Large Scale Systems
CS 410 / 510

Lecture 14:

Parallelizing Consensus

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Assignment 4 is Out!

- Assignment 4 is due on **June 2, 2025** at **11:59pm PST**.
- Please start working with your groups.

Presentations

- Presentation slots are out!
- Each group will present their MiniSpanner in their respective time slots.
- Presentation Format:
  - Each group will get **15-16 min** to present their progress.
  - **5 min** for a working demo
  - **10 min** for Q/A.
  - Every student should present for around 4 minutes.
  - Every student should state their contributions.
  - Based on Q/A and presentation quality, grades will be decided for each student.

Reading Material

- For this class and next lecture:
  - Read **Chapters 3-4** from **Fault-Tolerant Distributed Transactions on Blockchain**.

Last Class

- Last class we looked at:

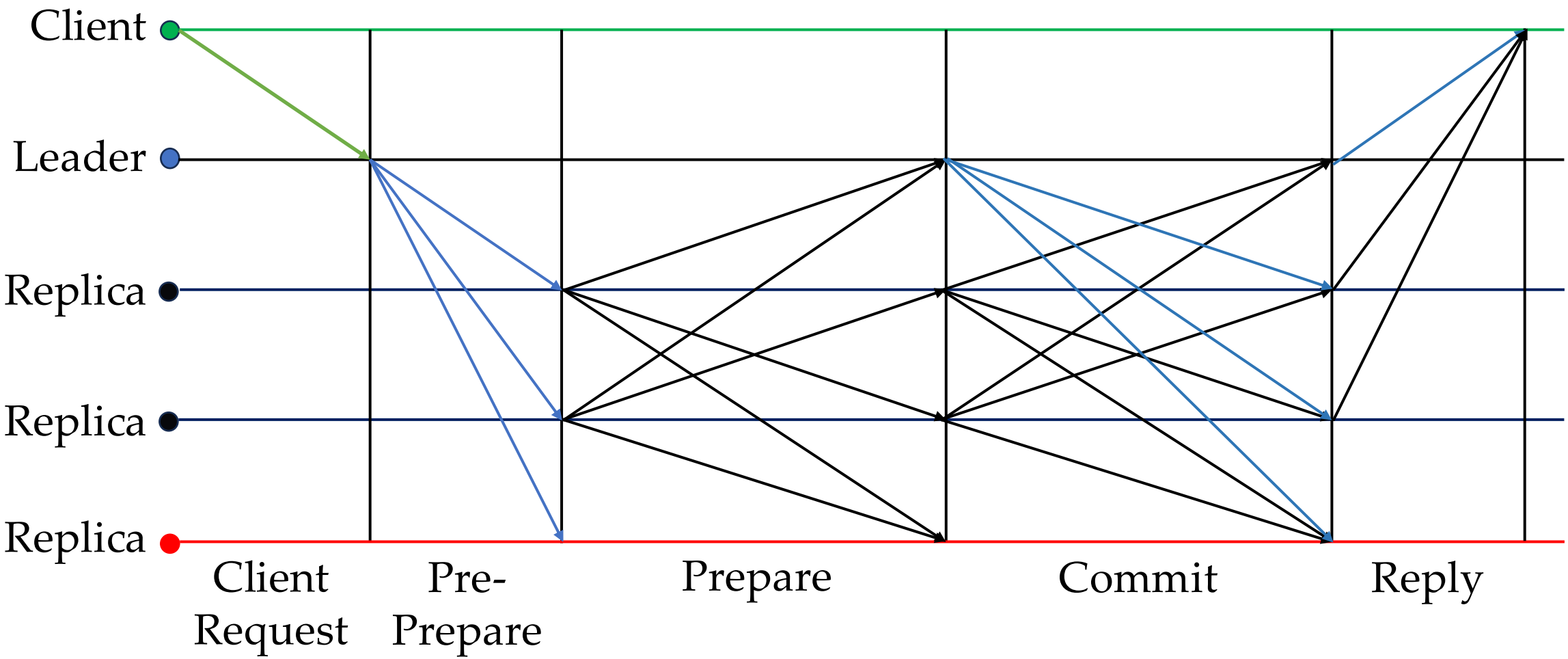
- Speculation in Consensus
- PoE Protocol

Optimizing PBFT

- Today, our goal is to optimize PBFT through parallelism.

- How can we introduce parallelism in PBFT apart from out-of-order message processing?

PBFT Protocol



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Parallelizing PBFT

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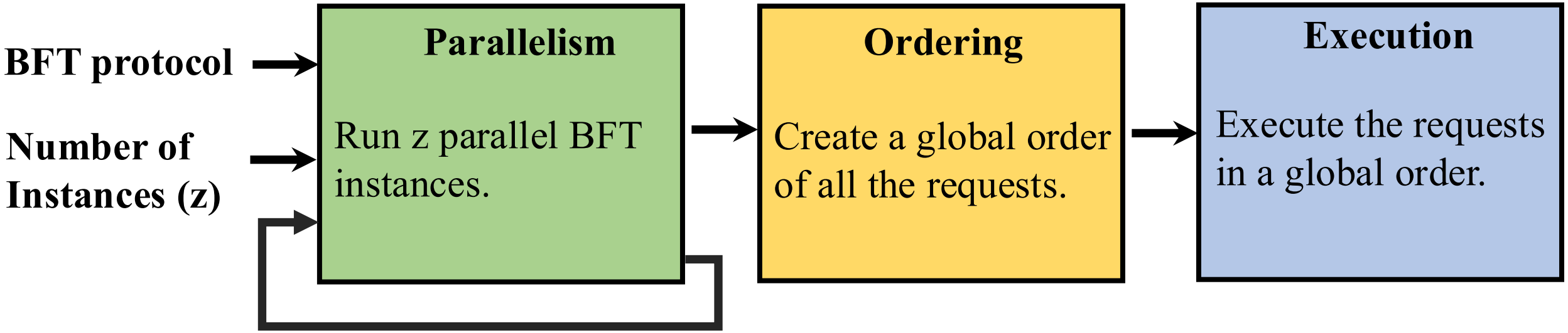
- To allow all replicas to act as leaders at the same time, we need to allow them to propose client requests at the same time → run consensus at the same time.

- Essentially, we are looking at a protocol where multiple instances of PBFT protocol are running in parallel.

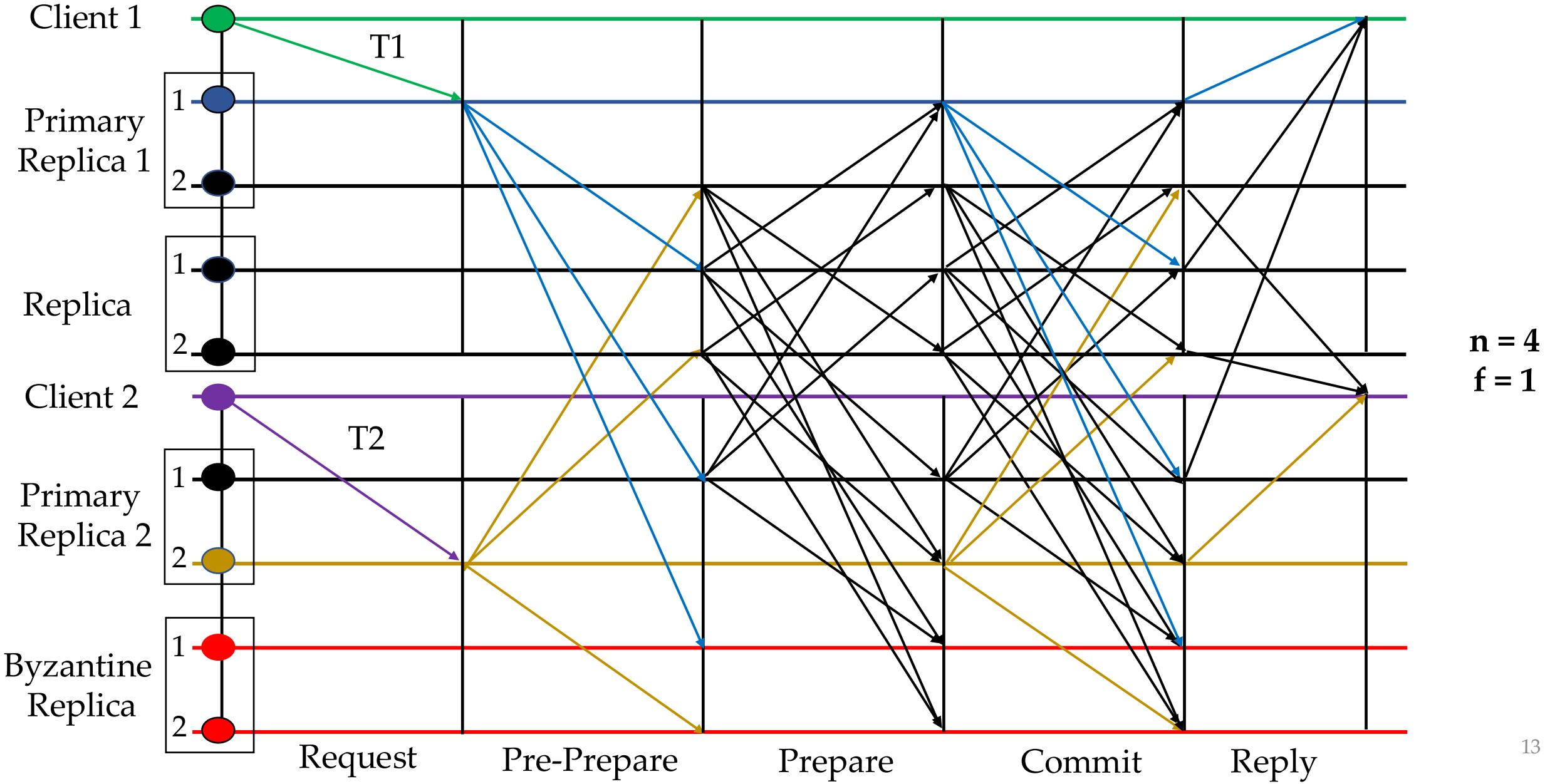
Resilient Concurrent Consensus

- **RCC [ICDE'21]** allows running multiple instances of PBFT in parallel.
- Either all replicas can act as leaders or a subset of replicas act as leaders.
- Total replicas: **n = 3f + 1**
  - Maximum number of Byzantine Replicas: **f**

RCC Protocol Overview



RCC Protocol with 2 Leaders



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- In what order should we execute the requests from all instances?
  - We need a global order of all requests.
  - **Simplest solution**:
    - Create a deterministic order.
    - Pre-assign each instance a unique identifier (e.g. 0,1,2,…,z).
    - Execute all transactions in the ascending/descending order of identifiers.

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  - But, epochs are forcing lock-step synchrony?
  - **Allow consensus to keep proceeding but halt execution at epoch boundary**.

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  - Does failure of one instance causes other instances to stop?
  - Can there be continuous ordering of requests?
  - How to defend against coordinated attacks?

Multi-Leader Dilemma

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- Having multiple leaders and multiple parallel instances can **boost throughput**!
- But now we must deal with **multiple Byzantine leaders** at the same time.
  - **PBFT** → only one leader → at most **one** Byzantine leader.
  - **RCC** → multiple leaders → at most **f** Byzantine leaders!

Need for Secure Ordering

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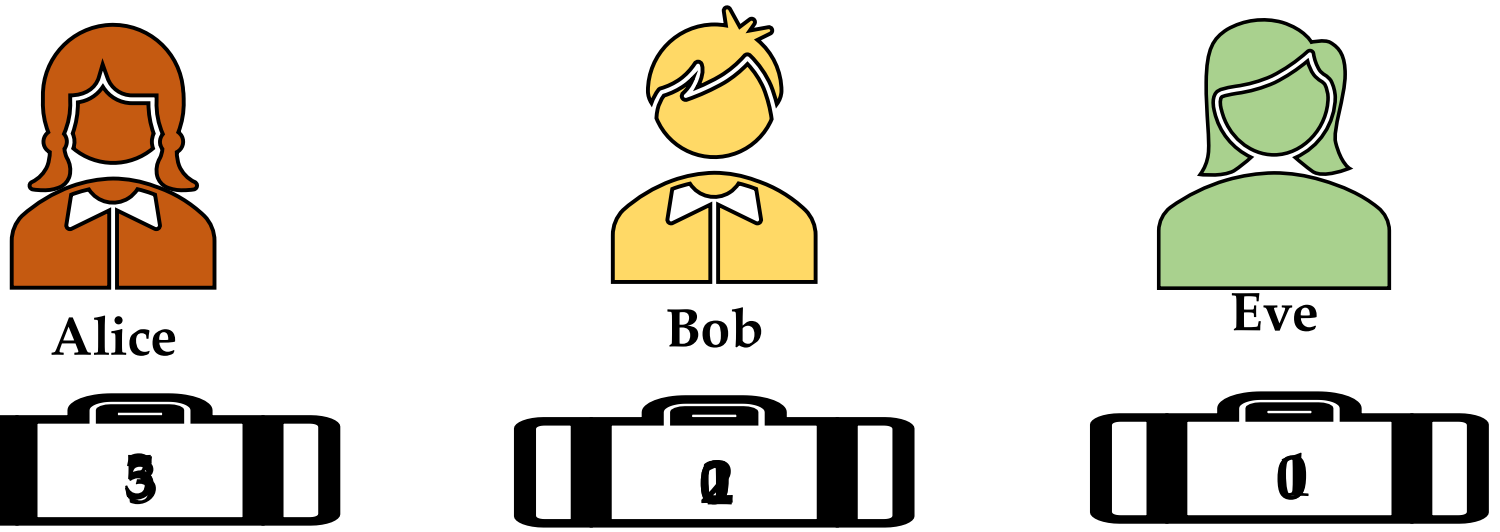
transfer(A,B,m) → *if*

bal(A) > m

then

bal(A) = bal(A) – m;
bal(B) = bal(B) + m;

Benefit to Bob!



T1: transfer(Alice, Bob, 2)

T2: transfer(Bob, Eve, 1)

Case 1: T1 then T2

Case 2: T2 then T1

Collusion by Malicious Primaries

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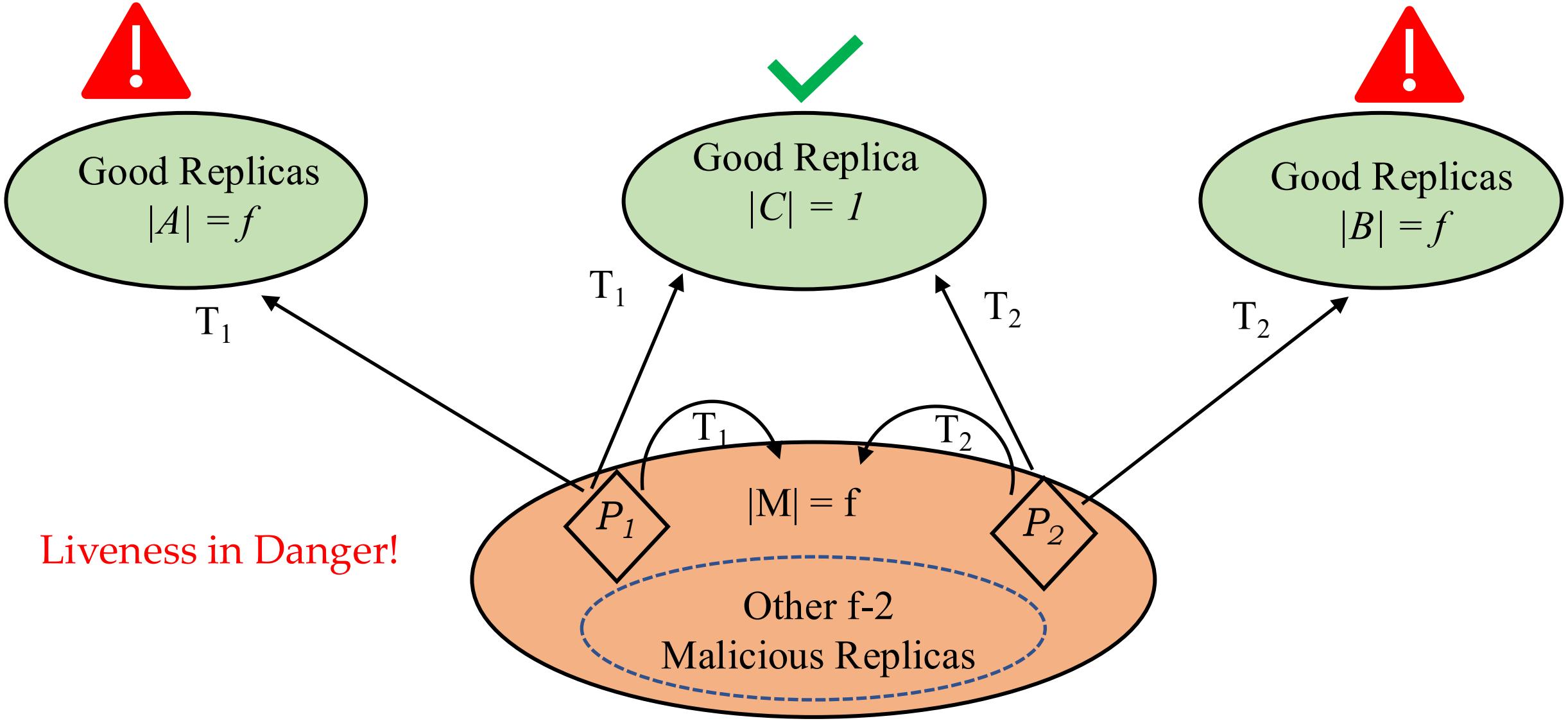

Liveness in Danger!

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- **Protocol:**
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  - Each replica creates a sequence of these requests.
  - Each replica hashes this sequence.
  - Calls a function that randomly reorders the sequence based on a seed (hash).

Guaranteeing Secure Ordering

We define a function f_S recursively:

$$f_S(i) = \begin{cases} S & \text{if } |S| = 1; \\ f_{S \setminus S[q]}(r) \oplus S[q] & \text{if } |S| > 1, \end{cases}$$

Here,

$q = i \div (|S| - 1)!$

$r = i \bmod (|S| - 1)!$

Observe,

f_S partitions any value j, $0 \leq j \leq |S|! - 1$ into q and r.

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- **Detection:**
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  - Detecting a malicious leader → If f+1 replicas complain.
  - Collusion Attack → No more than f replicas are complaining about the same leader.
  - **Solution:**
    - If f+1 replicas complain about multiple leaders, assume a collusion attack.

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- **Resolution:**
  - Run the checkpoint protocol to exchange states.
  - But checkpoint protocol is expensive as full state needs to be exchanged.
  - **Solution:**
    - Run a lightweight checkpoint protocol.
    - Only exchange requests of the last epoch.