Large Scale Systems
CS 410 / 510

Lecture 9:

Crash Failures

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Assignment 2 is Out!

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- Please work with your groups to understand the underlying system.
- Assignment 2 report **deadline** → April 30, 2026 at 11:59pm.

Last Class

- Last class we looked at:

- How to evaluate a LSS

Reading Material

- For this class
  - Read **Chapter 8** from **Distributed System** by Maarten van Steen and Andrew Tanenbaum.
  - Authors provide students free online copy.

Failures

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- A failure in a large-scale system implies that some component in the system is no longer working in the expected manner.

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- What about network?

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- What about network? Even network failures are possible.

Categorization of Failures

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- **Omission Failures:**
  - Unexpected failures.
  - Failures due to something omitted, when it should have been done.

- **Commission Failures**
  - Caused Failures.
  - Failures due to doing some action that should not have been done.

Categorization of Failures

- **Crash Failure** → A node halts or fail stops.
- **Ommission Failure** → Failure to send, receive or respond to a message.
- **Timing Failure** → Message arrives beyond a specified time period.
- **Commission Failure** → Arbitrary failures like Byzantine attacks.

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  - **Asynchronous Systems**

  - **Synchronous Systems**

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- What are the different types of network models?
  - **Asynchronous Systems**
    - No timing assumptions made about process execution or message delivery.

  - **Synchronous Systems**
    - Process execution and message delivery are time bounded!

Asynchronous vs Synchronous System

- What are the key design issues with asynchronous and synchronous systems?

Asynchronous vs Synchronous System

- What are the key design issues with asynchronous and synchronous systems?
- A synchronous system is hard to practically **implement**.
- It is hard to **determine** the type of failure in an asynchronous system.
- In practice, no system is truly synchronous or asynchronous.

Partially Synchronous System

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- Common method to detect failures is to use timers.
  - Incorrect failure detection possible → Network failure may be categorized as node failure.

Availability under Failures

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  - **Crash failures** → For **f failures**, total replicas needed?
    - **Storage and Execution Systems** →

    - **Regular Systems** →

Availability under Failures

- How can you guarantee availability under failures?
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  - **Crash failures** → For **f failures**, total replicas needed?
    - **Storage and Execution Systems** →
      - If the goal is to just store and execute data, **f+1 replicas** sufficient.

    - **Regular Systems** →
      - Total **2f+1 replicas** needed.

Decision Making in Replicated Systems

Decision Making in Replicated Systems

- Once you have decided the replication factor, you need to enable agreement or consensus mechanism among the replicas.

- Consensus helps the system make progress under crash failures.

- **How to establish a consensus?**

Paxos

Paxos

- Published by Leslie Lamport in 1989.

- Considered as the first consensus protocol.

Paxos Preliminaries

- Partially synchronous setting (may also be asynchronous).
- Messages can get loss, delayed, duplicated or reordered.
- All participants behave deterministic → on same input, yield same output.
- Replicas can crash.

Paxos System Model

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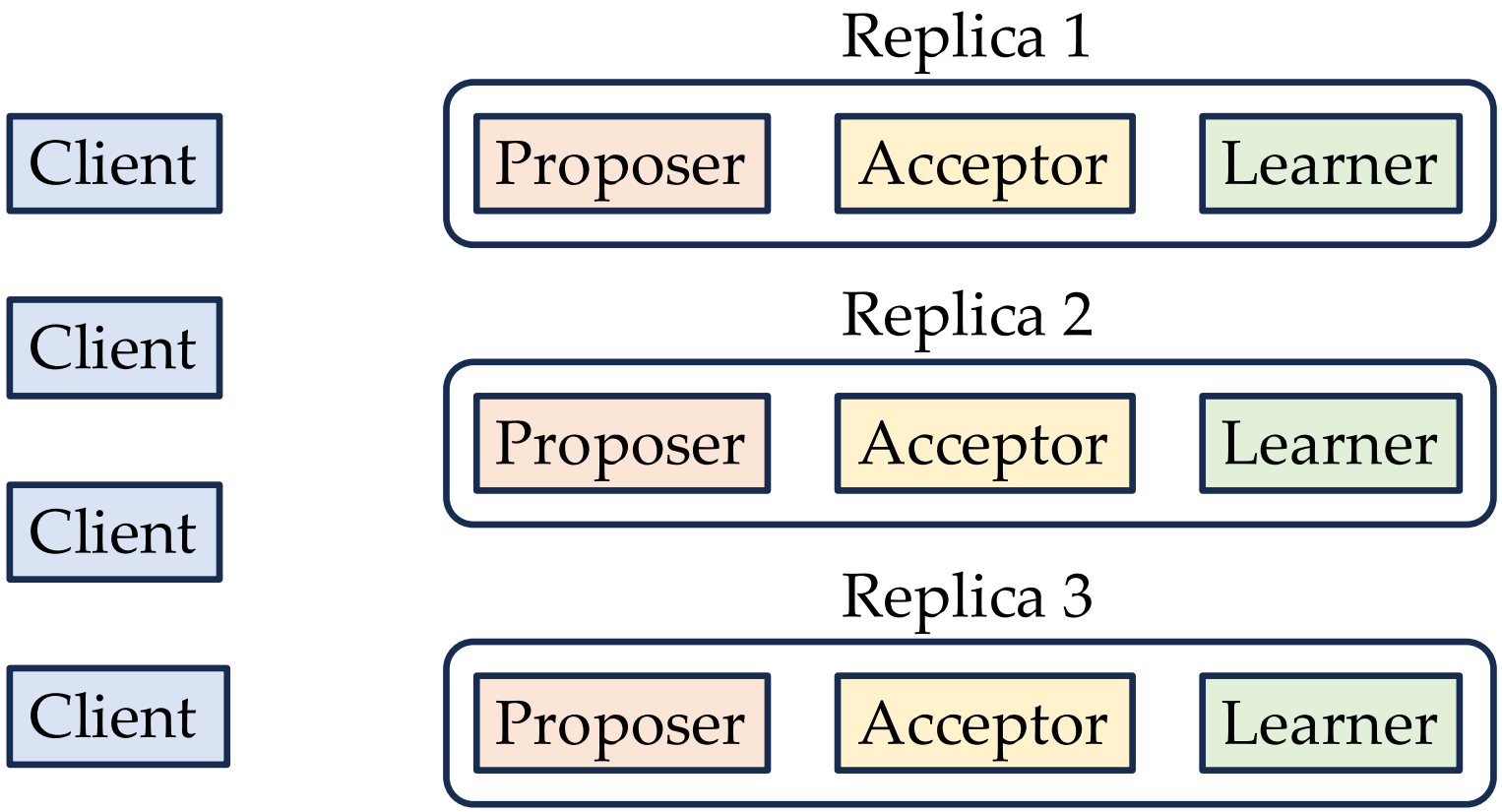
    - Decide whether to accept a proposal or not.
  - **Learners**
    - Learn accepted proposal and execute them.

Paxos System Model



Paxos Fault Tolerance

- To guard against up to **f** failures, Paxos needs at least **2f+1** replicas to reach consensus.

- A proposal becomes accepted if it is accepted by a majority of acceptors →**f+1**.

Paxos Protocol

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  A proposer selects a proposal number **n** and sends a prepare request with number **n** to a majority of acceptors.

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  A proposer selects a proposal number **n** and sends a prepare request with number **n** to a majority of acceptors.

- **Step 1b :**

  If an acceptor receives a prepare request with number **n** greater than that of any prepare request to which it has already responded, then it responds to the request with

  - a **promise** not to accept any more proposals numbered less than **n** and
  - with the highest-numbered proposal (if any) that it has accepted.

Paxos Protocol

- **Step 2a :**

  If the proposer receives a response to its prepare requests (numbered **n**) from a majority of acceptors, then it sends an accept request to each of those acceptors for a proposal numbered **n** with a value **v**,

  where **v** is the value of the highest-numbered proposal among the responses, or is any value if the responses reported no proposals.

Paxos Protocol

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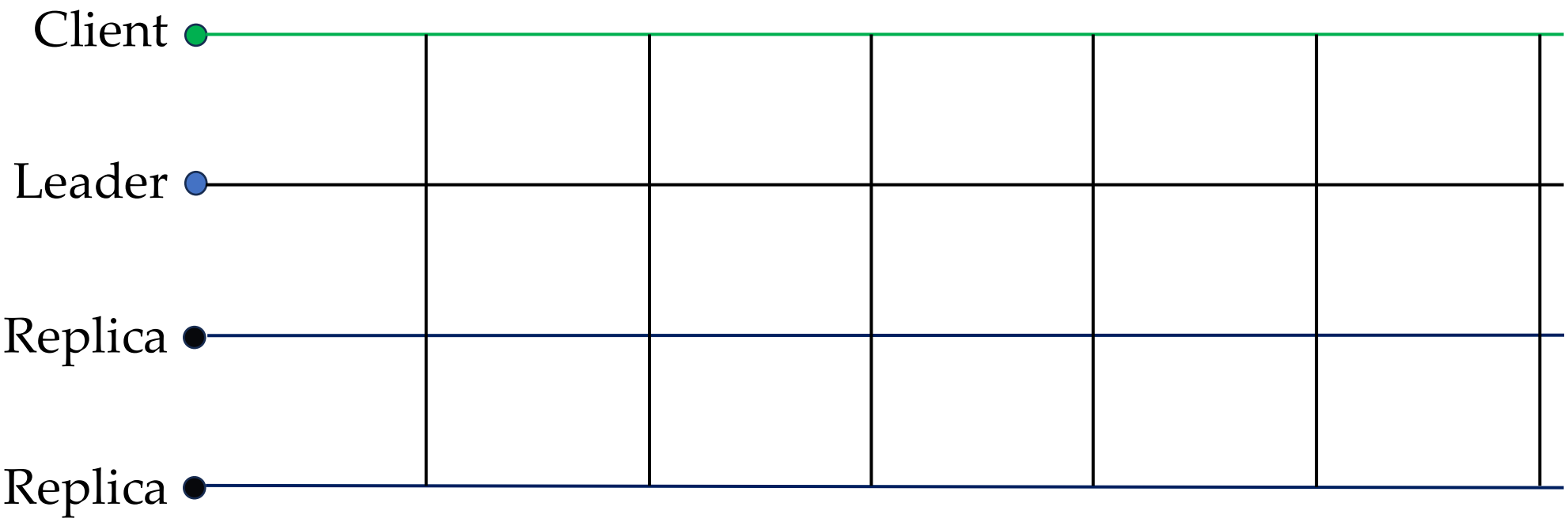
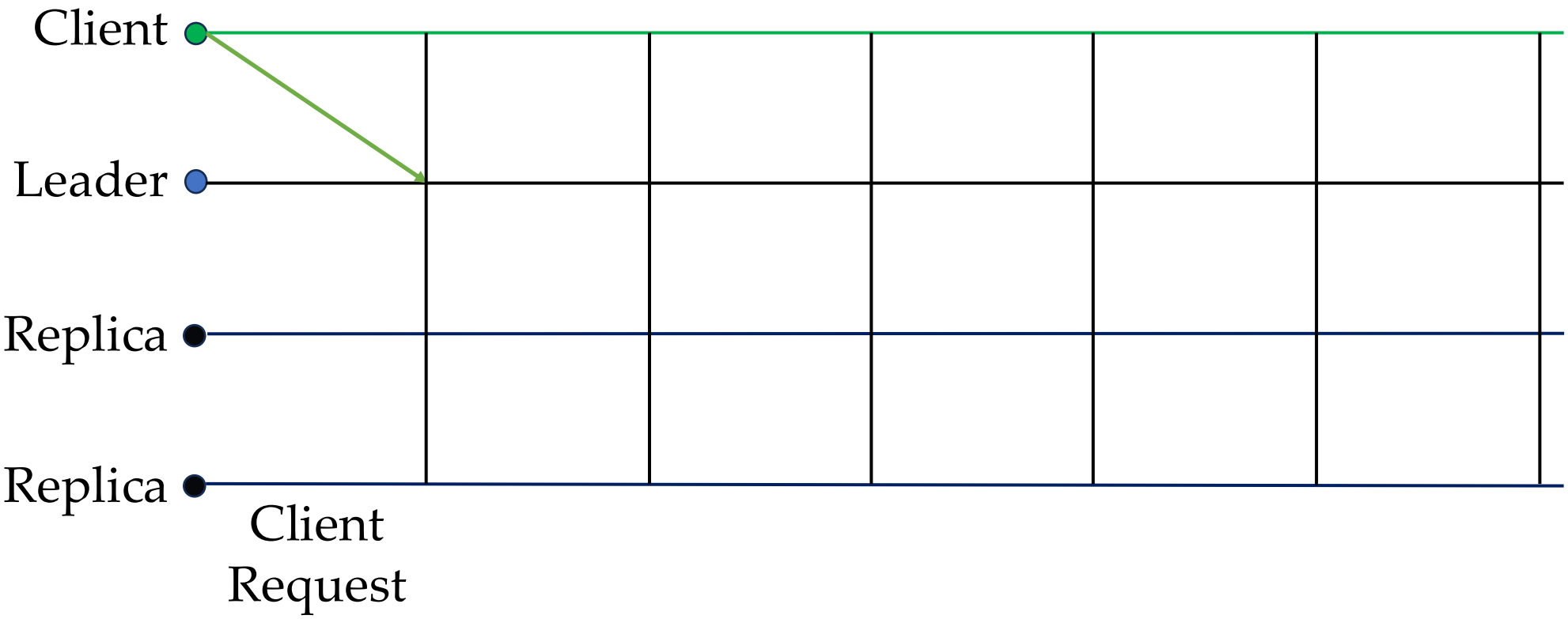
- **Step 2b :**

  If an acceptor receives an accept request for a proposal numbered **n**, it accepts the proposal unless it has already responded to a prepare request having a number greater than **n**.

Paxos Protocol



Paxos Protocol



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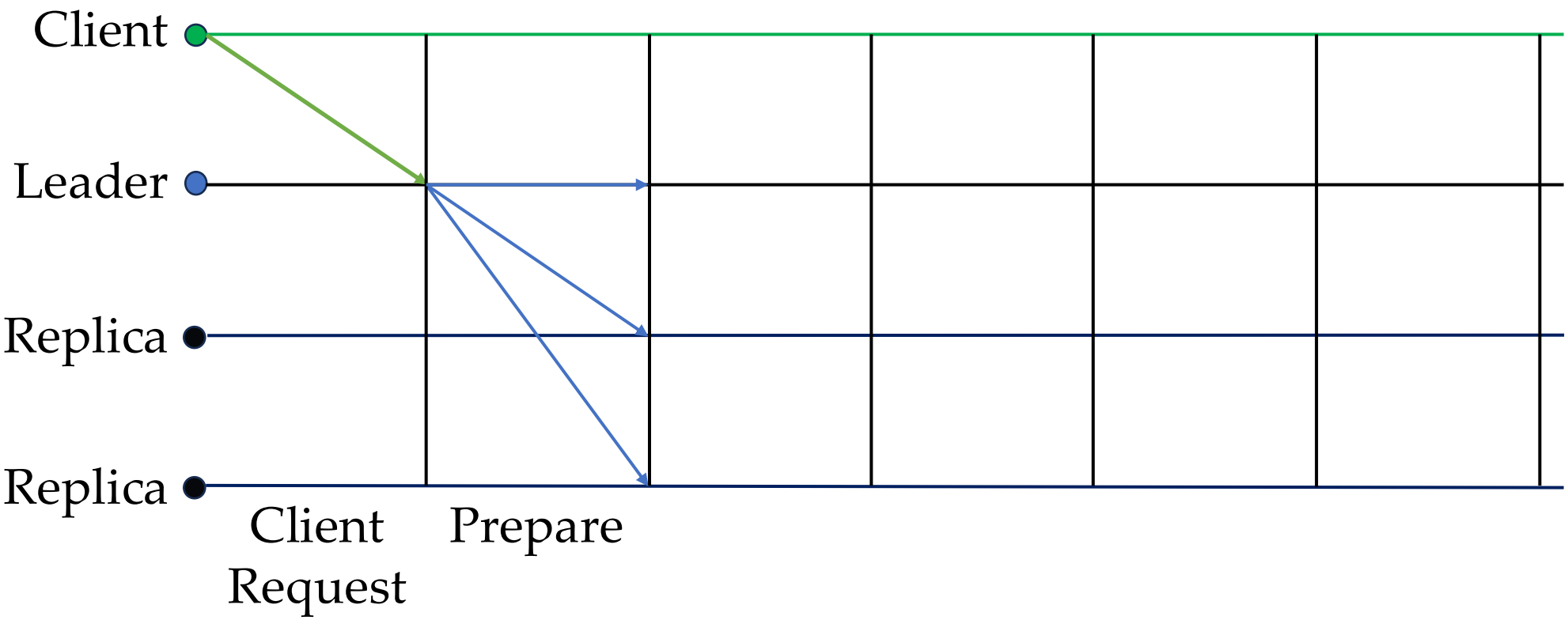

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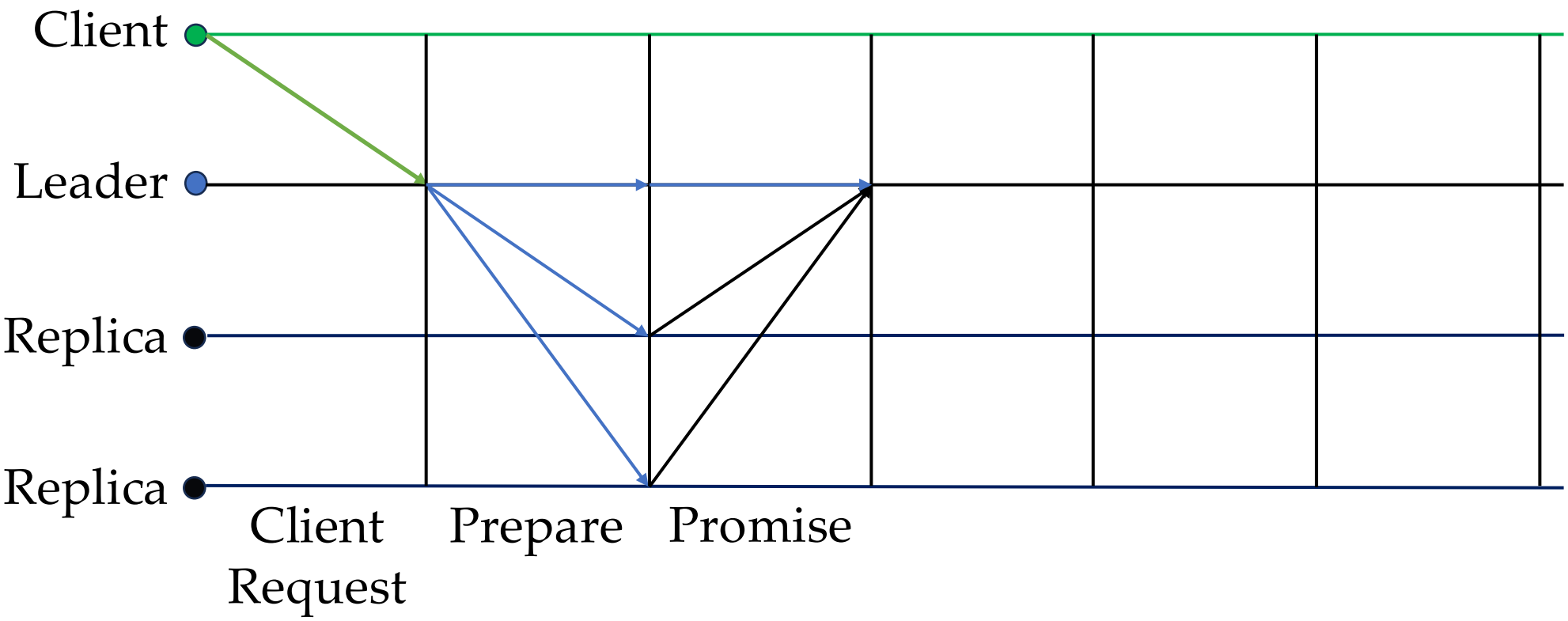

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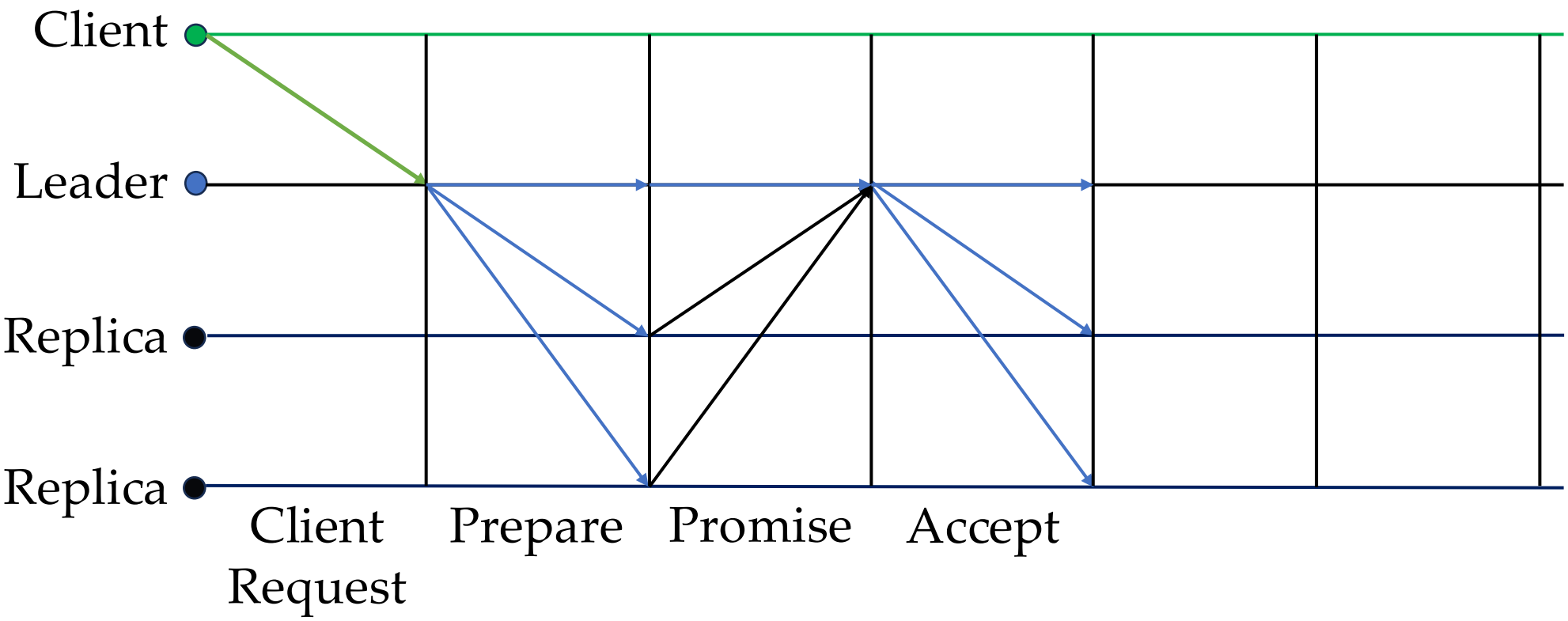

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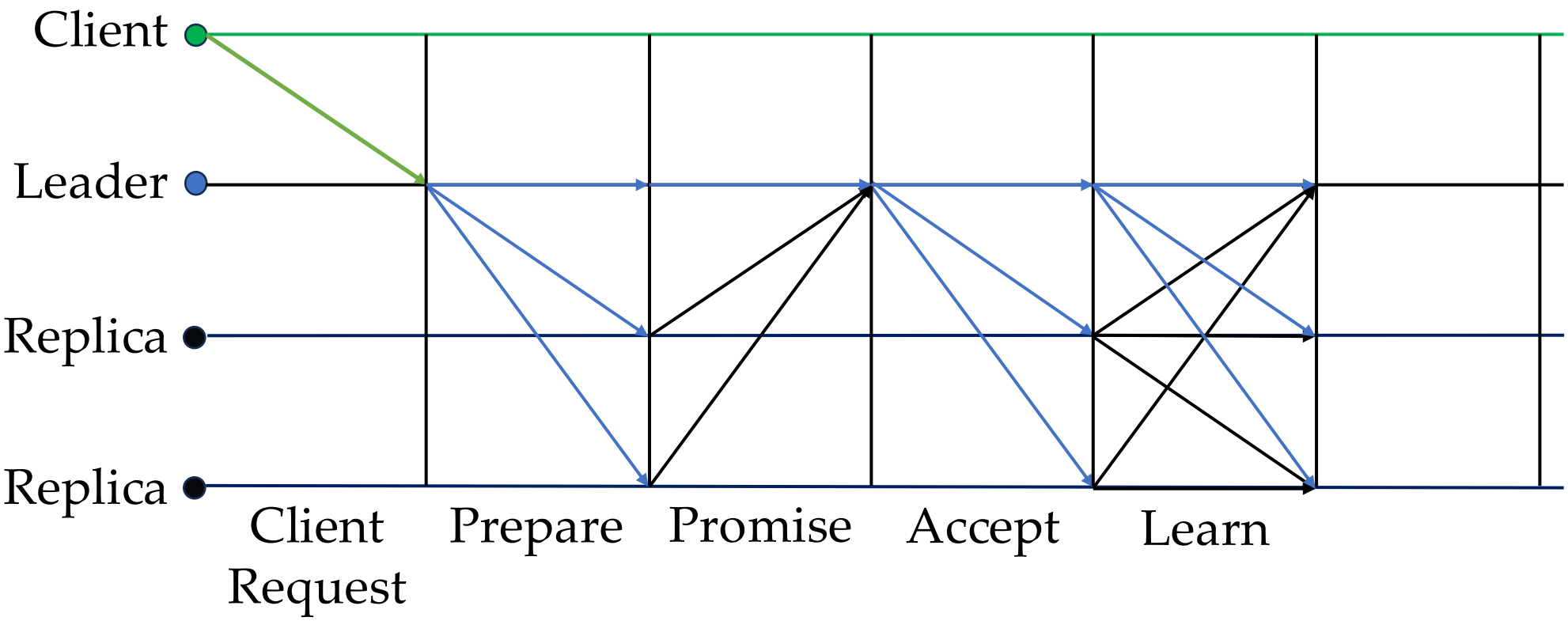

Liveness Issue with Paxos

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- In the case of multiple competing proposers, Paxos can get stuck and not make any progress!

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- Solution → Having a dedicated leader.