

# 7610: Distributed Systems

Distributed commit. 2PC. 3PC

# Required reading for this topic...

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- ▶ Non-Blocking Commit Protocols, D. Skeen, SIGMOD 1981



# Distributed Commit Problem

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- ▶ Some applications perform operations on multiple databases
- ▶ We would like a guarantee that either all the databases get updated, or none does
- ▶ Distributed Commit Problem:
  - ▶ Operation is committed when all participants can perform it
  - ▶ Once a commit decision is reached, this requirement holds even if some participants fail and later recover

# ACID Properties

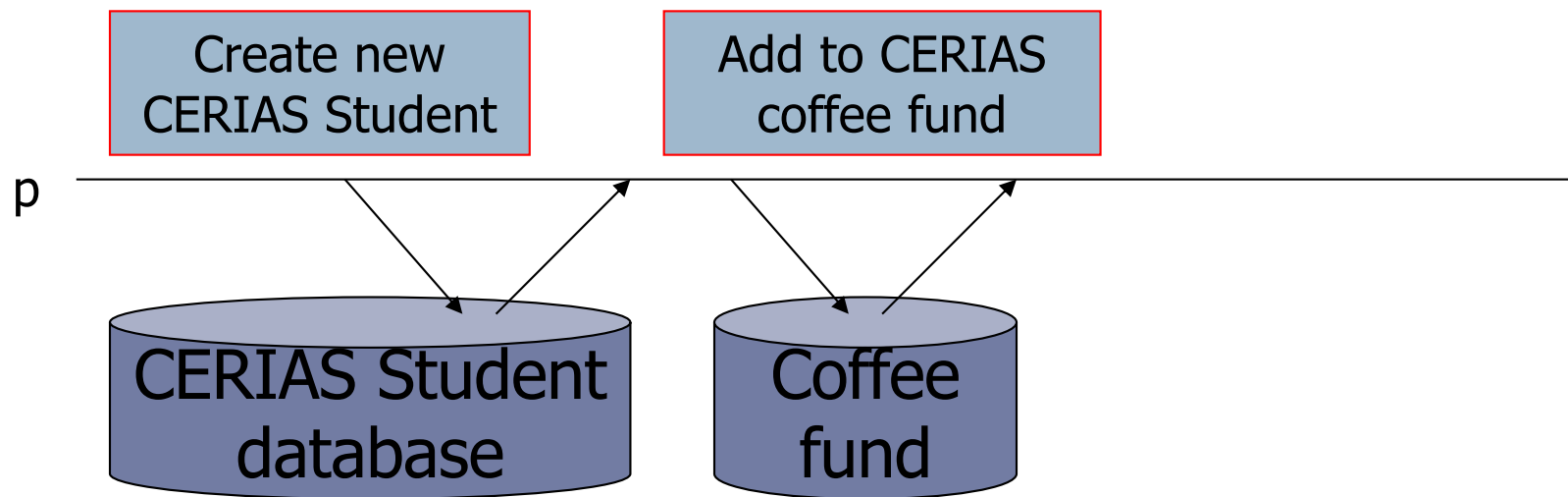
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- ▶ **Transaction behaves as one operation**
  - ▶ **(Failure) Atomicity**: all or none, if transaction failed then no changes apply to the database
  - ▶ **Consistency**: there is no violation of the database integrity constraints
  - ▶ **Isolation (Atomicity)**: partial results are hidden
  - ▶ **Durability**: the effects of transactions that were committed are permanent

# Example

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- ▶ Either  $p$  succeeds, and both tables get updated, or something fails and neither does



# What Can Go Wrong?

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- ▶ Process  $p$  could crash during the execution
- ▶ ... a database could throw an exception, e.g. “invalid SSN” or “duplicate record”
- ▶ ... a database could crash, then restart, and may have “forgotten” uncommitted updates (presumed abort)

# 2PC Overview

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- ▶ Assumes a coordinator that initiates the commit/abort
- ▶ Each database votes if it is ready to commit
  - ▶ Until the commit actually occurs, the update is considered temporary
  - ▶ Database is permitted to discard a pending update until all servers vote “ok” a database can abort
- ▶ Coordinator decides outcome and informs all databases

**SOUNDS EASY!**

# 2PC: More Details

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- ▶ Operates in rounds
- ▶ Coordinator assigns unique identifiers for each protocol run. How? Use logical clocks: run identifier can be process ID and the value of logical clock
- ▶ Messages carry the identifier of protocol run they are part of
- ▶ Since lots of messages must be stored, a garbage collection must be performed, the challenge is to determine when it is safe to remove the information



# 2PC Simplified Version: No Failures

## Coordinator:

Multicast *ready\_to\_commit*

Collect replies

All *Ok* => send *commit*

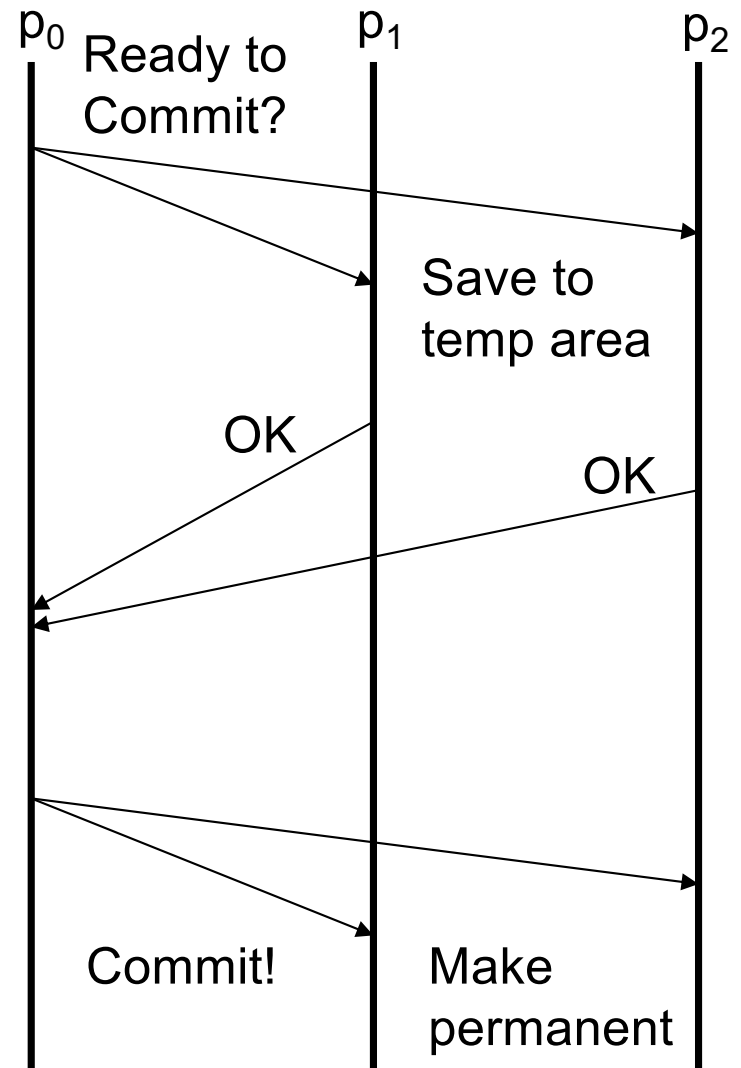
Else => send *abort*

## Participant receives:

*ready\_to\_commit* => save to temp area and reply *Ok*

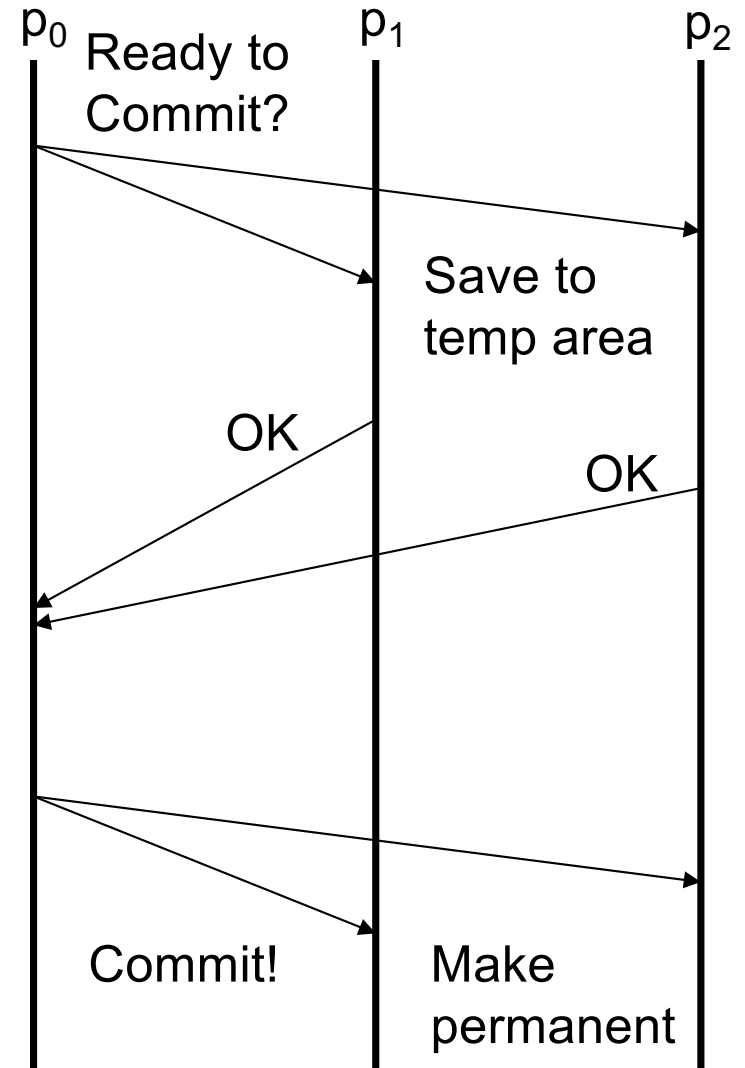
*commit* => make changes permanent

*abort* => delete temp area



# Participant States

- ▶ **Initial state:**  $p_i$  is not aware that protocol started, ends when  $p_i$  received *ready\_to\_commit* and it is ready to send its *Ok*
- ▶ **Prepared to commit:**  $p_i$  sent its *Ok*, saves in temp area and waits for the final decision (*commit* or *abort*) from coordinator
- ▶ **Commit or abort:**  $p_i$  knows the final decision, it must execute it



# Failures: Participant

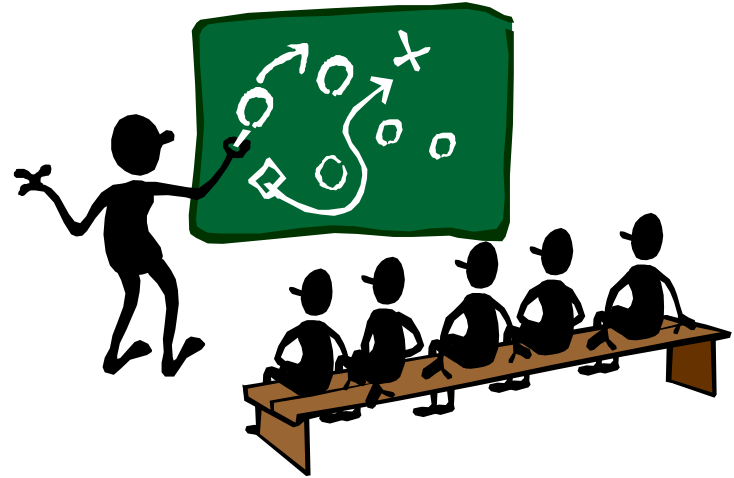
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- ▶ **Initial state:** if  $p_i$  crashes before receiving *ready\_to\_commit*, it does not send its *Ok* back, the coordinator will abort the protocol (not enough *Oks* are received).
- ▶ **Prepared to commit:** if  $p_i$  crashes before it learns the outcome, resources remained blocked. It is critical that a crashed participant learns the outcome of pending operations when it comes back: need logging system.
- ▶ **Commit or abort:**  $p_i$  crashes before executing, it must complete the commit or abort repeatedly in spite of being interrupted by failures.

# How to Fix It?

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- ▶ A process that crashed and recovered
  - ▶ Must remember in what state it was before crashing.
  - ▶ Must find out the outcome of a decision (by contacting the coordinator).
- ▶ The coordinator
  - ▶ Must keep track of pending protocols
  - ▶ Must find out when a process indeed completed the decision



# 2PC: Overcoming Participant Failures

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## Coordinator:

Multicast *ready\_to\_commit*

Collect replies

All OK => log 'commit' to 'outcomes' table and send *commit*

Else => send *abort*

Collect acknowledgments

Garbage-collect protocol 'outcomes' information

## Participant:

Receives:

*ready\_to\_commit* => save to temp area and reply OK

*commit* => make changes permanent, send *acknowledgment*

*abort* => delete temp area

After recovering from failure:

For each pending protocol: contact coordinator to learn outcome

# Failures: Coordinator

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- ▶ If coordinator crashed during first phase when collecting *Oks*:
  - ▶ Some participants will be ready to commit (they sent *Ok*)
  - ▶ Others will not be able to (they voted on abort)
  - ▶ Others may not know the state
- ▶ If coordinator crashed during its decision or before sending it out:
  - ▶ Some processes will be in prepare to commit state
  - ▶ Others will know the outcome

# Modifications ...

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- ▶ If coordinator fails, processes are blocked waiting for it to recover
- ▶ After the coordinator recovers, there are pending protocols that must be finished
- ▶ Coordinator must
  - ▶ remember its state before crashing (write commit or abort on permanent storage before sending commit or abort decision to other processes)
  - ▶ push pending operations through
- ▶ Participants may see duplicated messages

# 2PC Overcoming Coordinator Failures: Coordinator

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Multicast *ready\_to\_commit*

Collect replies

All OK => log 'commit' to 'outcomes' table, wait until safe on persistent storage and send commit

Else => send *abort*

Collect *acknowledgments*

Garbage collect protocol outcome information

After failure:

For each pending protocol in 'outcomes' table

Send outcome (*commit* or *abort*)

Wait for *acknowledgments*

Garbage collect outcome information



# 2PC Overcoming Coordinator Failures: Participant

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First time message received

*ready\_to\_commit*

save to temp area and reply *OK*

*commit*

make changes permanent

*abort*

delete temp area

Message is a duplicate (because of a recovering coordinator)

Send *acknowledgment*

After failure:

For each pending protocol:

contact coordinator to learn outcome

# Allowing Progress...

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- ▶ **WHAT IF THE COORDINATOR DOES NOT RECOVER? HOW CAN WE ALLOW PROGRESS?**
- ▶ One option instead of blocking is to allow the other participants to complete the protocol on their own.
- ▶ **Caveat: Any participant taking over will not be able to safely conclude that the coordinator actually failed. WHY?**
- ▶ **Timeout expired at a participant that is in the prepare-to-commit state:**
  - ▶ The process can send out the first phase message, querying the state at other processes to learn outcome
  - ▶ Continue with second phase

# Allowing Progress (cont.)

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- ▶ Can a process always determine the outcome?
- ▶ Example: all processes are in prepared-to-commit state with the exception of one process let's say  $p_j$ , which can not be reached
- ▶ Only the coordinator and  $p_j$  can determine the outcome
- ▶ If the coordinator is itself a participant, only one failure blocks the protocol
- ▶ All participants must now maintain information about the outcome of the protocol until they are sure that all participants learnt the outcome

# Garbage Collection

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- ▶ Add a third phase from the coordinator to all participants, tell participants that it is safe to garbage collect the protocol information
- ▶ If coordinator fails:
  - ▶ If a participant in final state but did not see the garbage collect message, it will send again the commit or abort message
  - ▶ All participants will acknowledge when they executed
  - ▶ Once all participants acknowledged the message, garbage collection message can be sent out and garbage collection can be performed.
- ▶ Garbage collection can be run periodically

# 2PC Final Version: Coordinator

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Multicast: ready\_to\_commit

Collect replies

All OK => log 'commit' to 'outcomes' table, wait until safe on persistent storage and send commit

Else => send abort

Collect acknowledgments

After failure:

For each pending protocol in outcomes table

Send outcome (commit or abort)

Wait for acknowledgments

Periodically

Query each process: terminated protocols?

Determine fully terminated protocols to garbage collect  
protocol outcome information

# 2PC Final Version: Participant

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## First time message received

*ready\_to\_commit*

save to temp area and reply *OK*

*commit*

Log outcome, make changes permanent

*abort*

Log outcome, delete temp area

## Message is a duplicate (recovering coordinator)

Send *acknowledgment*

## After failure:

For each pending protocol:

contact coordinator to learn outcome

## After timeout in prepare to commit state:

Query other participants about state

If outcome can be deduced: Run coordinator-recovery protocol

If outcome uncertain: must wait

# 2PC: Summary

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- ▶ Message complexity  $O(n^2)$
- ▶ Worst case: network disrupts the communication in each phase
- ▶ Pure 2PC will always block if coordinator fails
- ▶ Final version provides increased availability but can still block if a failure occurs at a critical stage: will be unable to terminate if both coordinator and a participant fail during the decision stage



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▶ **Three-Phase Commit**



# 3 PC Overview

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- ▶ Guarantees that the protocol will not block when only fail-stop failures occur
- ▶ A process fails only by crashing, crashes are accurately detectable
- ▶ Model is not realistic, but still interesting to look at
- ▶ Requires a fourth round for garbage collection
- ▶ Remember that 2 PC blocks when coordinator and one more participant fail
- ▶ Fundamental problem: coordinator will make a decision which will be known and acted upon for some process, while other processes will not know it

## 3 PC Key Idea

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- ▶ Introduces an additional round of communication and delays to prepare-to-commit state to ensure that the state of the system can always be deduced by a subset of alive processes that can communicate with each other

before the commit, coordinator tells all participants that everyone sent OKs

# 3PC Simplified Version: No Failures

Coordinator:

Multicast *ready\_to\_commit*

Collect OKs

All *Ok* => send *precommit*

Else => send *abort*

Collect ACKs

All *ACK* => send *commit*

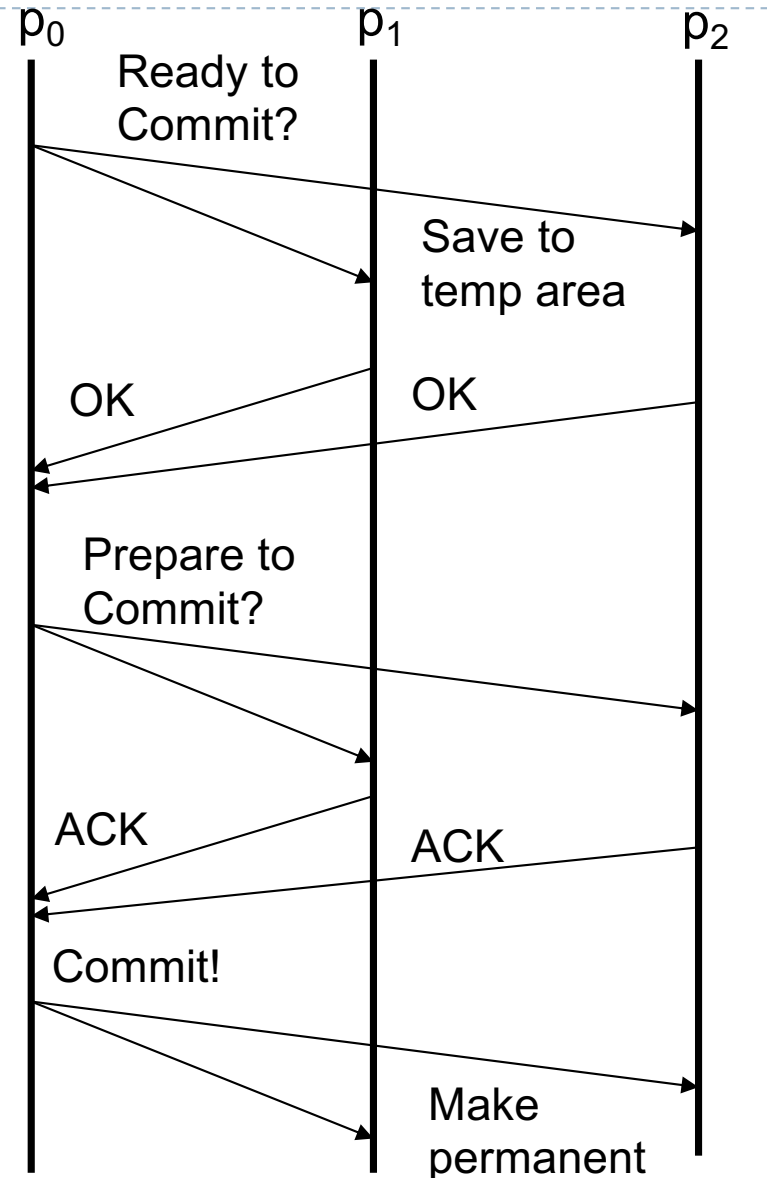
Participant receives:

*ready\_to\_commit* => save to temp area and reply *Ok*

*Precommit* => send *ACK*

*commit* => make changes permanent

*abort* => delete temp area



Distributed commit.

# What happens in case of failures?

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- ▶ Alive processes ( $p_i$ ) will select a new coordinator and try to complete transaction, based on their current states
- ▶ New coordinator selection: membership is static, detection is accurate, alive process with lowest id is selected
- ▶ If crashed nodes committed or aborted, then survivors should not contradict, otherwise, survivors can do as they decide

# 3PC: Coordinator

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Multicast *ready\_to\_commit*

Collect replies

All *OK* => log 'precommit' and send precommit

Else => send *abort*

Collect acks from non-failed participants

All *ack* => log commit and send commit

Collect acknowledgements that operation was finished

Garbage collect protocol outcome information

# 3PC: Participant

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## Participant logs state on each message

*ready\_to\_commit*

save to temp area and reply *OK*

*precommit*

Enter precommit state, send *ack*

*commit*

make changes permanent

*abort*

delete temp area

**After failure:**

Collect participant state information

All *precommit* or any *commit*, push forward the commit

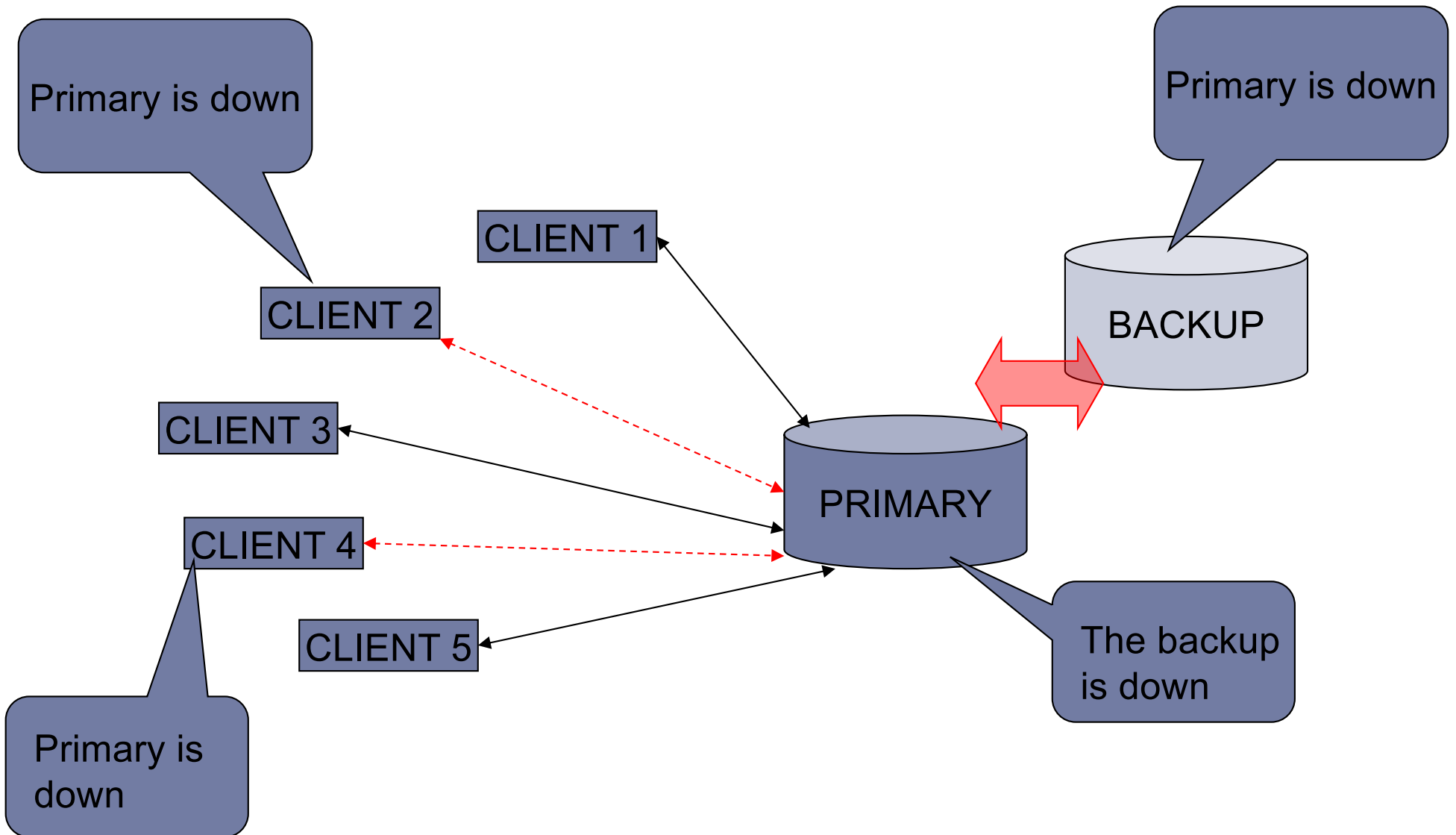
Else, push back the abort

# 3PC and Network Partitions

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- ▶ Consider the case when a network partition separates the processes in two groups:
  - ▶ One group sees that they are prepared to commit and go and terminate the protocol by commit
  - ▶ The other group sees a state that is ok to commit and would consider the safe decision to be abort
- ▶ 3PC does not work in case of network partitions

# Things go wrong...





# 3PC

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- ▶ Requires 3 phases (4 with garbage collection)
- ▶ Works only under fail-stop (model unrealistic)
- ▶ Does not work if network partitions happen



# CAP Theorem

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- ▶ States that any networked shared-data system can have at most two of three desirable properties:
  - ▶ consistency (C) equivalent to having a single up-to-date copy of the data;
  - ▶ high availability (A) of that data (for updates);
  - ▶ tolerance to network partitions (P).
- ▶ During a network partition and recovery from partition one can not have perfect availability and consistency
- ▶ Modern CAP goal should be to maximize combinations of consistency and availability that make sense for a specific application

*CAP Twelve Years Later: How the "Rules" Have Changed, E. Brewer*

# Beyond CAP: PACELC Theorem

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- ▶ States that:
  - ▶ In case of network partitioning (P) in one has to choose between availability (A) and consistency (C)
  - ▶ but else (E), even when the system is running normally in the absence of partitions, one has to choose between latency (L) and consistency (C).
- ▶ Address the fact that CAP does not capture the consistency/latency tradeoff of replicated systems present at all times during system operation
- ▶ Example: Dynamo, Cassandra, and Riak are PA/EL systems if a partition occurs, they give up consistency for availability, and under normal operation they give up consistency for lower latency.