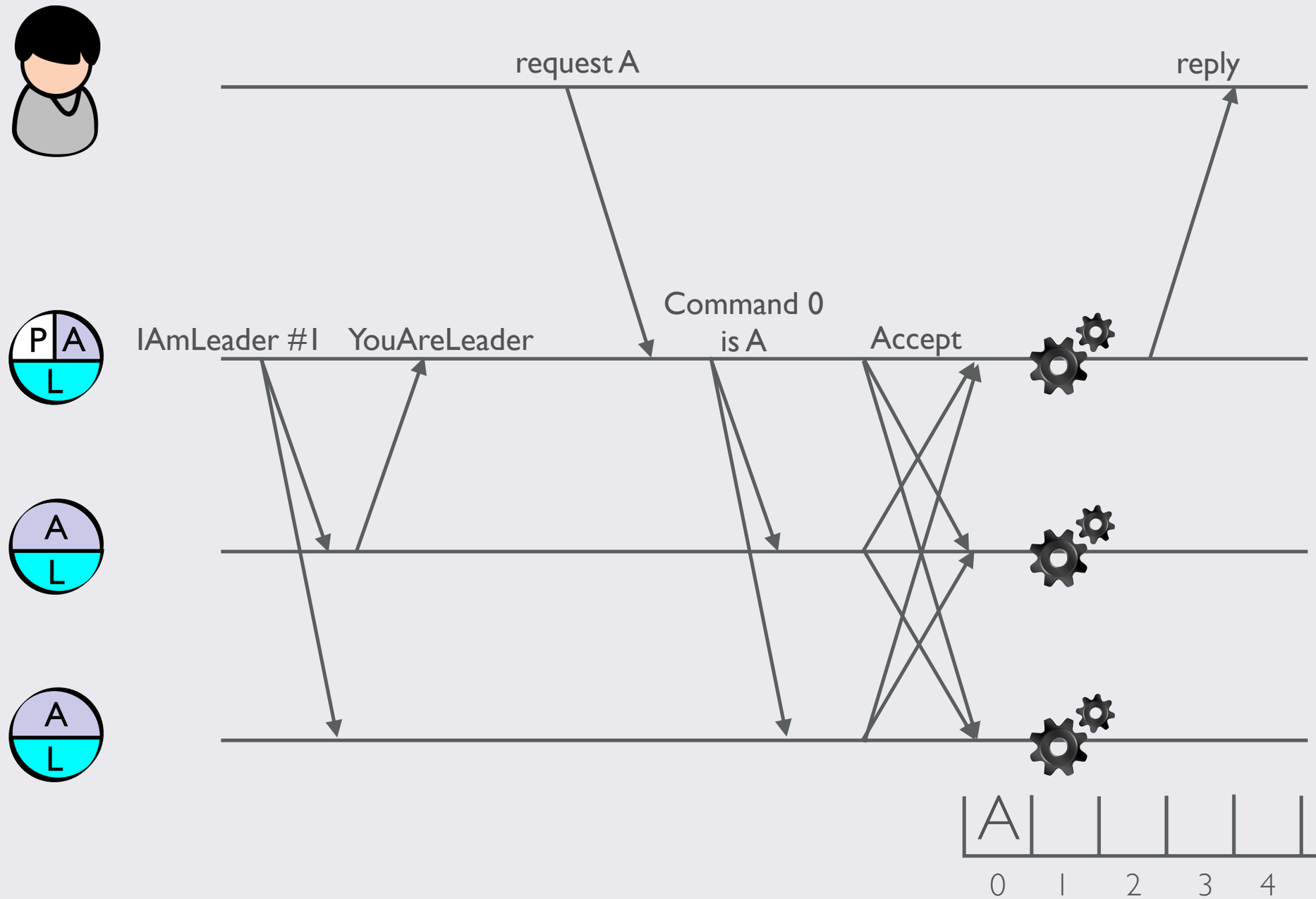


MultiPaxos: Run an instance of Paxos for each slot in the sequence

Important: we don't need to run phase 1 (election) every time!

PAXOS/SMR IN REAL LIFE

Proposers, acceptors and learners
are all collocated on $2f + 1$ replicas



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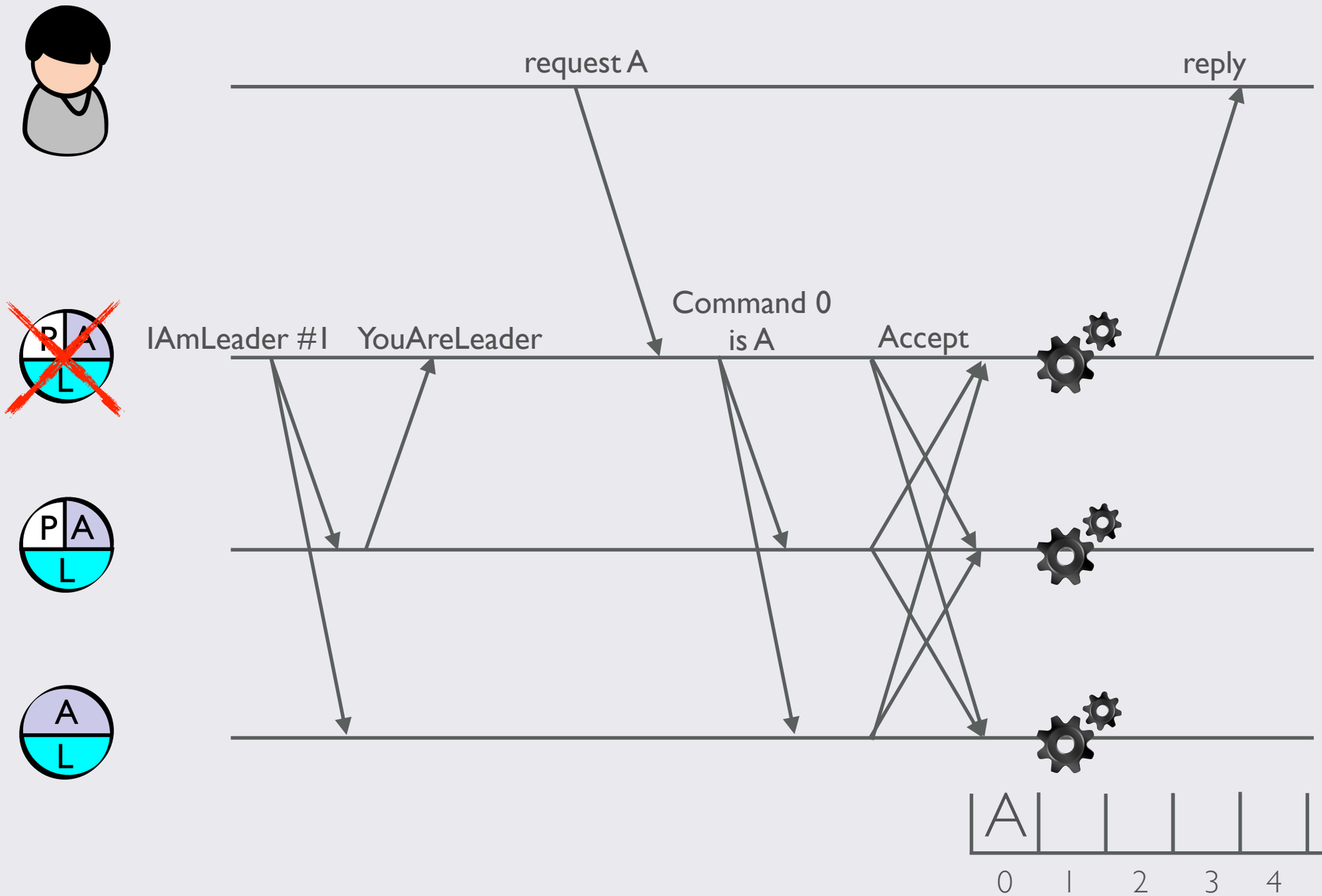


Administrivia

Midterm

- Wednesday 10/27, 12-1:20pm, during class
  - You can use any material listed on the course website

No class the next two Mondays

- Monday 10/18, UM study day
- Monday 10/15, conflict with SOSP workshops

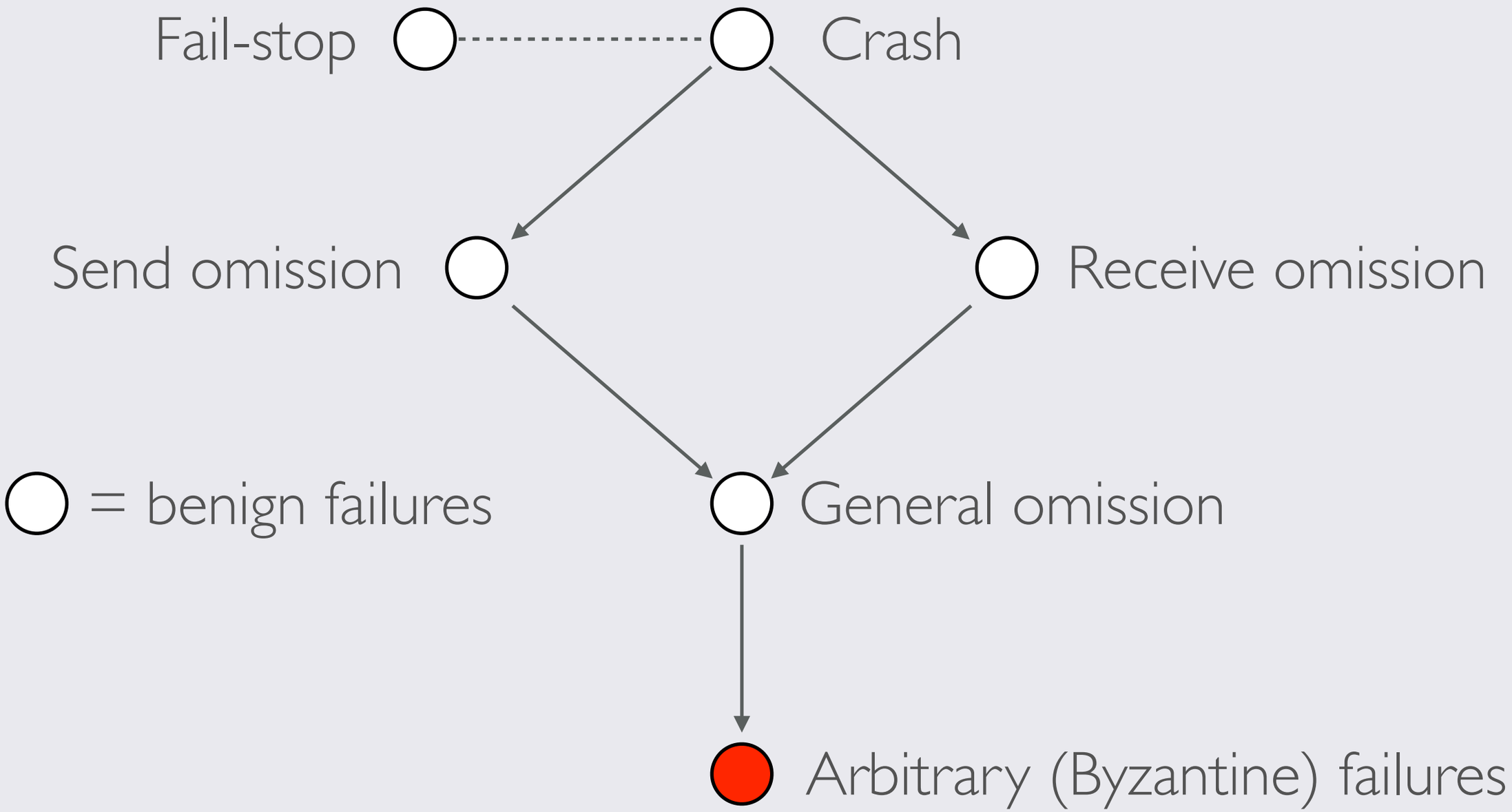
Research part

- Starts after midterm, Monday 11/1 with Fast Paxos and Flexible Paxos
  - You should read both papers and you can review either one

Byzantine Fault Tolerance

Slides by Lorenzo Alvisi

A HIERARCHY OF FAILURE MODELS



What are Byzantine Failures

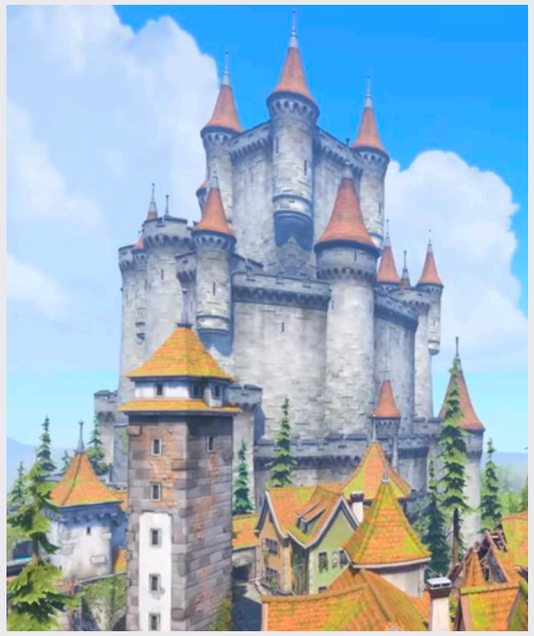
The short answer: they can be ***anything!***

(they can even be crash/omission failures)

Examples of commission failures

- A bit flip in memory
  - Manufacturing defect
  - Alpha particles
- Network card malfunction
- Intentional behavior
  - Rational node: trying to game the system for personal gain
  - Malicious node: trying to bring the system down

The Byzantine Generals



- Synchronous communication
- One general may be a traitor

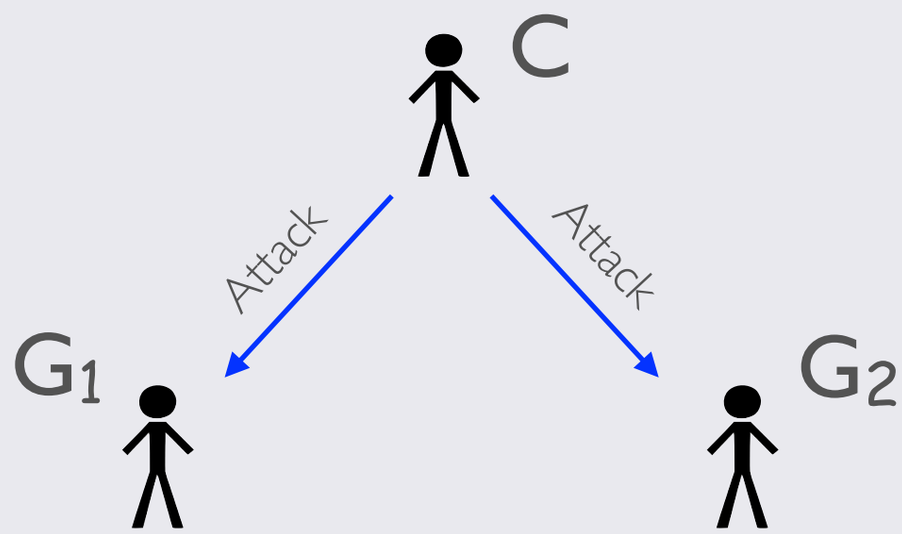
The Byzantine Generals

- Synchronous communication
- One general may be a traitor
- One of the generals is the commander **C**
  - The commander decides **Attack** or **Retreat**

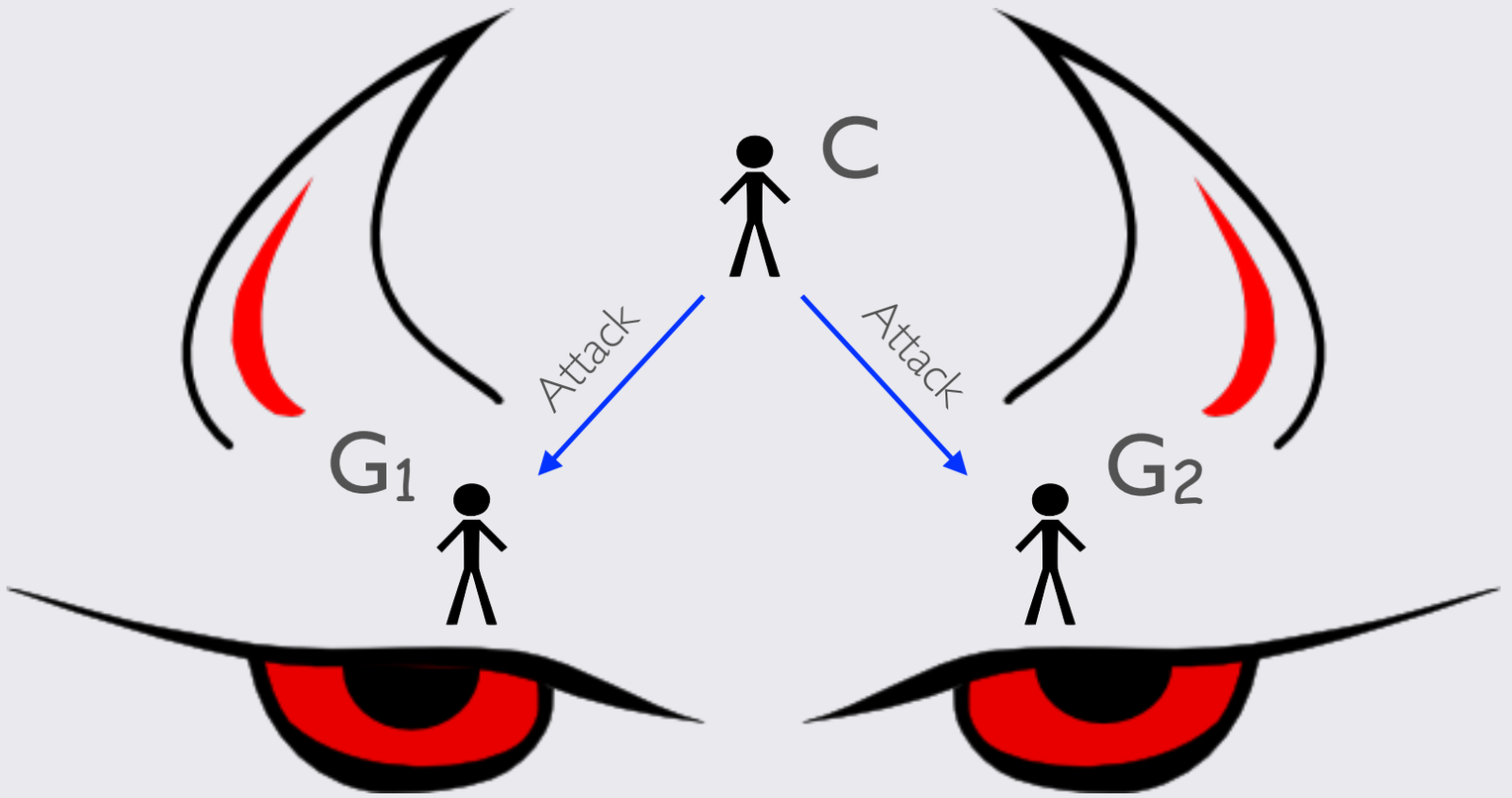
Goals

1. If **C** is trustworthy, every trustworthy general must follow **C**'s orders
2. Every trustworthy general must follow the same battle plan

Remember when things were simpler?



YOU CAN'T TRUST ANYONE THESE DAYS…



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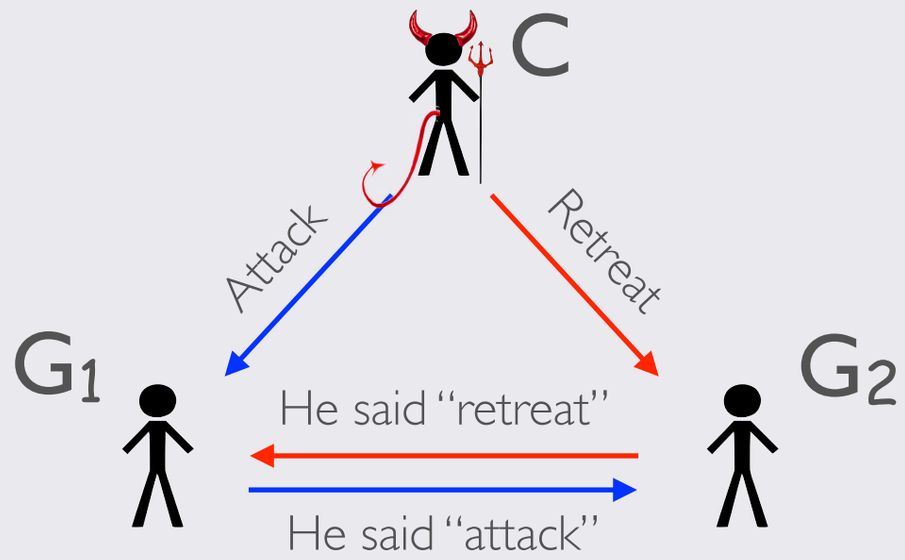

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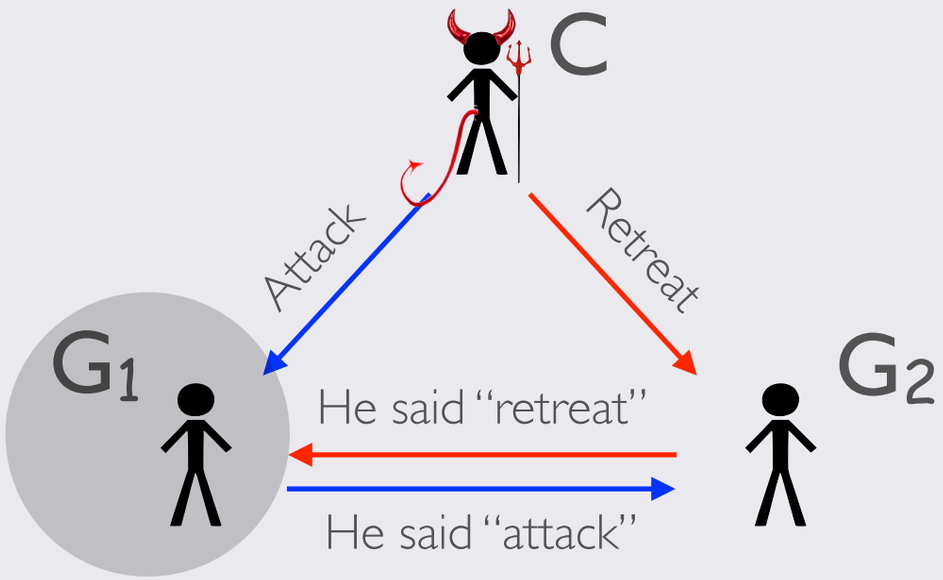
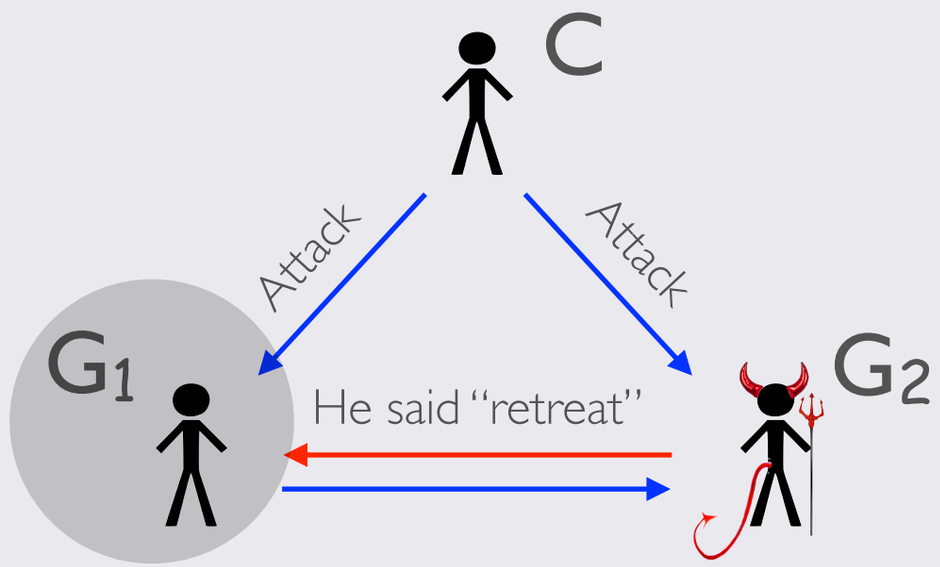
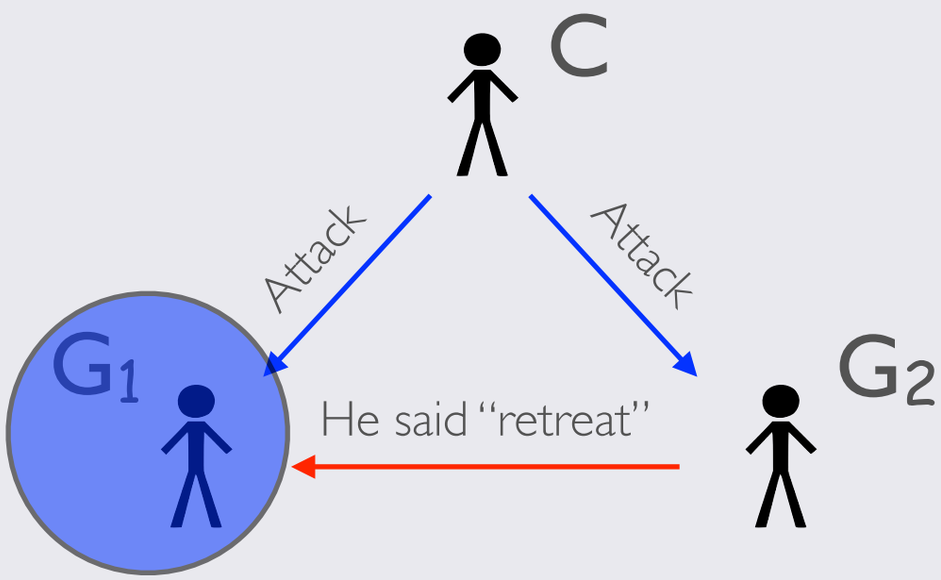
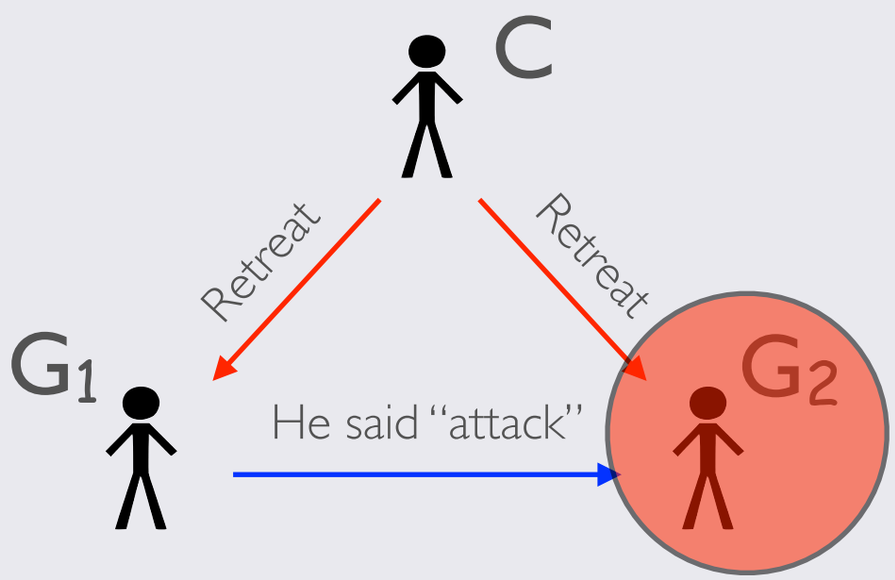
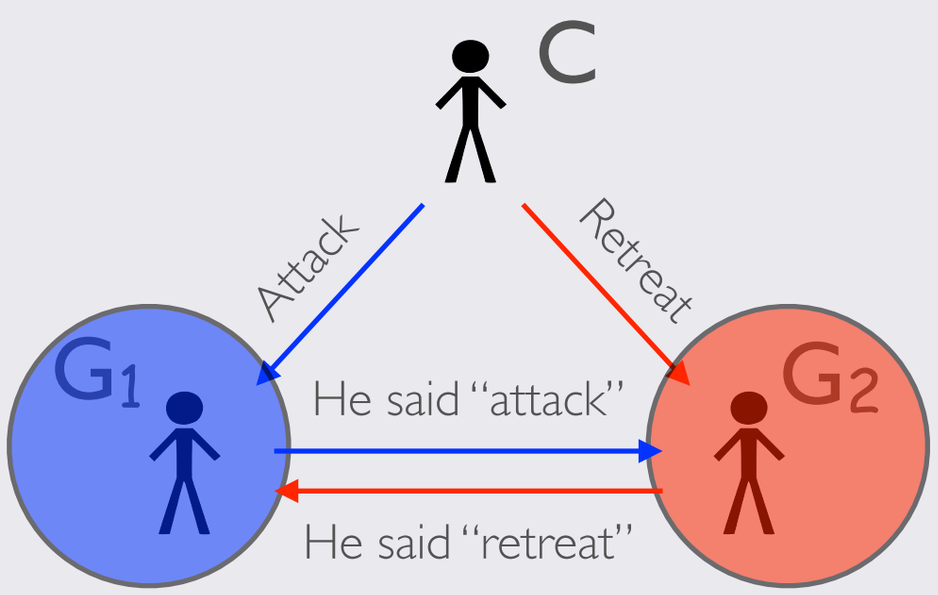




"BUT THEY WERE ALL OF THEM DECEIVED…"







A LOWER BOUND

Theorem

There is no algorithm that solves TRB for Byzantine failures if $n \leq 3f$

Lamport, Shostak and Pease, The Byzantine Generals Problem, 1982

PBFT: A Byzantine Renaissance

Practical Byzantine Fault Tolerance

(Castro, Liskov 1999-2000)

- First practical protocol for **asynchronous BFT replication**
- Like Paxos, PBFT is safe all the time, and live during periods of synchrony

Barbara Liskov

Turing Award 2008

The setup

System model

- Asynchronous system
- Unreliable channels

Crypto

- Public/private key pairs
- Signatures
- Collision-resistant hashes

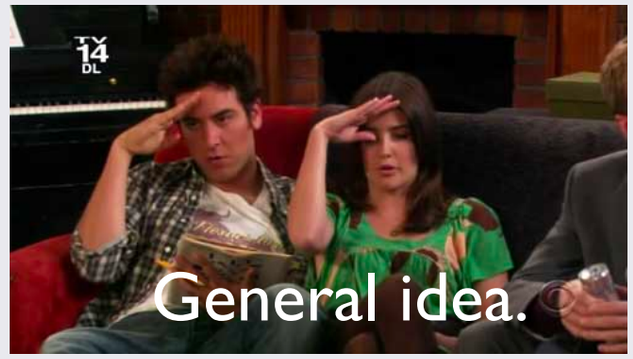
Service

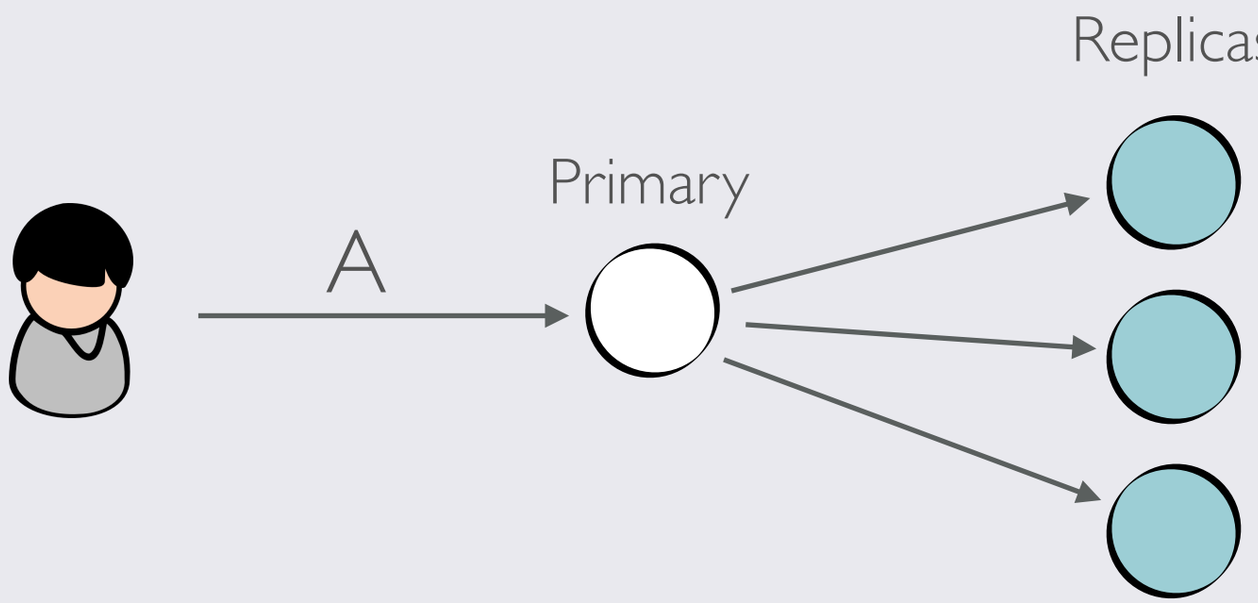
- Byzantine clients
- Up to f Byzantine servers
- $n = 3f + 1$ total servers

System goals

- Always safe
- Live during periods of synchrony

THE GENERAL IDEA





- One primary, 3f replicas
- Execution proceeds as a sequence of **views**
  - A view is a configuration with a well-defined primary
- Client sends signed commands to primary of current view
- Primary assigns sequence number to client's command
- Primary is responsible for the command eventually being decided

What could possibly go wrong!?

- The primary could be faulty!
  - could ignore commands, assign same sequence number to different requests, skip sequence numbers, etc.
  - ☑ Backups monitor primary's behavior and trigger **view changes** to replace a faulty primary

- Replicas could be faulty!
  - could incorrectly forward commands received by a correct primary
  - ☑ any single request may be misleading; need to rely on **quorums** of requests

  - could send incorrect responses to the client
  - ☑ client waits for $f + 1$ matching responses before accepting

Certificates

Protocol steps are justified by **certificates**

- Sets (quorums) of signed messages from distinct replicas proving that a property holds

Certificates are of size at least $2f + 1$

- Any two quorums intersect in at least **one correct** replica (for safety)
- There is always a quorum of correct replicas (for liveness)