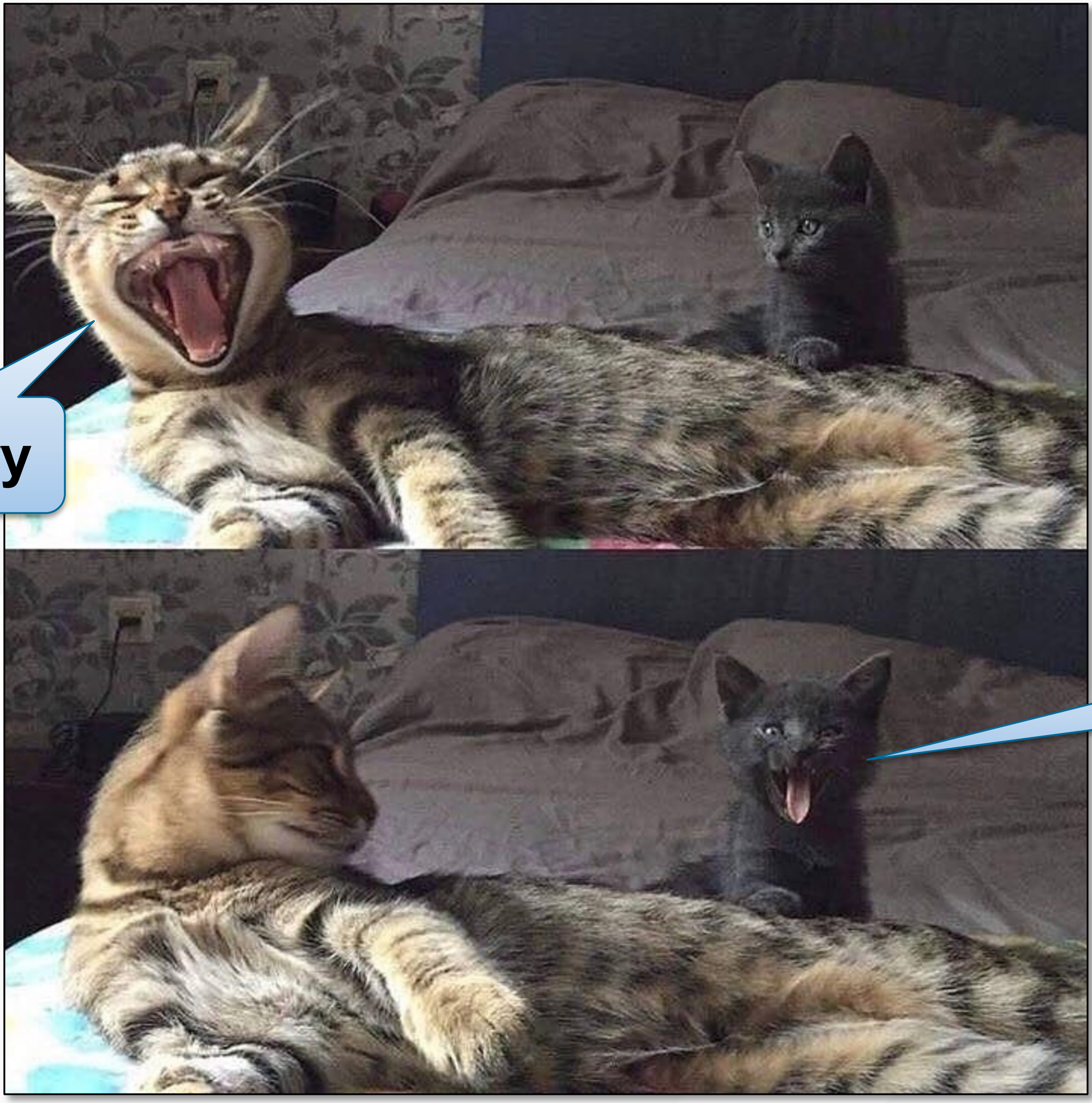
# FAULT TOLERANCE VIA REPLICATION



Primary

Replica

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UC San Diego

# ATTRIBUTION

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- These slides incorporate material from:
  - Tanenbaum and Van Steen, Dist. Systems: Principles and Paradigms
  - Kyle Jamieson, Princeton University (also under a CC BY-NC-SA 3.0 Creative Commons license)

# ANNOUNCEMENTS

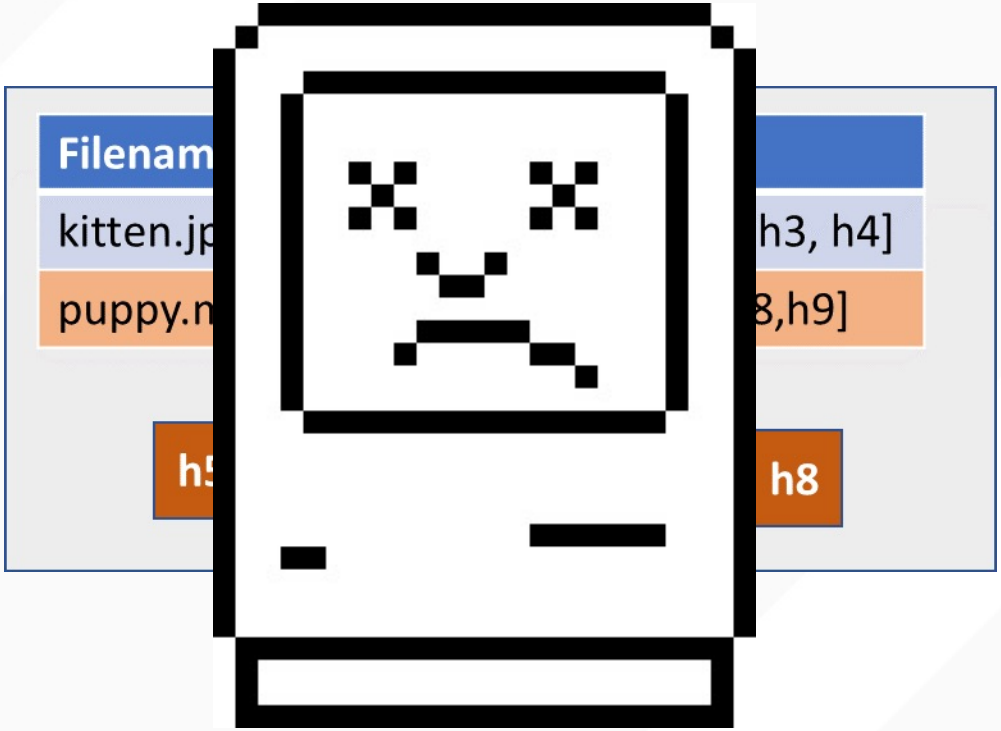
# Outline

1. Two-phase commit

2. Two-phase commit failure scenarios

# WHAT HAPPENS IF THE METADATA STORE CRASHES?

```
UpdateFile(
  file="kitten.jpg",
  ver=2,
  hashlist = {h3,h4}
);
```

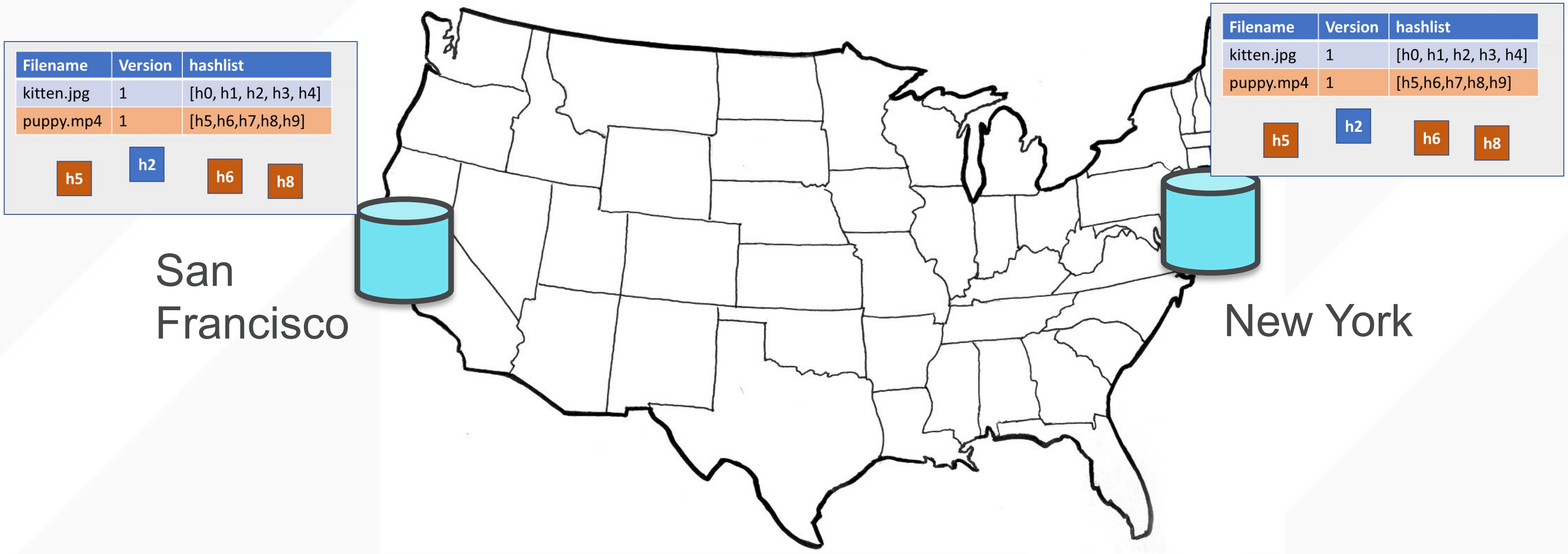


*All data is lost!*

Surfstore
Client

# MOTIVATION: MULTI-SITE METADATA REPLICATION

- SurfStore needs to be **resilient** to **whole-site failures**
- **Replicate** the metadata, keep one copy in San Francisco, one in New York

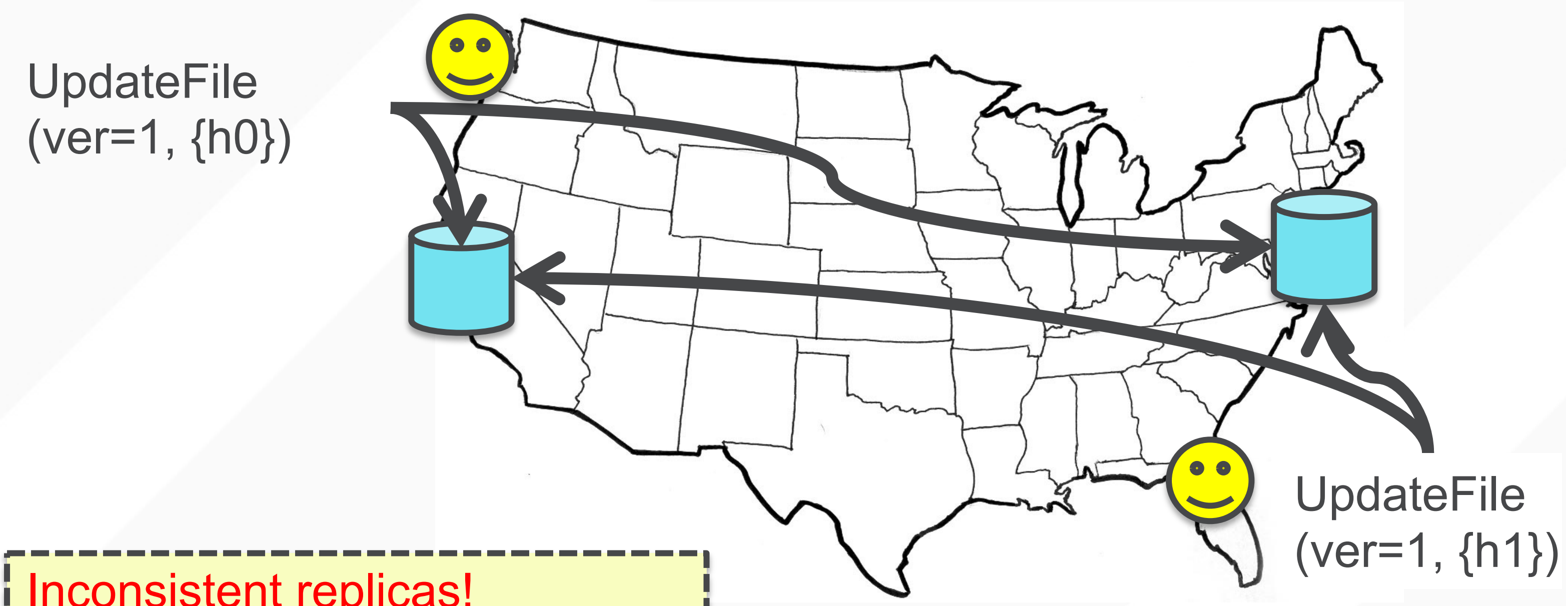


| Filename | Version | hashlist |
|---|---|---|
| kitten.jpg | 1 | [h0, h1, h2, h3, h4] |
| puppy.mp4 | 1 | [h5,h6,h7,h8,h9] |

| Filename | Version | hashlist |
|---|---|---|
| kitten.jpg | 1 | [h0, h1, h2, h3, h4] |
| puppy.mp4 | 1 | [h5,h6,h7,h8,h9] |

# MOTIVATION: MULTI-SITE DATABASE REPLICATION

- **Replicate** the database, keep one copy in SF, one in NYC
    - Client in Seattle creates ucsd.txt = “Go Tritons!” {h0}
    - Client in Florida creates ucsd.txt = “Go Racoons!” {h1}



Inconsistent replicas!

Updates should have been performed in the same order at each copy

# ANOTHER EXAMPLE: SENDING MONEY

```
send_money(A, B, amount) {
   Begin_Transaction();
   if (A.balance - amount >= 0) {
    A.balance = A.balance - amount;
    B.balance = B.balance + amount;
    Commit_Transaction();
   } else {
    Abort_Transaction();
   }
}
```

# SINGLE-SERVER: ACID

- **Atomicity**: all parts of the transaction execute or none (A’s decreases and B’s balance increases)
- **Consistency**: the transaction only commits if it preserves invariants (A’s balance never goes below 0)
- **Isolation**: the transaction executes as if it executed by itself (even if C is accessing A’s account, that will not interfere with this transaction)
- **Durability**: the transaction’s effects are not lost after it executes (updates to the balances will remain forever)

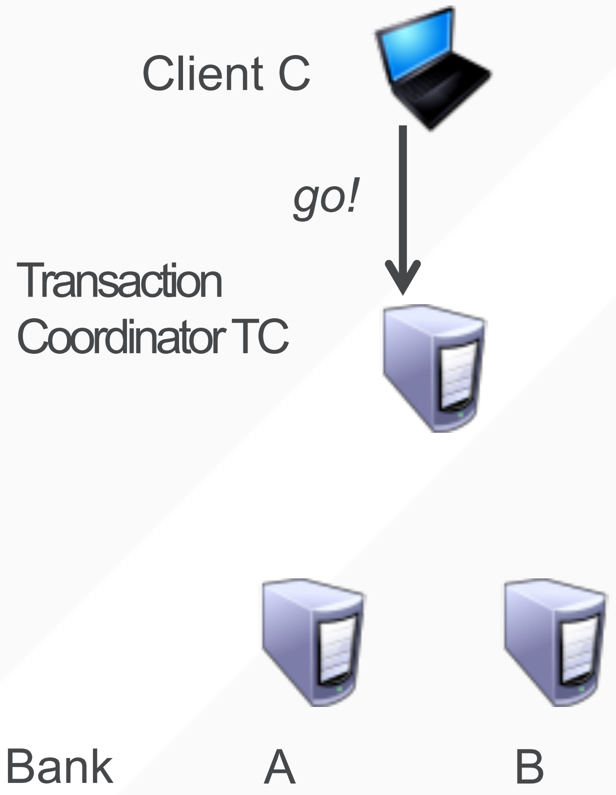
# DISTRIBUTED TRANSACTIONS?

- Partition databases across multiple machines for scalability (A and B might not share a server)
- A transaction might touch more than one partition
- How do we guarantee that all of the partitions commit the transactions or none commit the transactions?

# TWO-PHASE COMMIT (2PC)

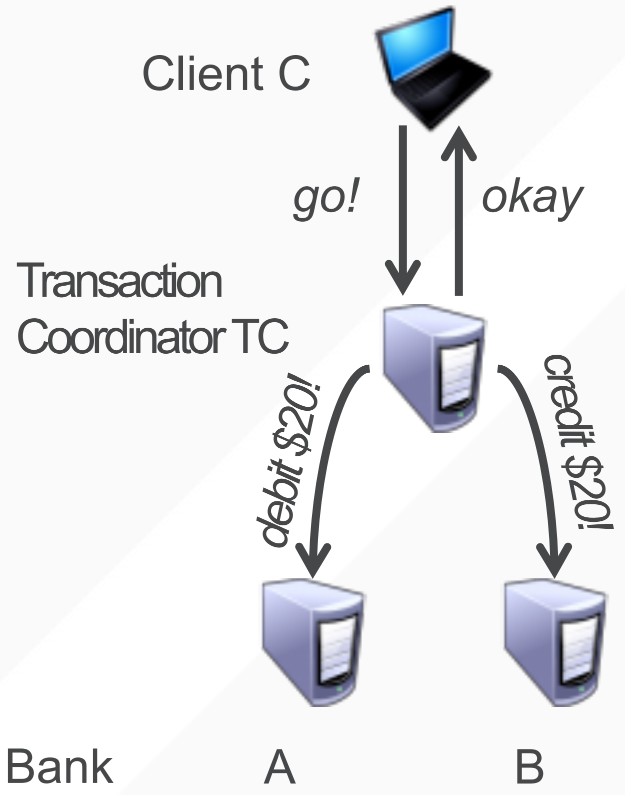
- **Goal:** General purpose, distributed agreement on some action, with failures
  - Different entities play different roles in the action
- **Running example:** Transfer money from A to B
  - Debit at A, credit at B, tell the client “okay”
  - Require **both** banks to do it, or **neither**
  - Require that **one bank never act alone**

# STRAW MAN PROTOCOL



1. C → TC: *"go!"*

# STRAW MAN PROTOCOL



1. **C → TC**: *"go!"*

2. **TC → A**: *"debit $20!"*

   **TC → B:** *"credit $20!"*

   **TC → C:** *"okay"*

- **A, B** perform actions on receipt of messages

# REASONING ABOUT THE STRAW MAN PROTOCOL

What could **possibly** go wrong?

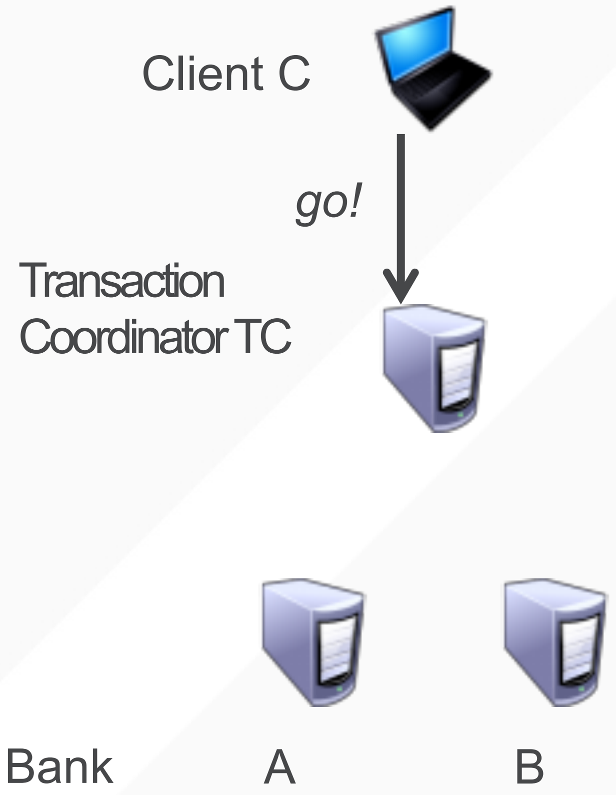
1. Not enough money in **A's** bank account?
2. **B's** bank account no longer exists?
3. **A** or **B** **crashes** before receiving message?
4. The best-effort network to **B** **fails**?
5. **TC** **crashes** after it sends *debit* to **A** but before sending to **B**?

# SAFETY VERSUS LIVENESS

- Note that **TC**, **A**, and **B** each have a notion of committing
- We want two properties:

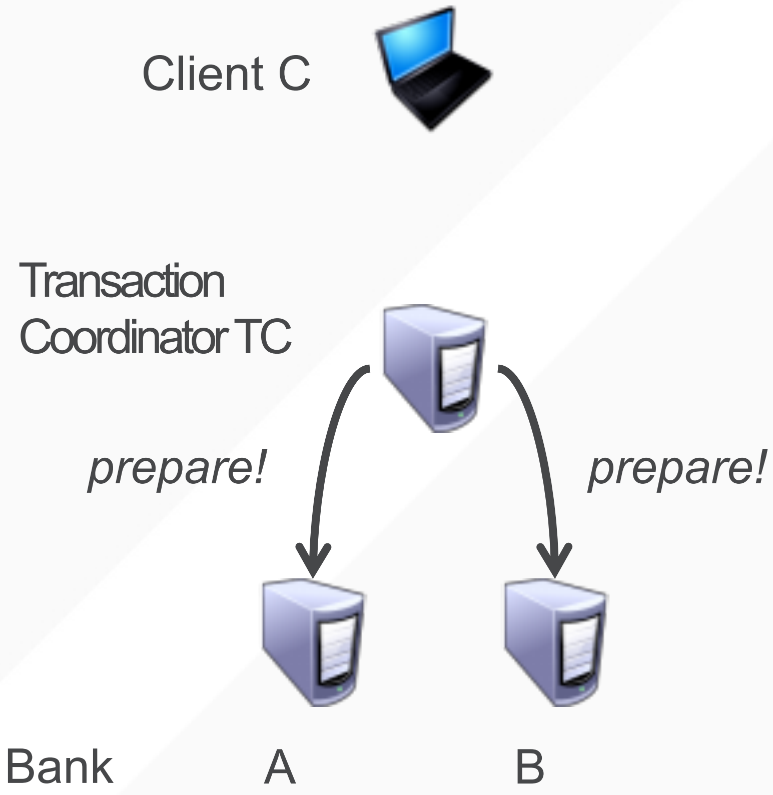
1. Safety
   - If **one commits, no one aborts**
   - If **one aborts, no one commits**
2. Liveness
   - If **no failures** and **A** and **B** can commit, **action commits**
   - If **failures,** reach a conclusion ASAP

# A *CORRECT* ATOMIC COMMIT PROTOCOL



1. C → TC: *“go!”*

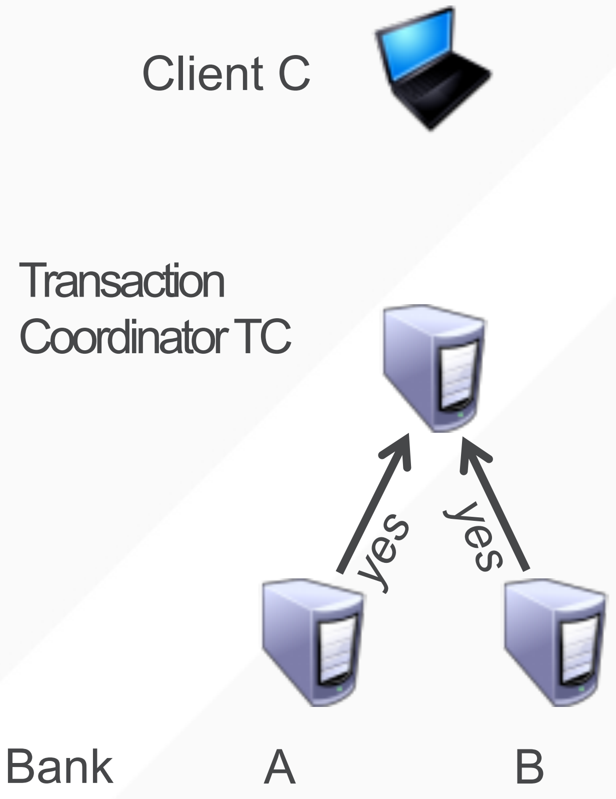
# A *CORRECT* ATOMIC COMMIT PROTOCOL



1. **C → TC:** *“go!”*

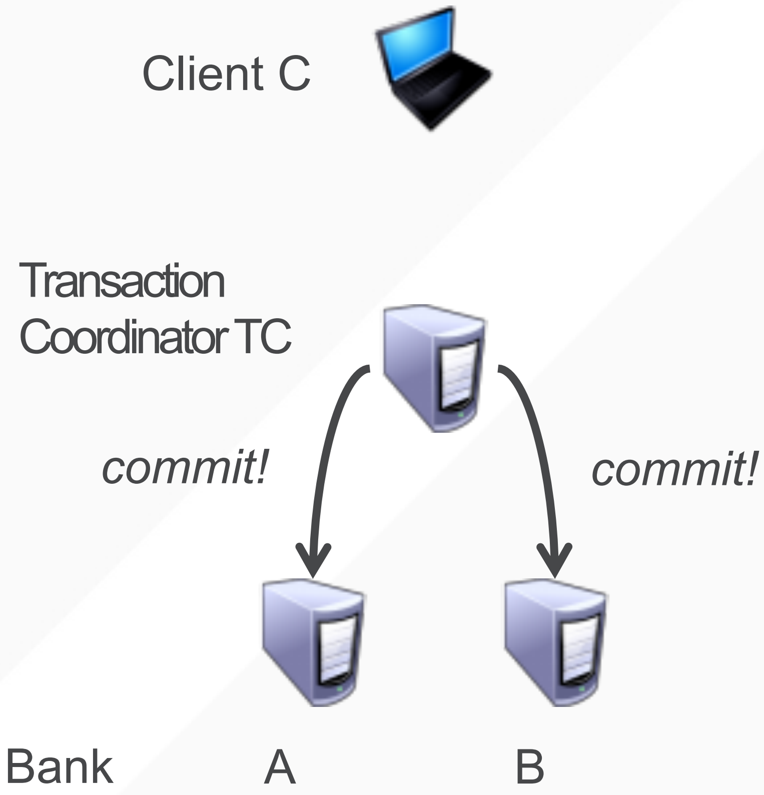
2. **TC → A, B:** *“prepare!”*

# A *CORRECT* ATOMIC COMMIT PROTOCOL



1. **C → TC:** *“go!”*
2. **TC → A, B:** *“prepare!”*
3. **A, B → P:** *“yes”* or *“no”*

# A *CORRECT* ATOMIC COMMIT PROTOCOL



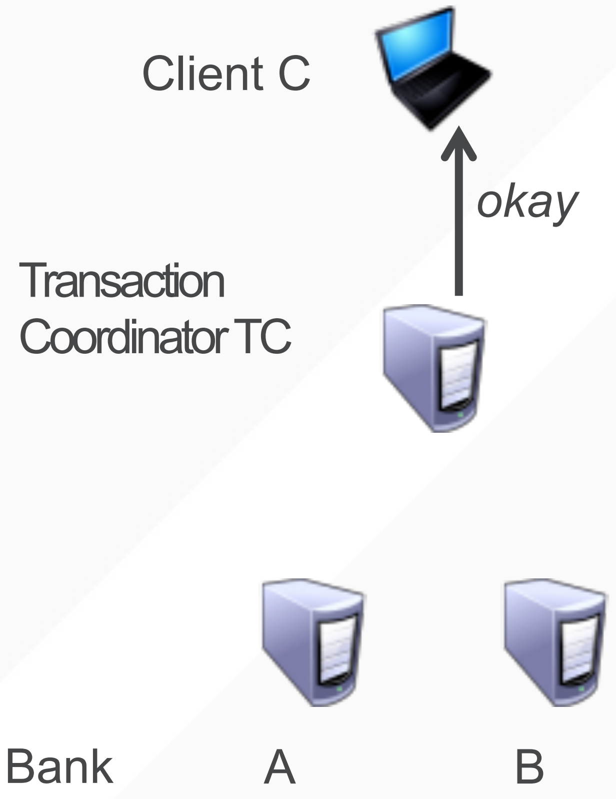
1. **C → TC:** *"go!"*

2. **TC → A, B:** *"prepare!"*

3. **A, B → P:** *"yes"* or *"no"*

4. **TC → A, B:** *"commit!"* or *"abort!"*
   - **TC** sends ***commit*** if **both** say *yes*
   - **TC** sends ***abort*** if **either** say *no*

# A *CORRECT* ATOMIC COMMIT PROTOCOL



1. **C → TC:** *"go!"*
2. **TC → A, B:** *"prepare!"*
3. **A, B → P:** *"yes"* or *"no"*
4. **TC → A, B:** *"commit!"* or *"abort!"*
   - **TC** sends ***commit*** if **both** say *yes*
   - **TC** sends ***abort*** if **either** say *no*
5. **TC → C:** *"okay" or "failed"*

- **A, B** commit on receipt of commit message

# REASONING ABOUT ATOMIC COMMIT

- *Why is this correct?*
  - Neither can commit unless both agreed to commit
- *What about performance?*

1. **Timeout:** I'm up, but didn't receive a message I expected
   - Maybe other node crashed, maybe network broken
2. **Reboot:** Node crashed, is rebooting, must clean up

# TIMEOUTS IN ATOMIC COMMIT

Where do hosts **wait** for messages?

1. **TC** waits for "yes" or "no" from **A** and **B**
   - **TC** hasn't yet sent any commit messages, so can **safely abort** after a timeout
   - But this is **conservative:** might be network problem
     - We've preserved correctness, sacrificed performance
2. **A** and **B** wait for "commit" or "abort" from **TC**
   - If it sent a *no*, it can **safely abort** *(why?)*
   - If it sent a *yes*, can it unilaterally abort?
   - Can it unilaterally commit?
   - A, B could wait forever, but there is an alternative…

# SERVER TERMINATION PROTOCOL

- Consider Server **B** (Server **A** case is symmetric) waiting for *commit* or *abort* from **TC**
  - Assume **B** voted *yes* (else, unilateral abort possible)
- **B** → **A:** “status?” **A** then replies back to **B.** Four cases:
  - (No reply from **A**): no decision, **B** waits for **TC**
  - Server **A** received commit or abort from **TC:** Agree with the **TC’s** decision
  - Server **A** hasn’t voted yet or voted *no:* both **abort**
    - **TC** can’t have decided to commit
  - Server **A** voted *yes:* both must **wait** for the **TC**
    - **TC** decided to **commit** if both replies received
    - **TC** decided to **abort** if it timed out

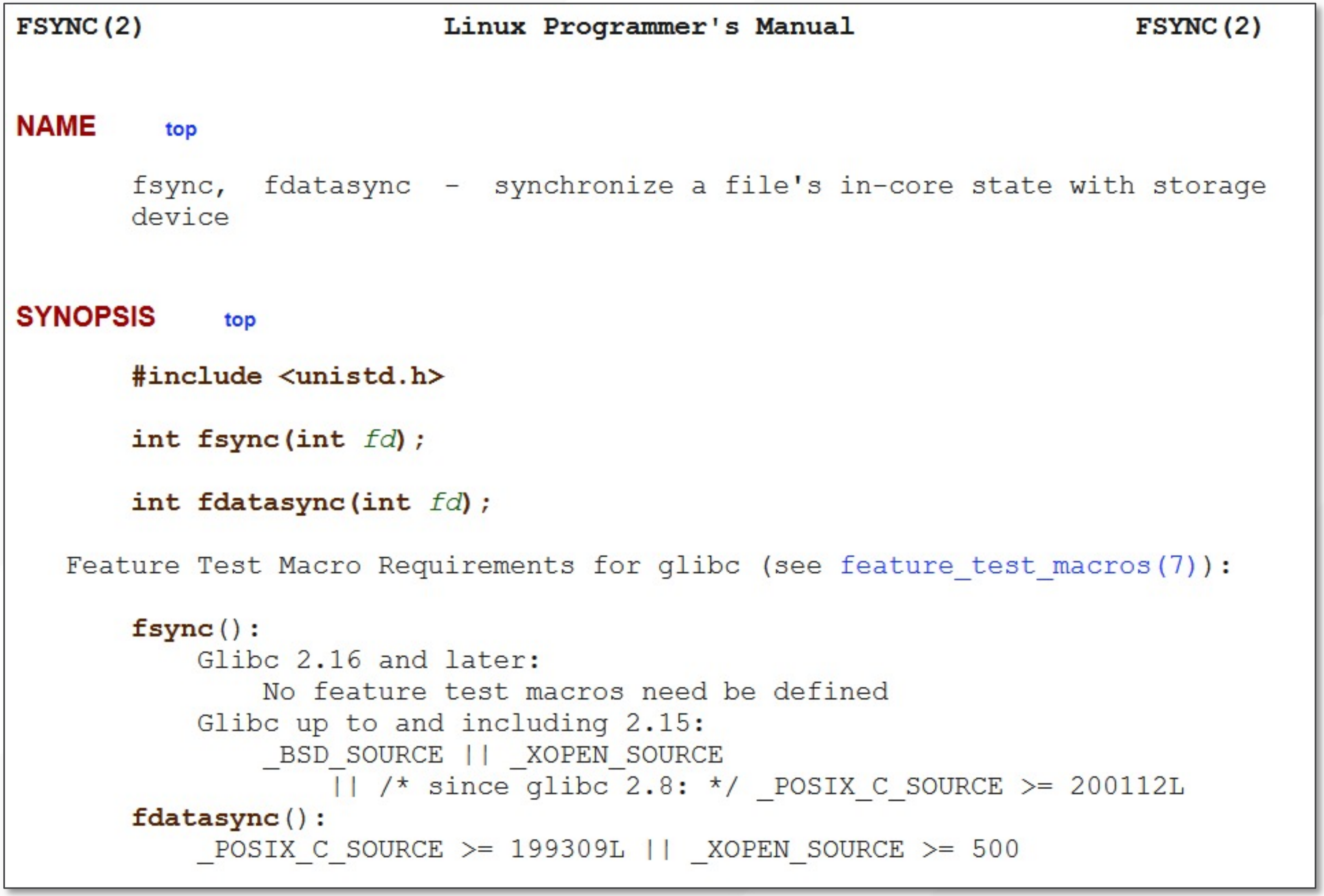
# REASONING ABOUT THE SERVER TERMINATION PROTOCOL

- *What are the liveness and safety properties?*
  - **Safety**: if servers don't crash, all processes will reach the same decision
  - **Liveness**: if failures are eventually repaired, then every participant will eventually reach a decision
- Can resolve **some** timeout situations with guaranteed correctness
- Sometimes however **A** and **B** must block
  - Due to failure of the **TC** or network to the **TC**
- But what will happen if **TC, A,** or **B** **crash and reboot?**

# HOW TO HANDLE CRASH AND REBOOT?

- Can’t back out of commit if already decided
  - **TC** crashes just after sending *“commit!”*
  - **A** or **B** crash just after sending *“yes”*
- If all nodes knew their state before crash, we could use the termination protocol…
  - Use **write-ahead log** to record *“commit!” and “yes”* to disk

# DURABILITY ACROSS REBOOTS



FSYNC(2) Linux Programmer's Manual FSYNC(2)

**NAME** top

fsync, fdatasync - synchronize a file's in-core state with storage device

**SYNOPSIS** top

```
       #include <unistd.h>

       int fsync(int fd);

       int fdatasync(int fd);

   Feature Test Macro Requirements for glibc (see feature_test_macros(7)):

       fsync():
           Glibc 2.16 and later:
               No feature test macros need be defined
           Glibc up to and including 2.15:
               _BSD_SOURCE || _XOPEN_SOURCE
                   || /* since glibc 2.8: */ _POSIX_C_SOURCE >= 200112L
       fdatasync():
           _POSIX_C_SOURCE >= 199309L || _XOPEN_SOURCE >= 500
```

# RECOVERY PROTOCOL WITH NON-VOLATILE STATE

- If everyone rebooted and is reachable, TC can just check for **commit** record on disk and **resend** action
- **TC:** If no **commit** record on disk, **abort**
  - You didn't send any *"commit!"* messages
- **A, B:** If no **yes** record on disk, **abort**
  - You didn't vote *"yes"* so **TC** couldn't have committed
- A, B: If **yes** record on disk, execute termination protocol
  - This might block

# TWO-PHASE COMMIT

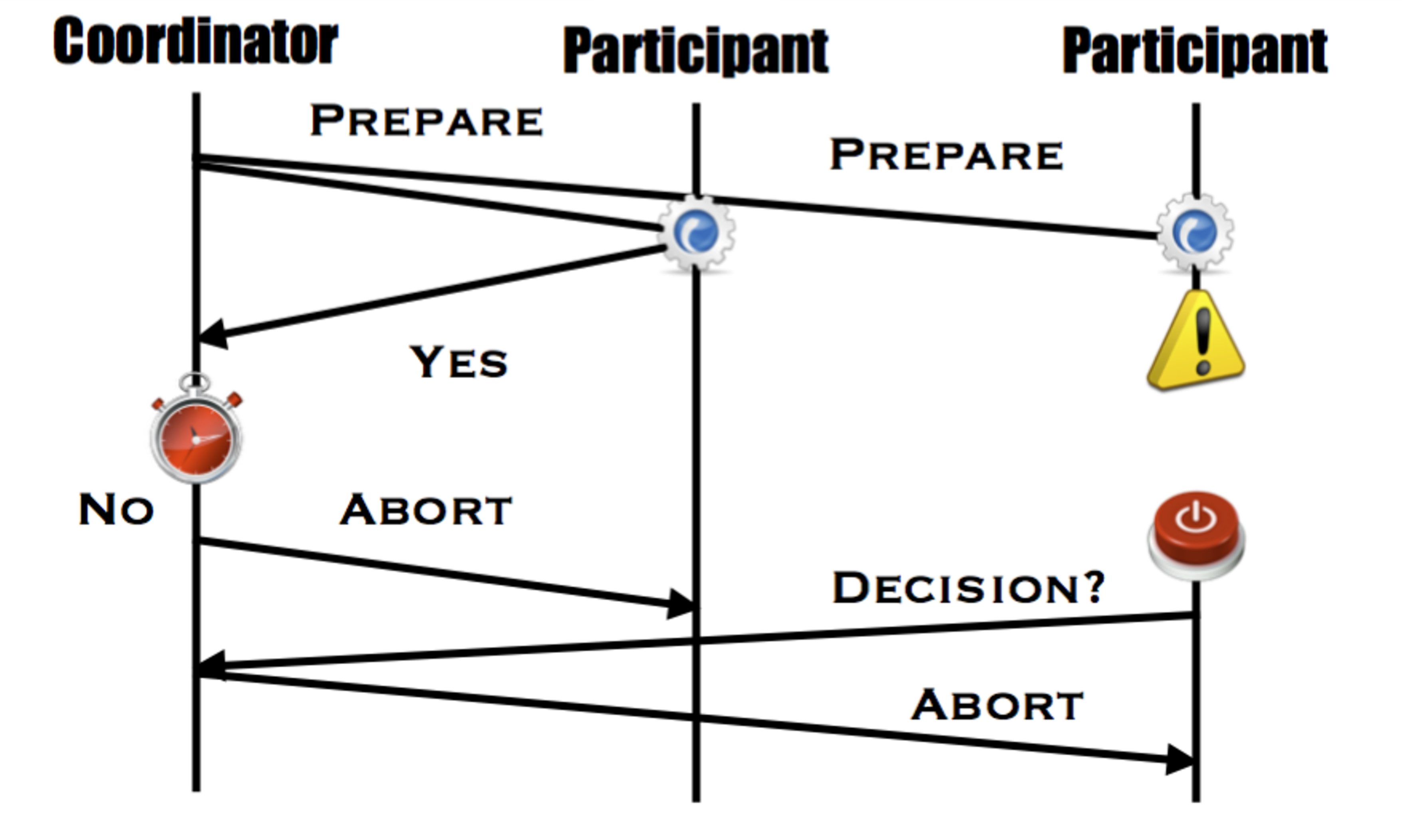
- This recovery protocol with non-volatile logging is called ***Two-Phase Commit (2PC)***
- **Safety:** All hosts that decide reach the same decision
  - No commit unless everyone says “yes”
- **Liveness:** If no failures and all say “yes” then commit
  - **But if failures then 2PC might block**
  - **TC must be up to decide**
- **Doesn’t tolerate faults well: must wait for repair**

# Outline

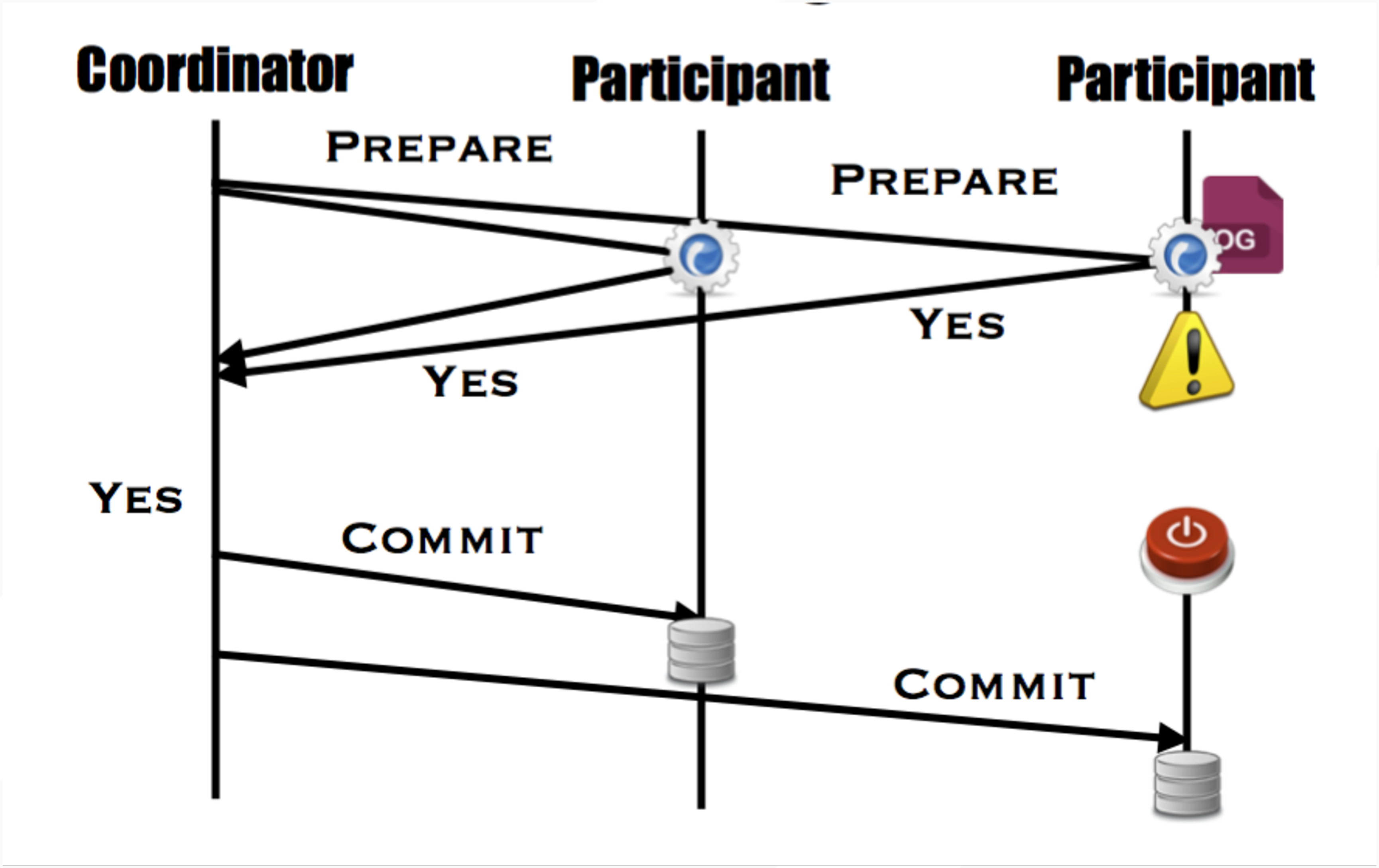
1. Two-phase commit

2. Two-phase commit failure scenarios

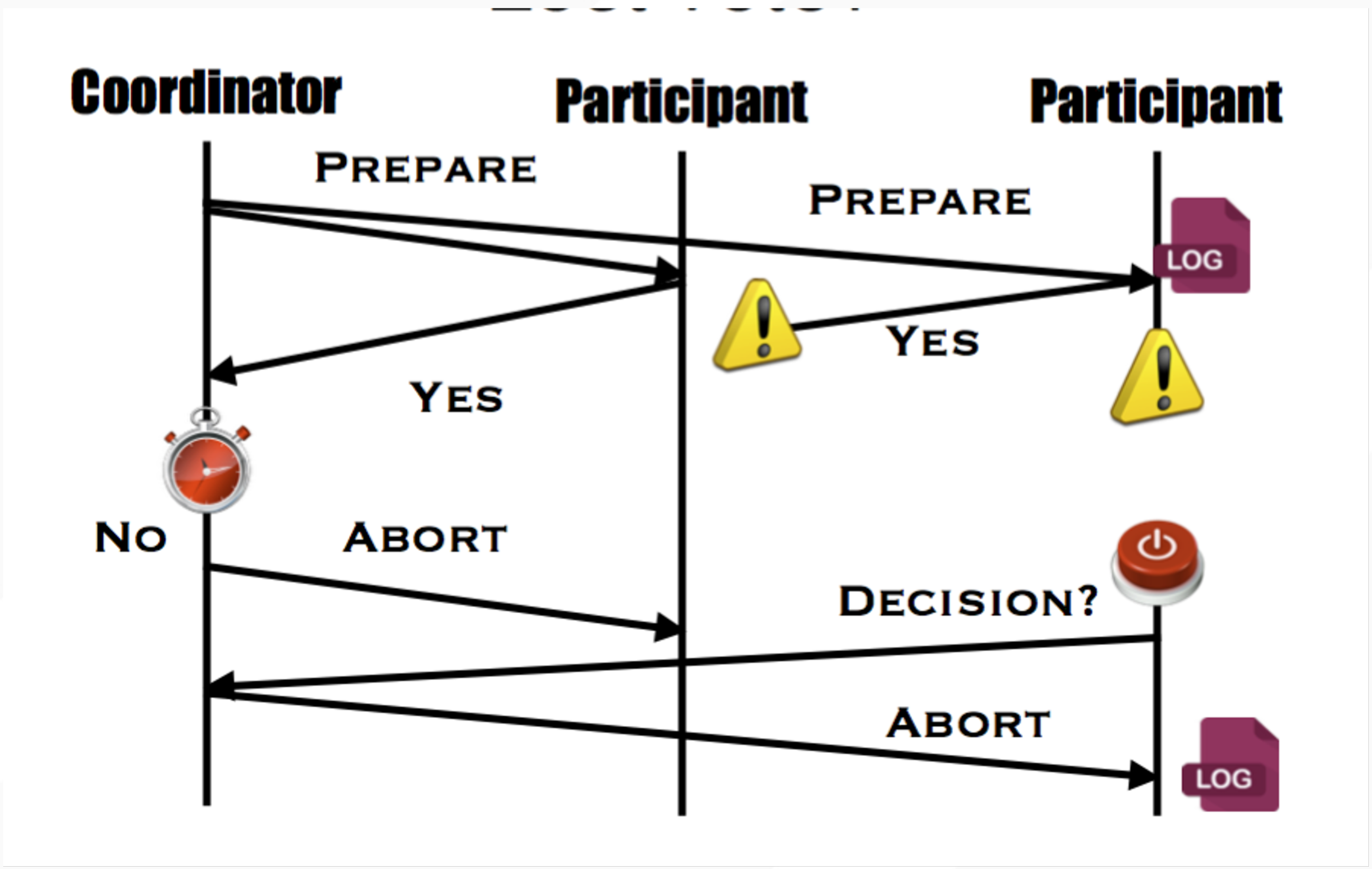
# WHAT IF PARTICIPANT FAILS BEFORE SENDING RESPONSE?



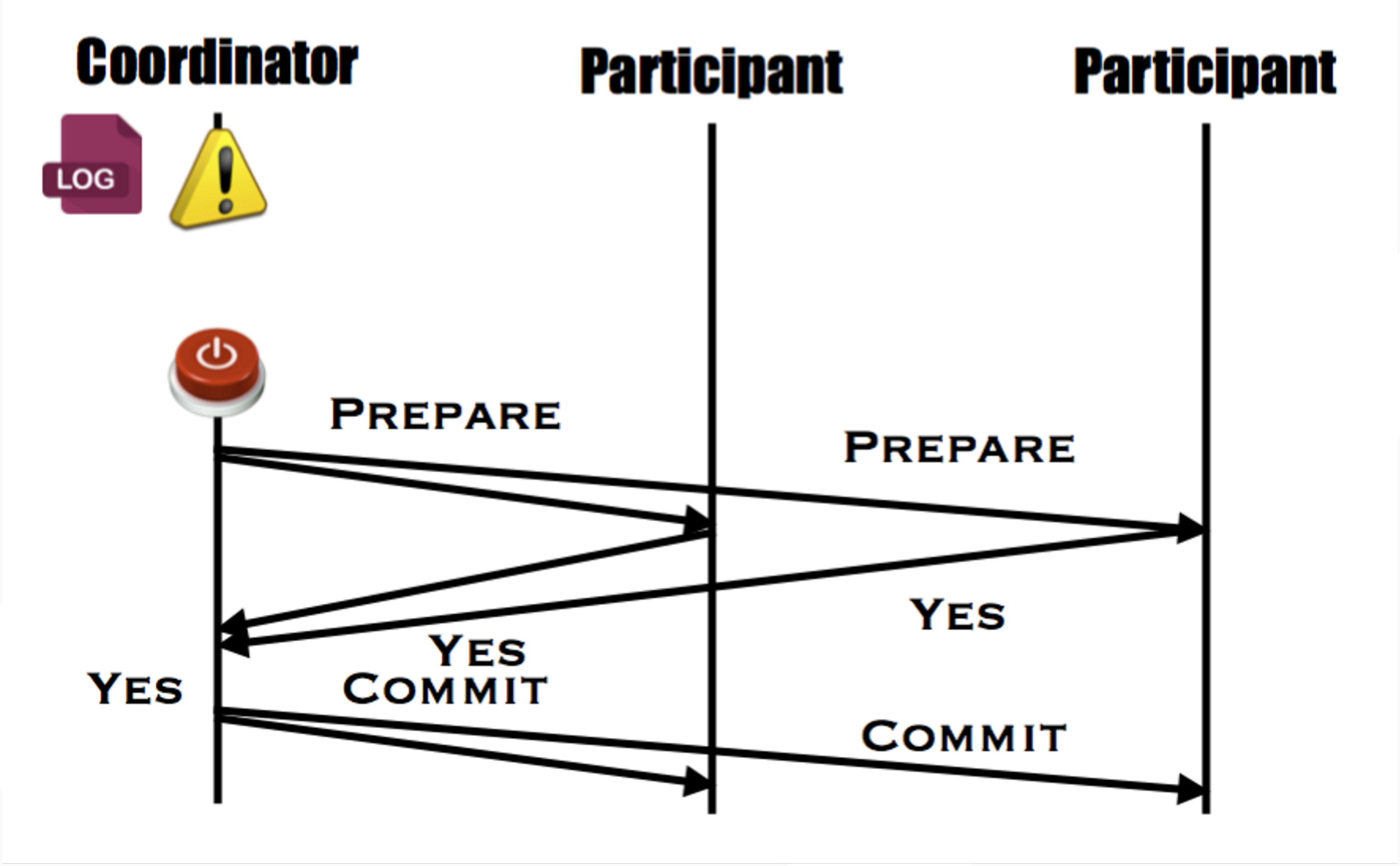
# WHAT IF PARTICIPANT FAILS AFTER SENDING VOTE



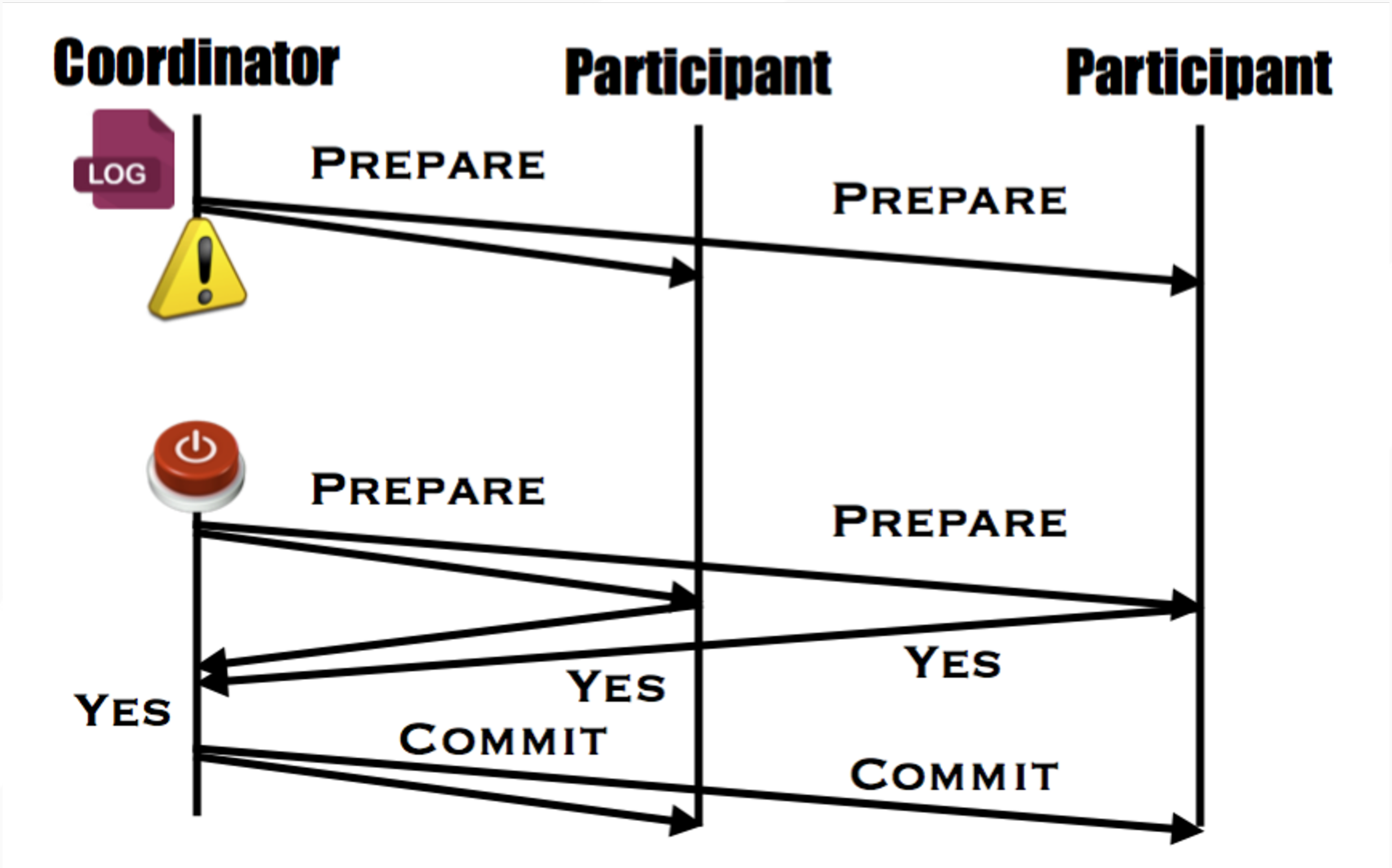
# WHAT IF PARTICIPANT LOST A VOTE?



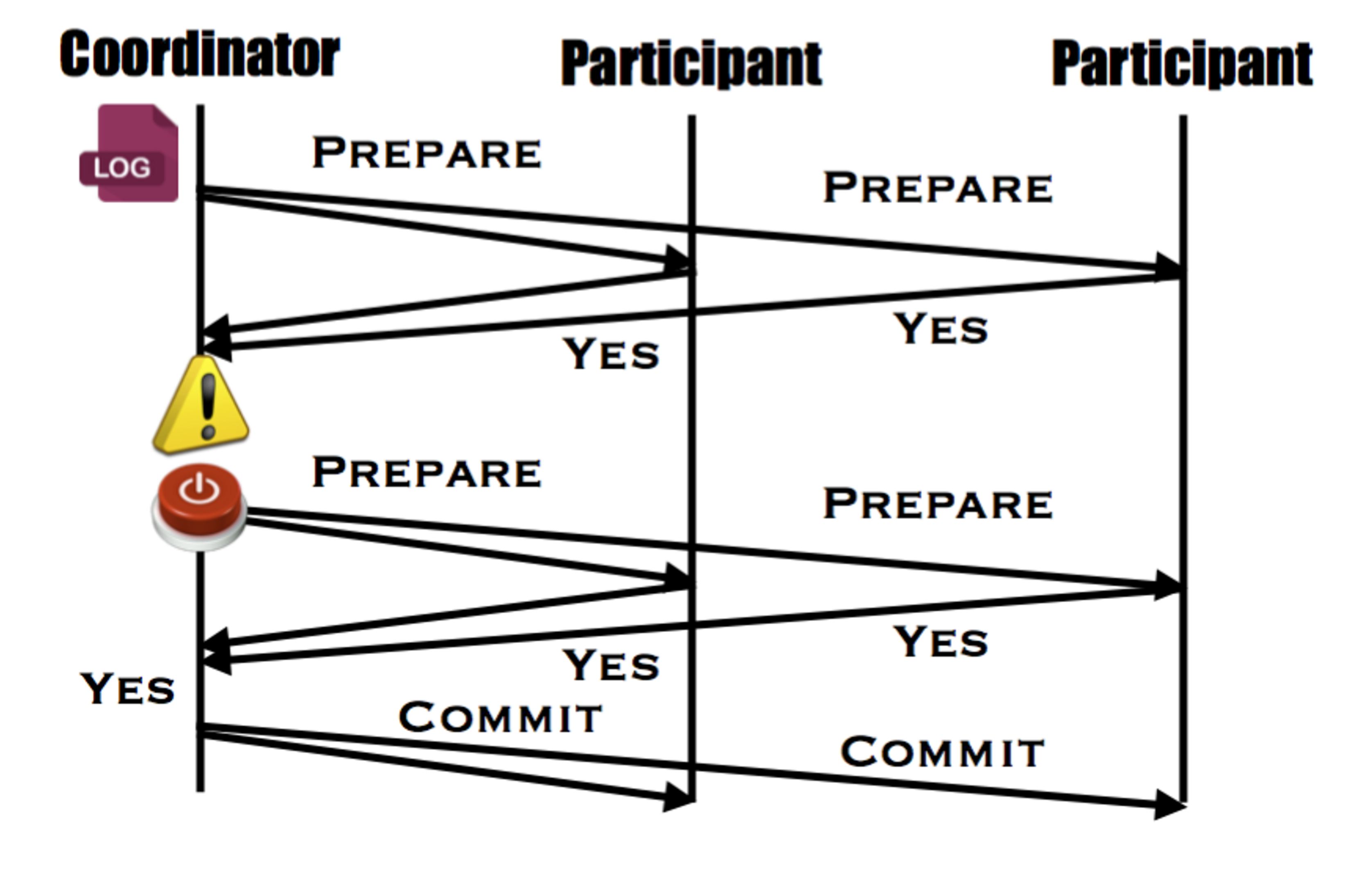
# WHAT IF COORDINATOR FAILS BEFORE SENDING PREPARE?



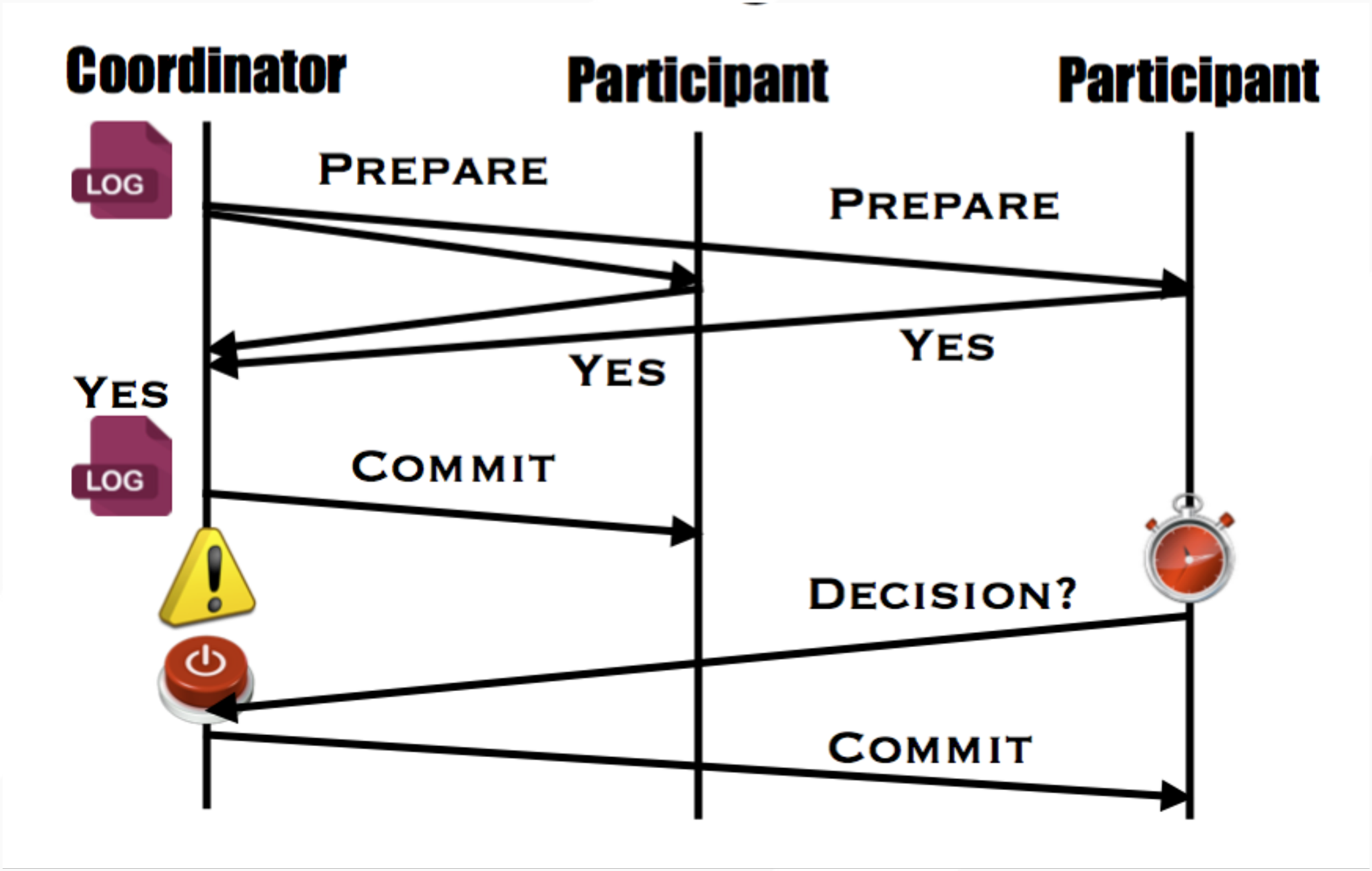
# WHAT IF COORDINATOR FAILS AFTER SENDING PREPARE?



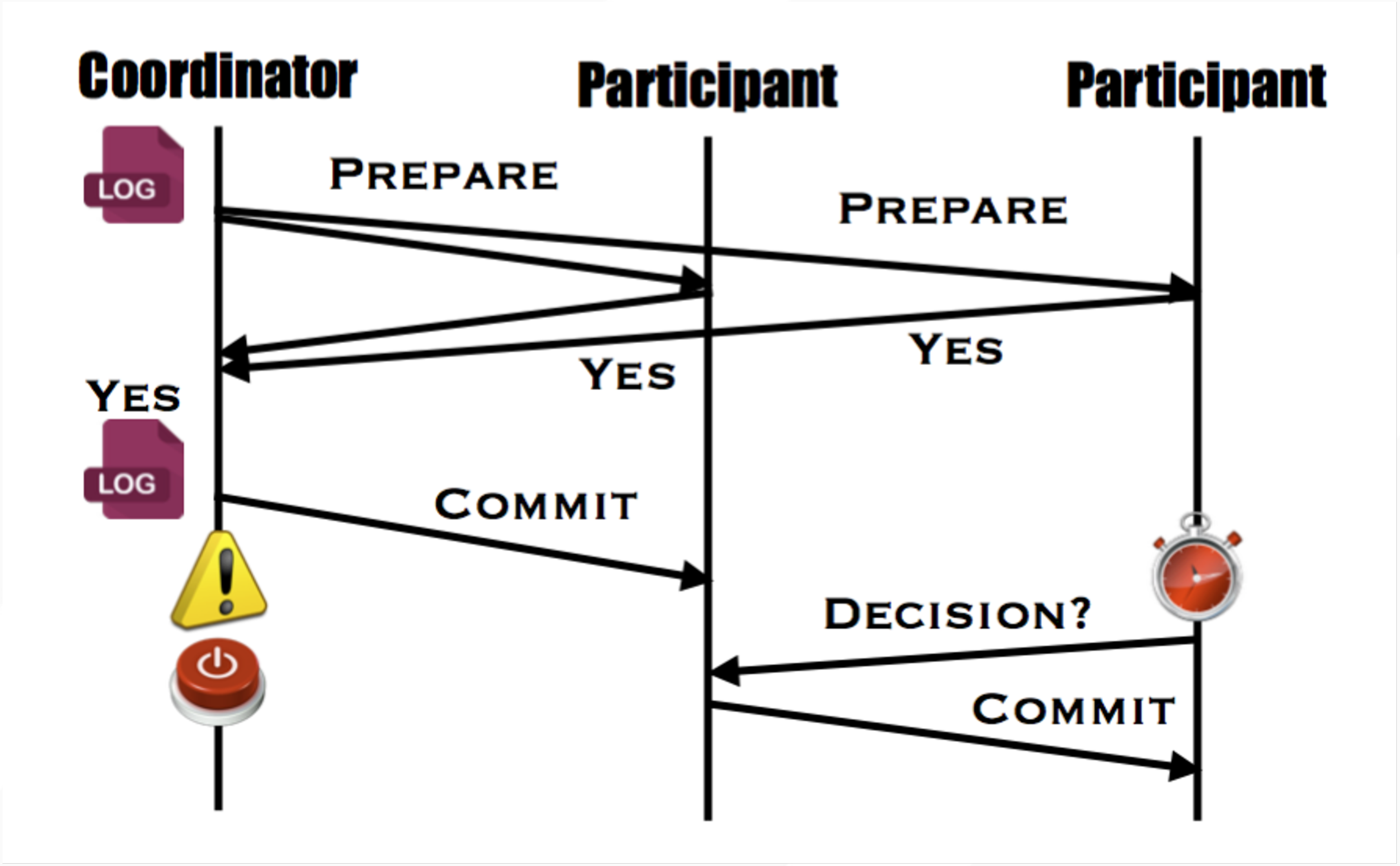
# WHAT IF COORDINATOR FAILS AFTER RECEIVING VOTES



# WHAT IF COORDINATOR FAILS AFTER SENDING DECISION?



# DO WE NEED THE COORDINATOR?



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