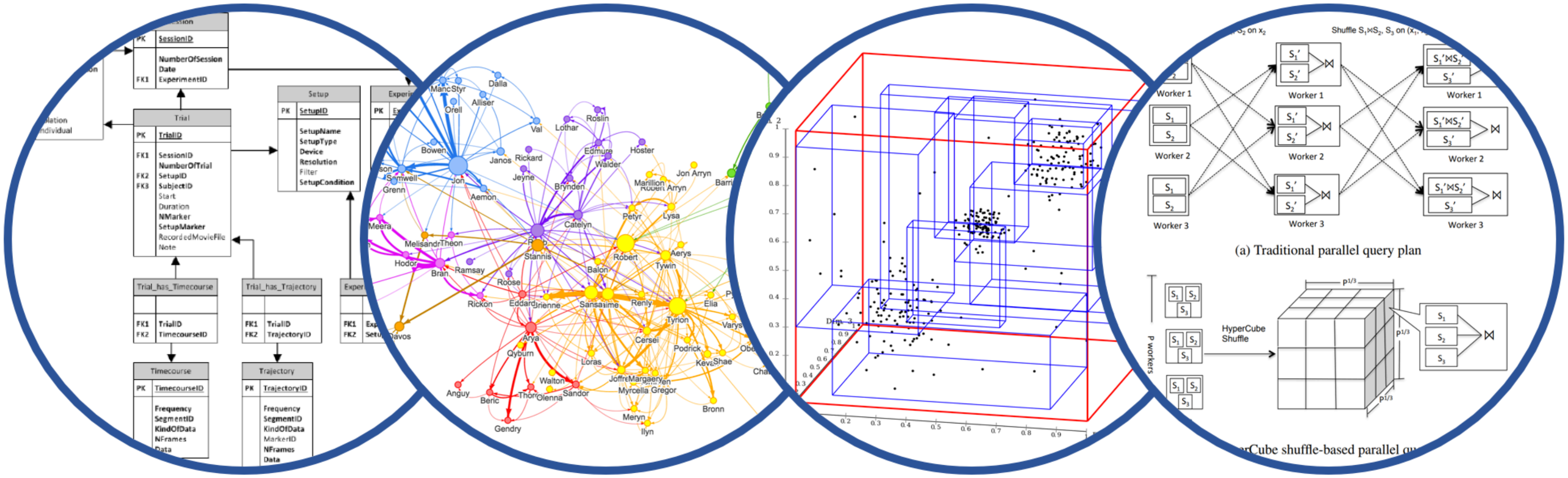

Database System Internals

Two-Phase Commit (2PC)

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University of Washington, Seattle

References

- Ullman book: Section 20.5
- Ramakrishnan book: Chapter 22

We are Learning about Scaling DBMSs

- Scaling the execution of a query
  - Parallel DBMS
  - MapReduce
  - Spark
- Scaling transactions
  - ☛ Distributed transactions
  - Replication
  - Scaling with NoSQL and NewSQL

Scaling Transactions Per Second

- OLTP: Transactions per second
  “Online Transaction Processing”

- Amazon
- Facebook
- Twitter
- … your favorite Internet application…

- Goal is to increase transaction throughput

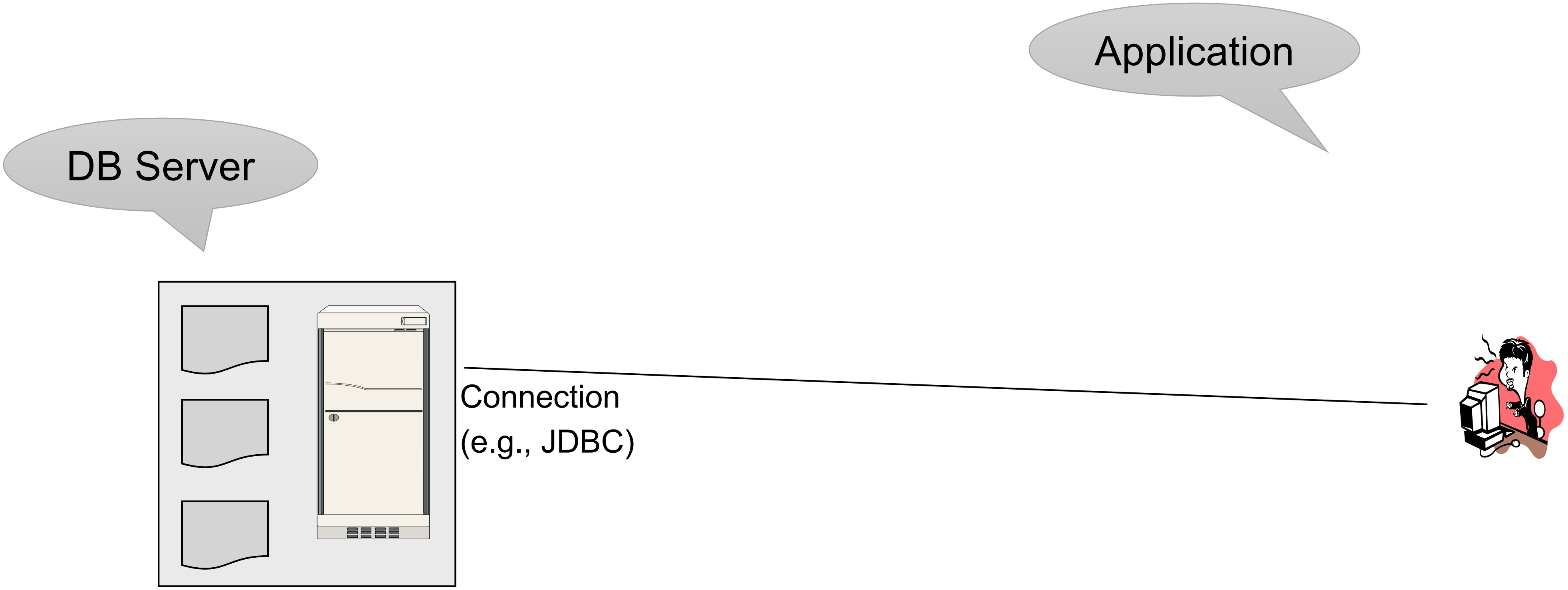
How to Scale the DBMS?

- Can easily replicate the web servers and the application servers

- We cannot so easily replicate the database servers, because the database is unique

- We need to design ways to **scale up the DBMS**

How to Scale?

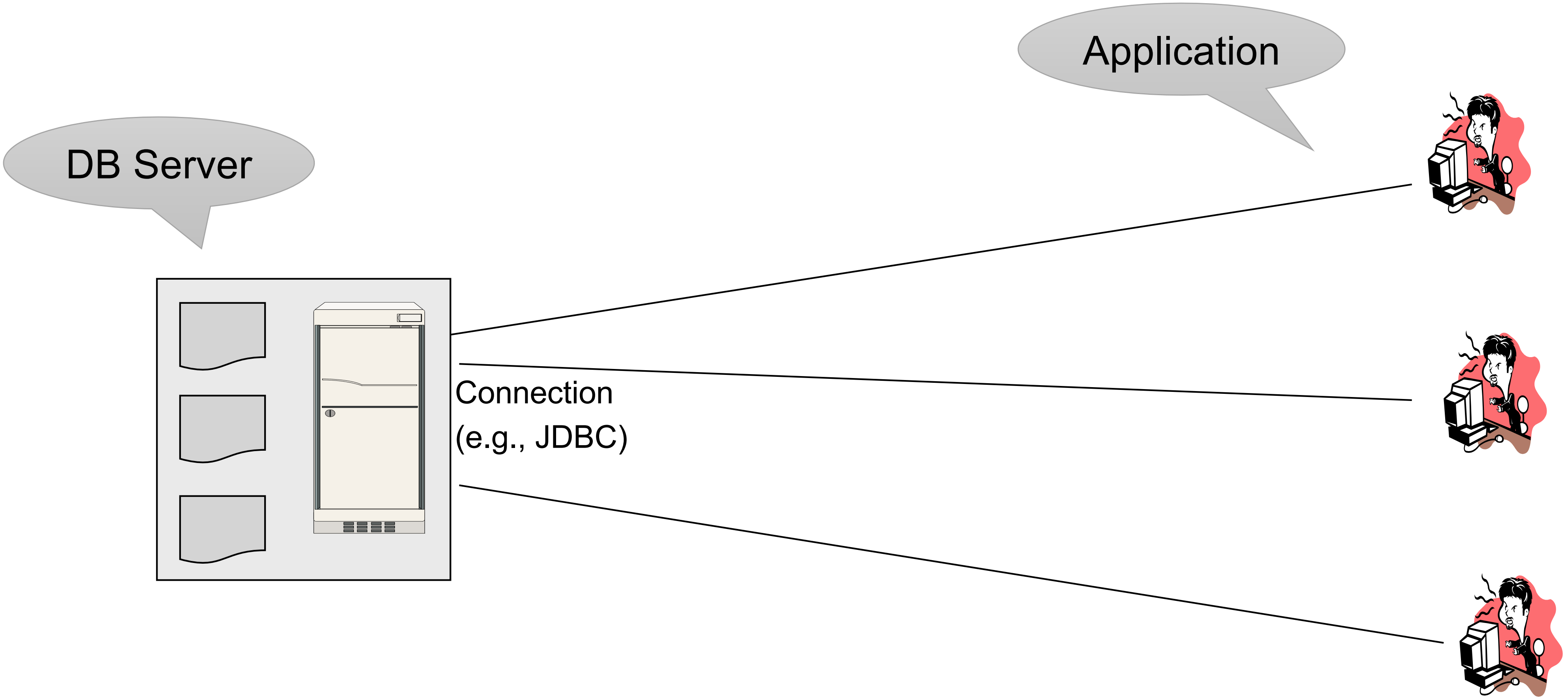


Application

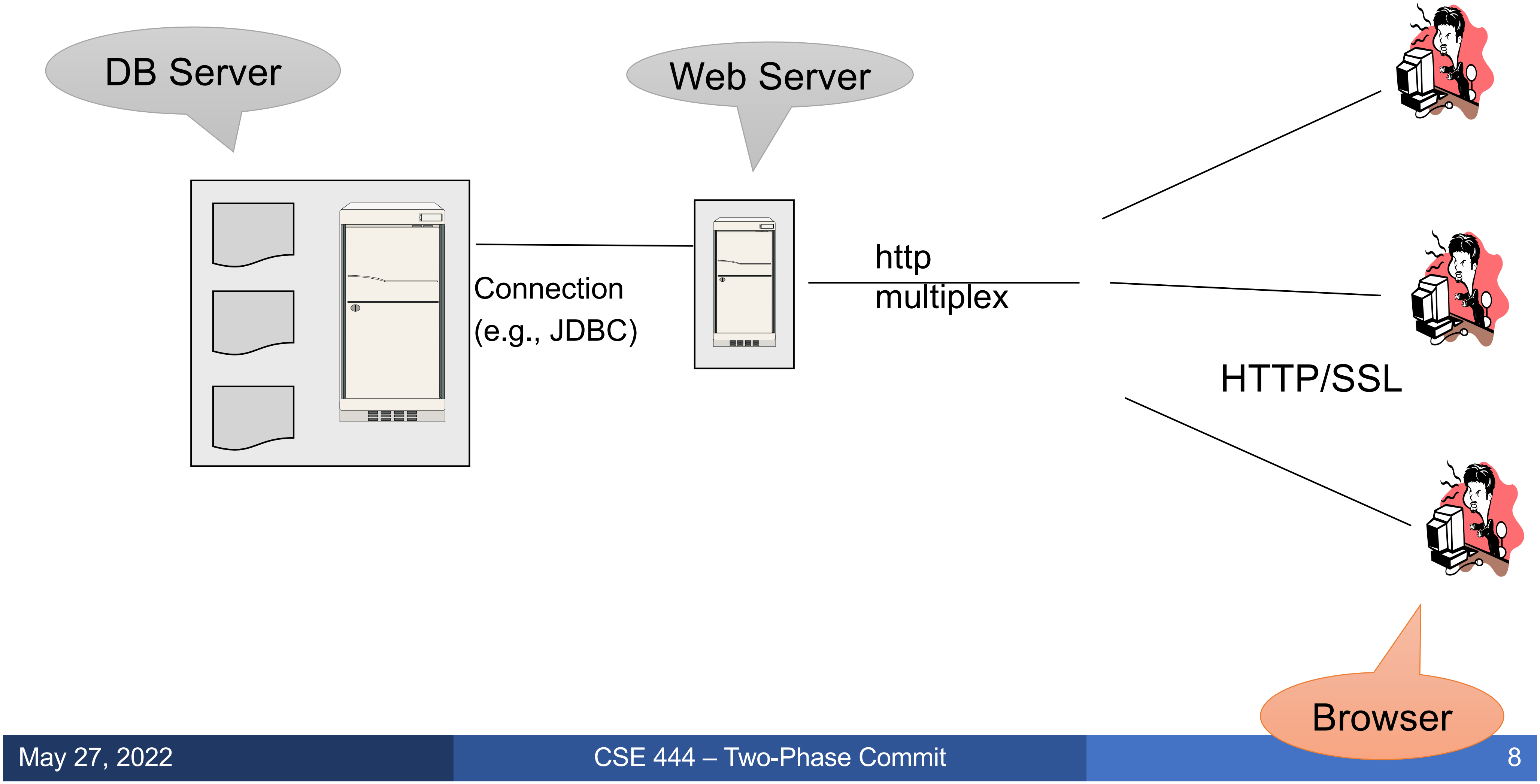
DB Server

Connection
(e.g., JDBC)

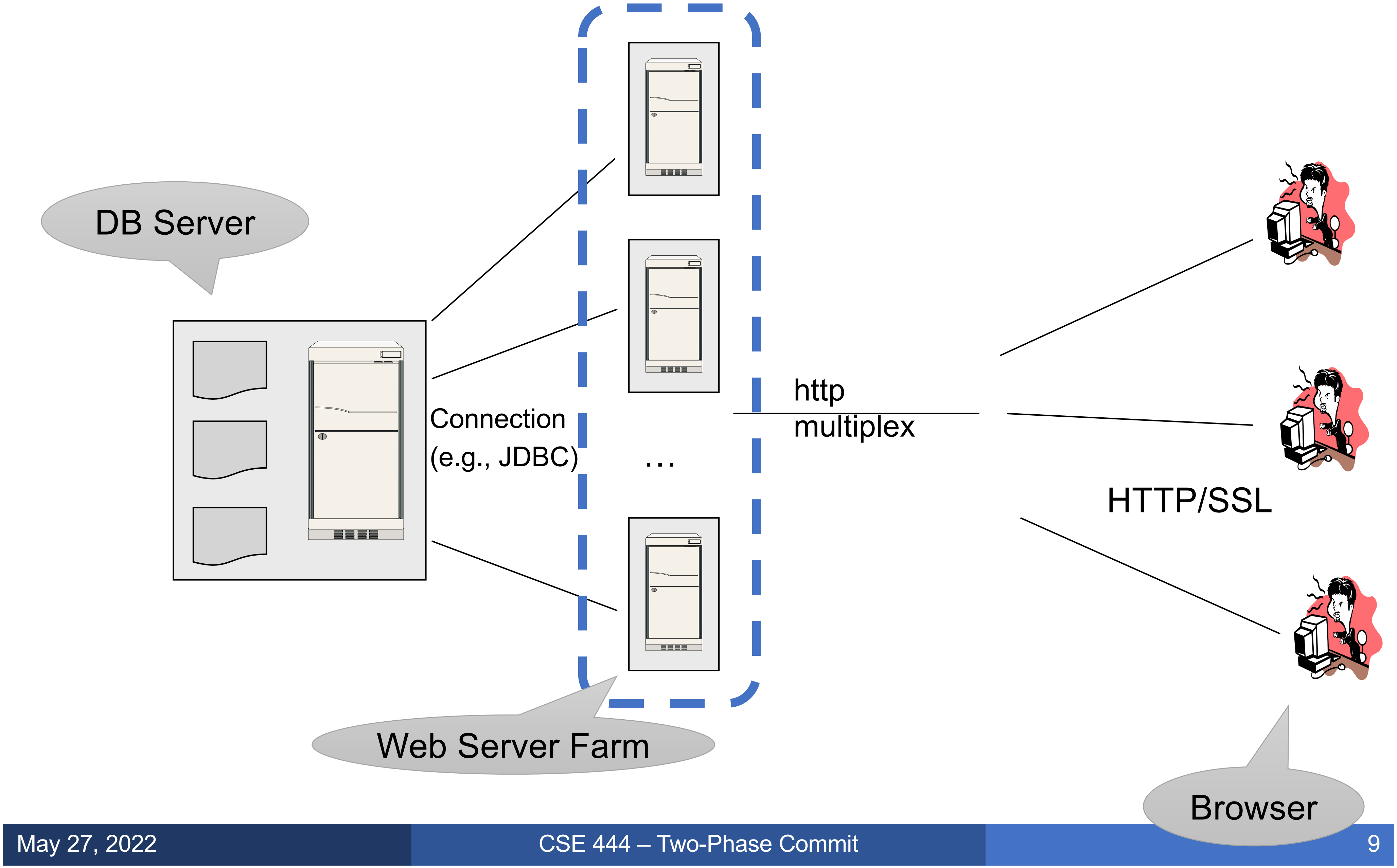
How to Scale?



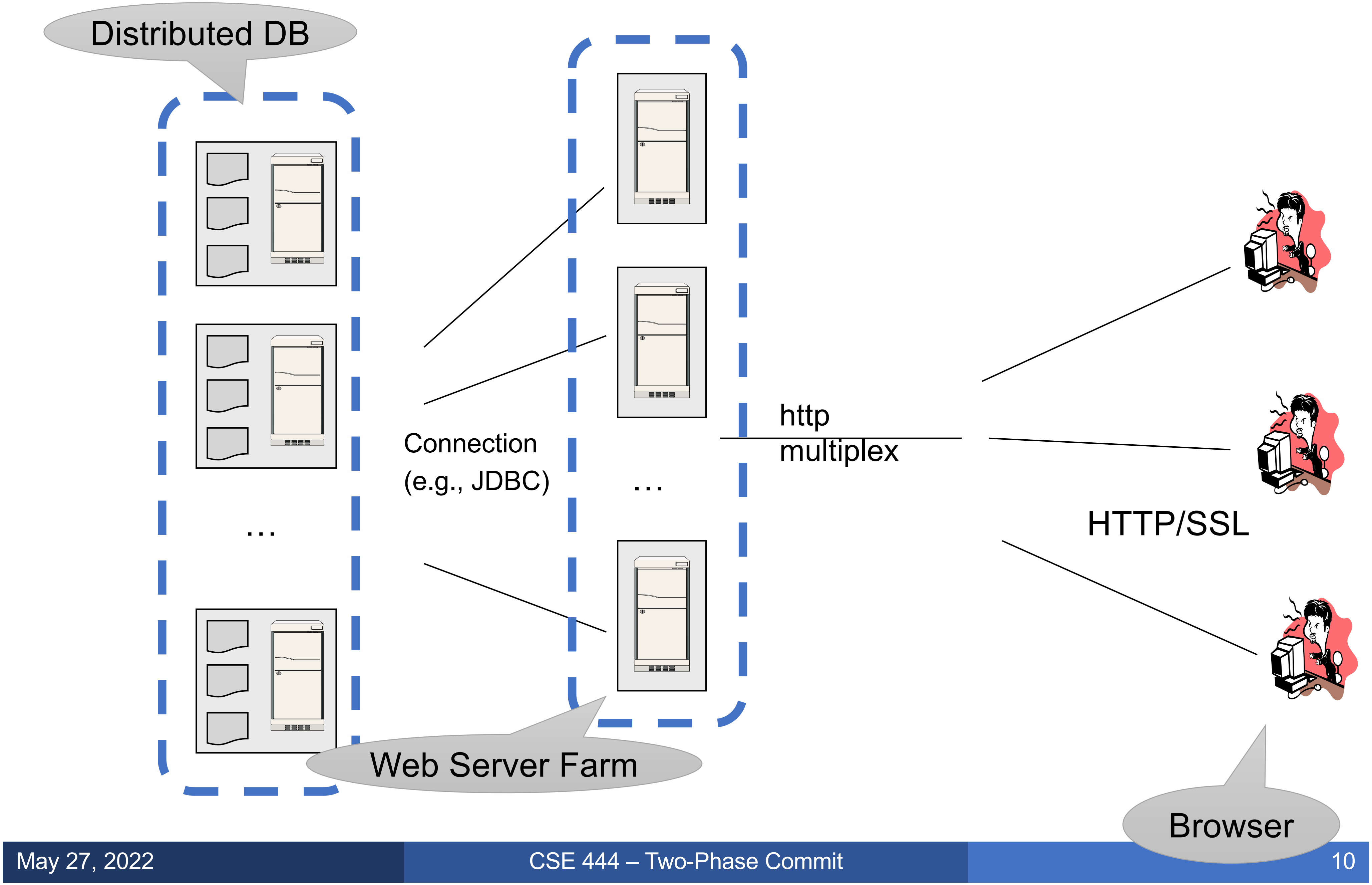
How to Scale?


DB Server
Web Server
Connection
(e.g., JDBC)
http
multiplex
HTTP/SSL
Browser

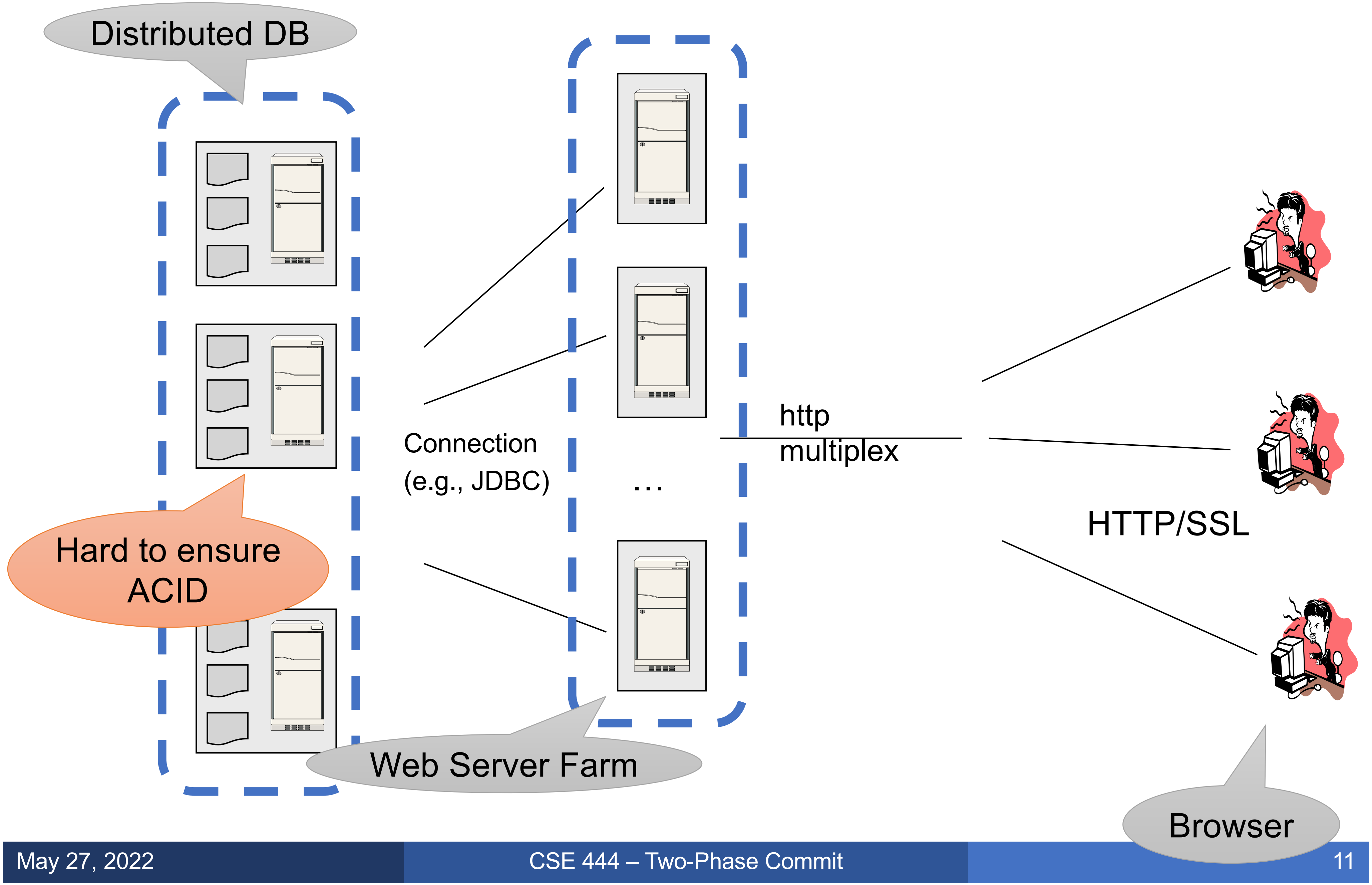
How to Scale?


DB Server
Connection
(e.g., JDBC)
…
http
multiplex
HTTP/SSL
Web Server Farm
Browser

How to Scale?


Distributed DB
…
Connection
(e.g., JDBC)
…
Web Server Farm
http
multiplex
HTTP/SSL
Browser

How to Scale?


Distributed DB
Hard to ensure ACID
Connection (e.g., JDBC)
…
http multiplex
HTTP/SSL
Web Server Farm
Browser

Transaction Scaling Challenges

- Distribution
  - There is a limit on transactions/sec on one server
  - Need to partition the database across multiple servers
  - If a transaction touches one machine, life is good!
  - If a transaction touches multiple machines, ACID becomes extremely expensive! Need two-phase commit

- Replication
  - Replication can help to increase throughput and lower latency
  - Create multiple copies of each database partition
  - Spread queries across these replicas
  - Easy for reads but writes, once again, become expensive!

Distributed Transactions

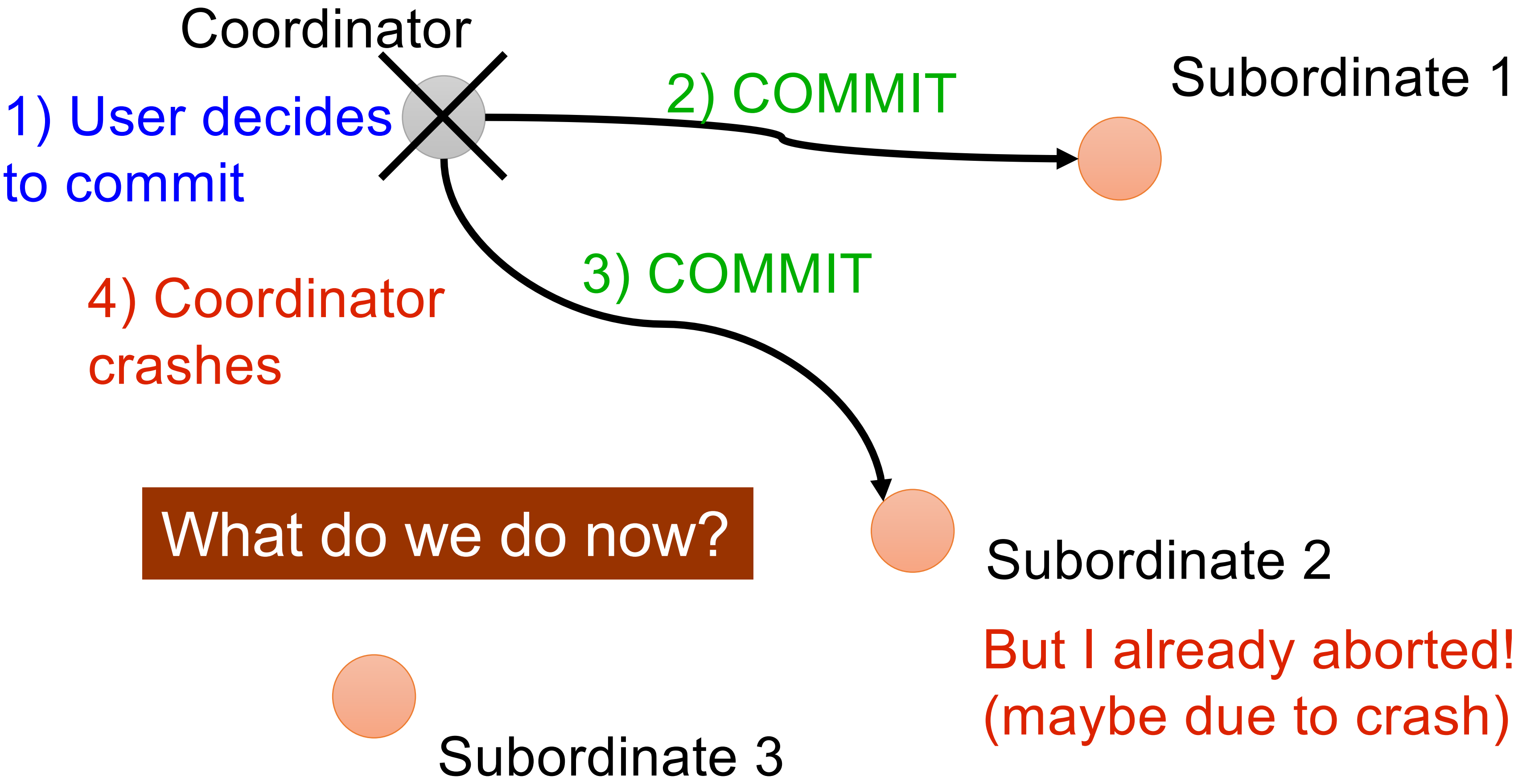
- Concurrency control

- Failure recovery
  - Transaction must be committed at all sites or at none of the sites!
  - No matter what failures occur and when they occur
  - Two-phase commit protocol (2PC)

Distributed Concurrency Control

- In theory, different techniques are possible
    - Pessimistic, optimistic, locking, timestamps
- In practice, distributed two-phase locking
    - Simultaneously hold locks at all sites involved
- Deadlock detection techniques
    - Global wait-for graph (not very practical)
    - Timeouts
- If deadlock: abort least costly local transaction

Two-Phase Commit: Motivation



Coordinator

1) User decides to commit

2) COMMIT

Subordinate 1

3) COMMIT

4) Coordinator crashes

What do we do now?

Subordinate 2

But I already aborted! (maybe due to crash)

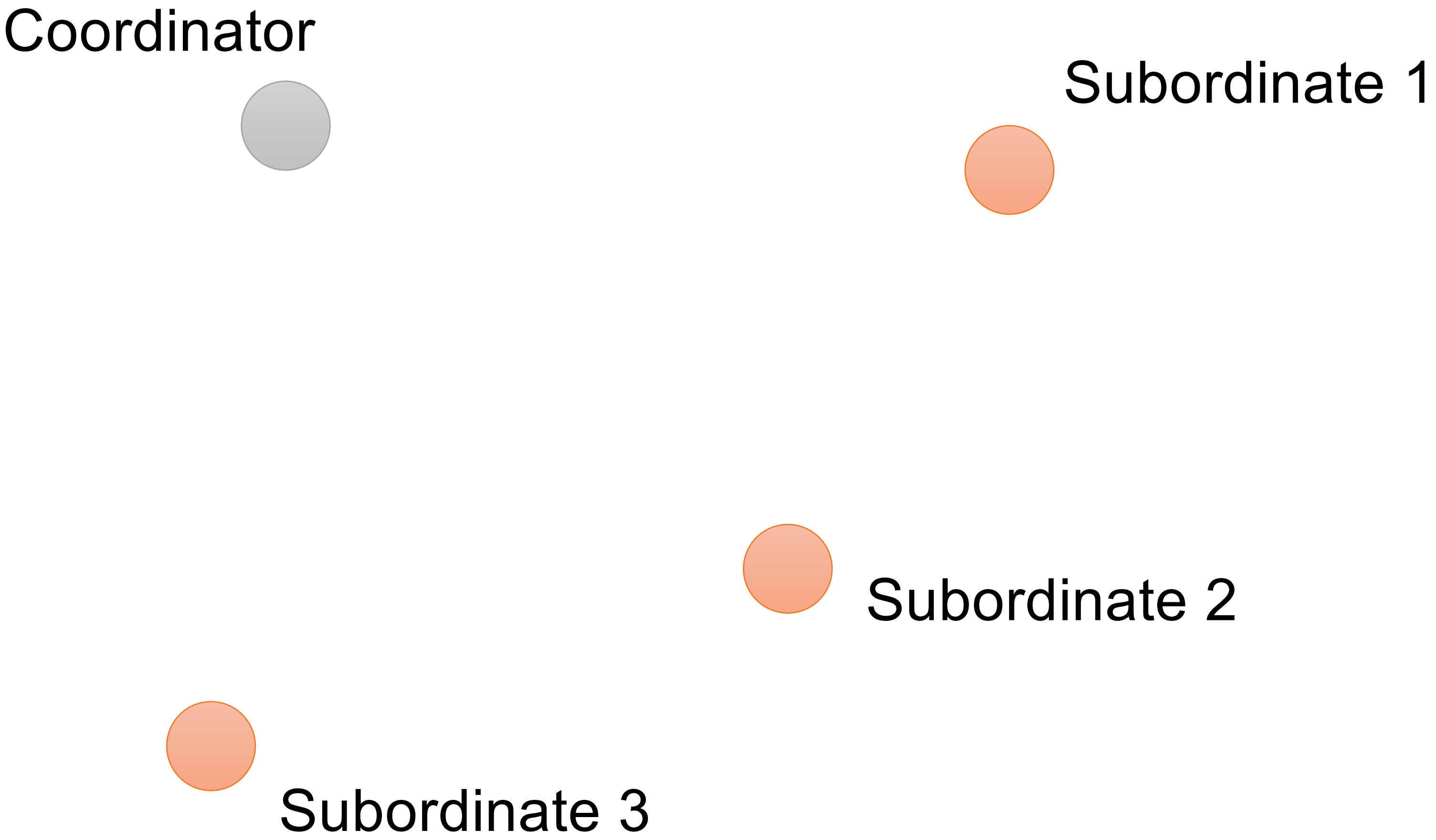
Subordinate 3

2PC Outline

- Phase 1: coordinator polls the subordinators whether they want to commit or abort

- Phase 2: coordinator notifies all subordinators of the decision commit or abort

2PC: Phase 1, Prepare



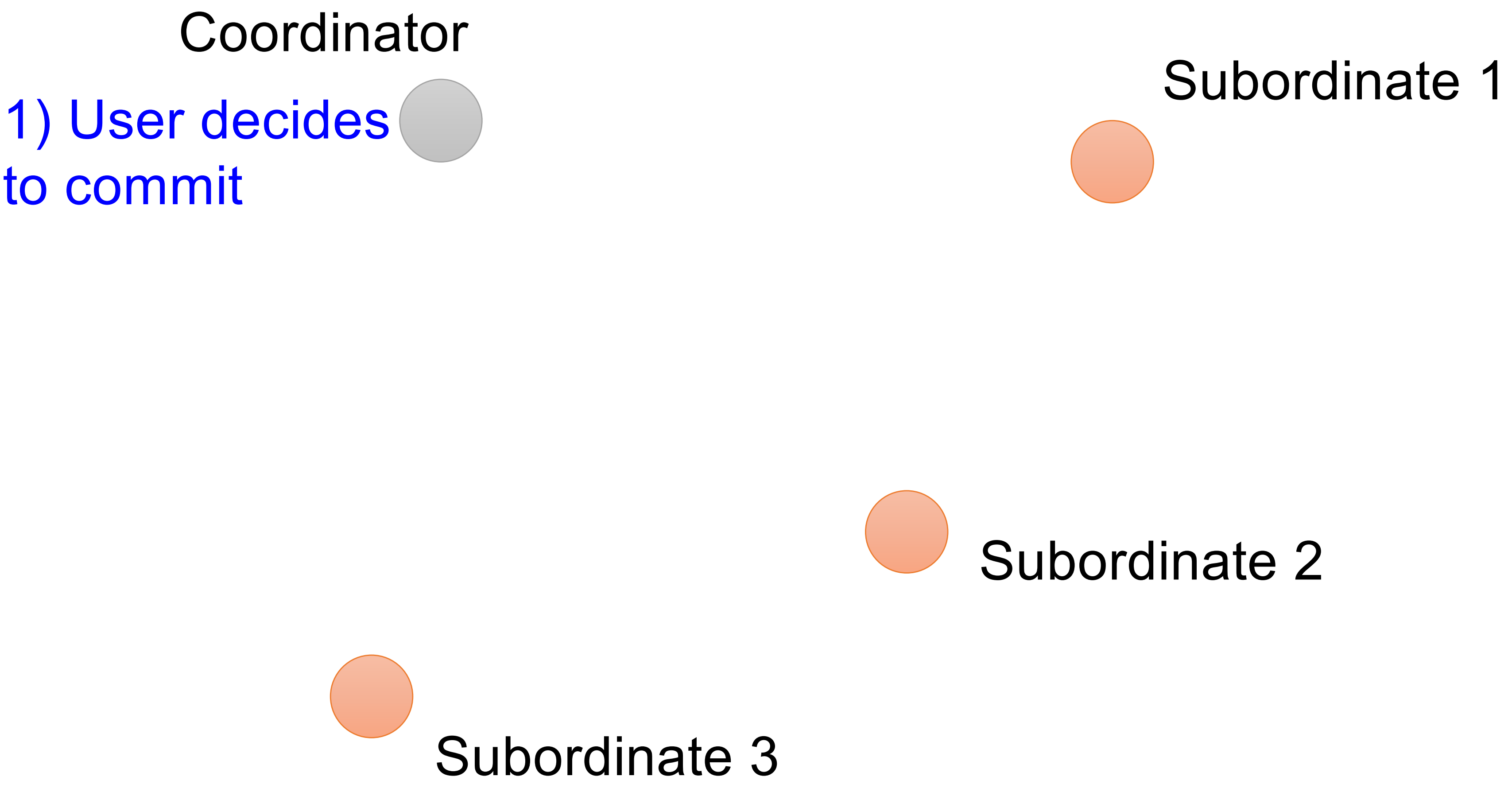
Coordinator

Subordinate 1

Subordinate 2

Subordinate 3

2PC: Phase 1, Prepare



Coordinator

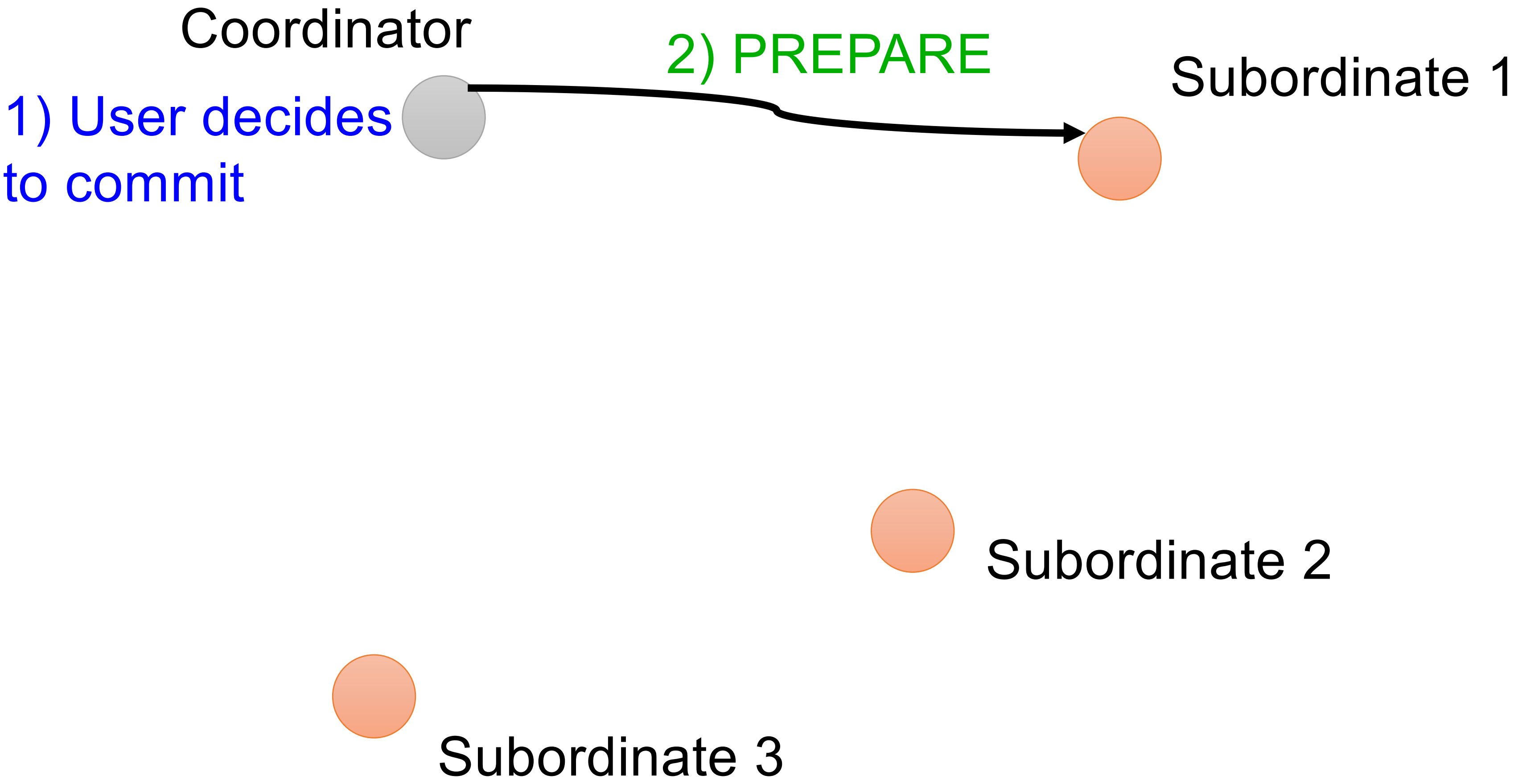
1) User decides to commit

Subordinate 1

Subordinate 2

Subordinate 3

2PC: Phase 1, Prepare



Coordinator

1) User decides to commit

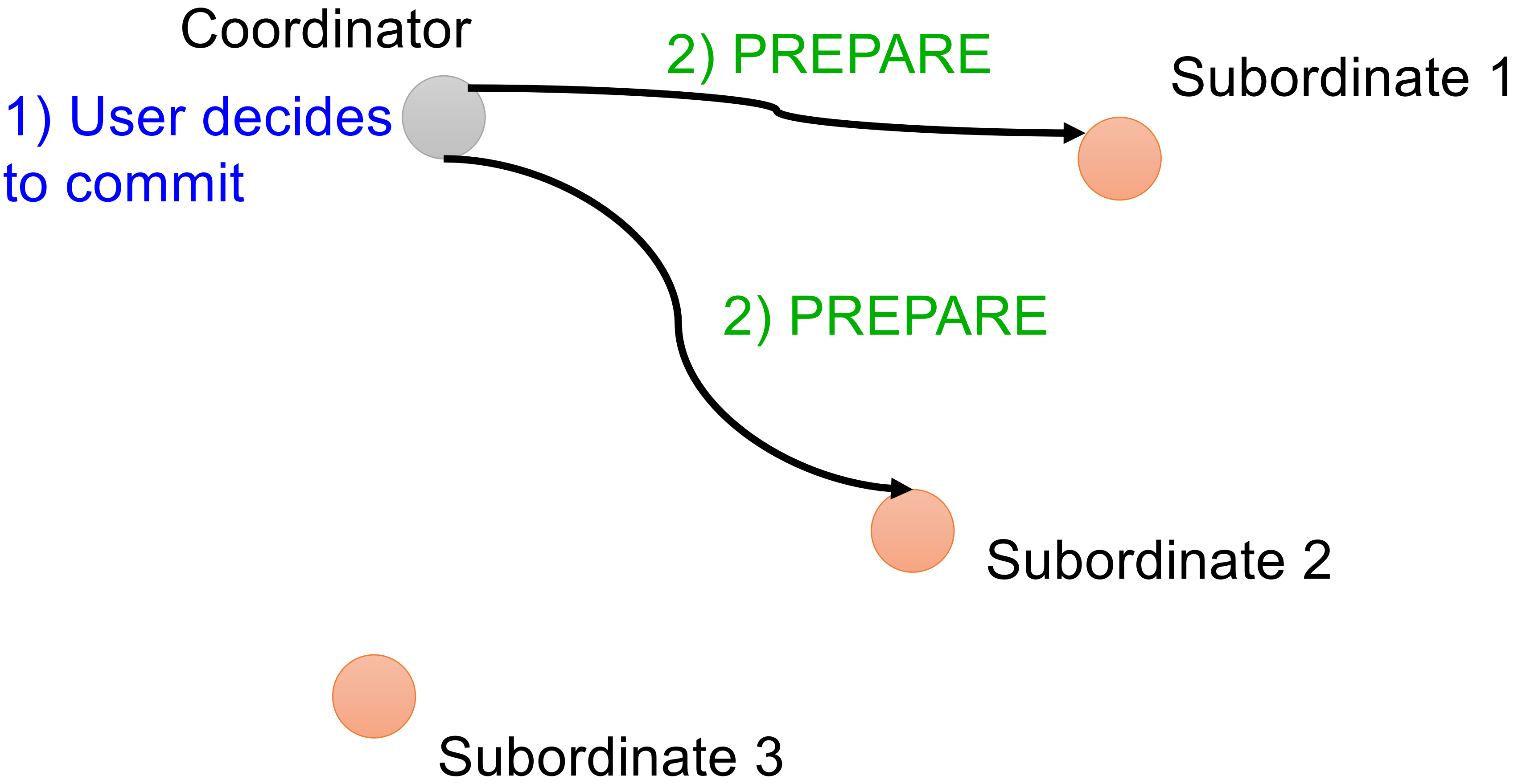
2) PREPARE

Subordinate 1

Subordinate 2

Subordinate 3

2PC: Phase 1, Prepare



Coordinator

1) User decides to commit

2) PREPARE

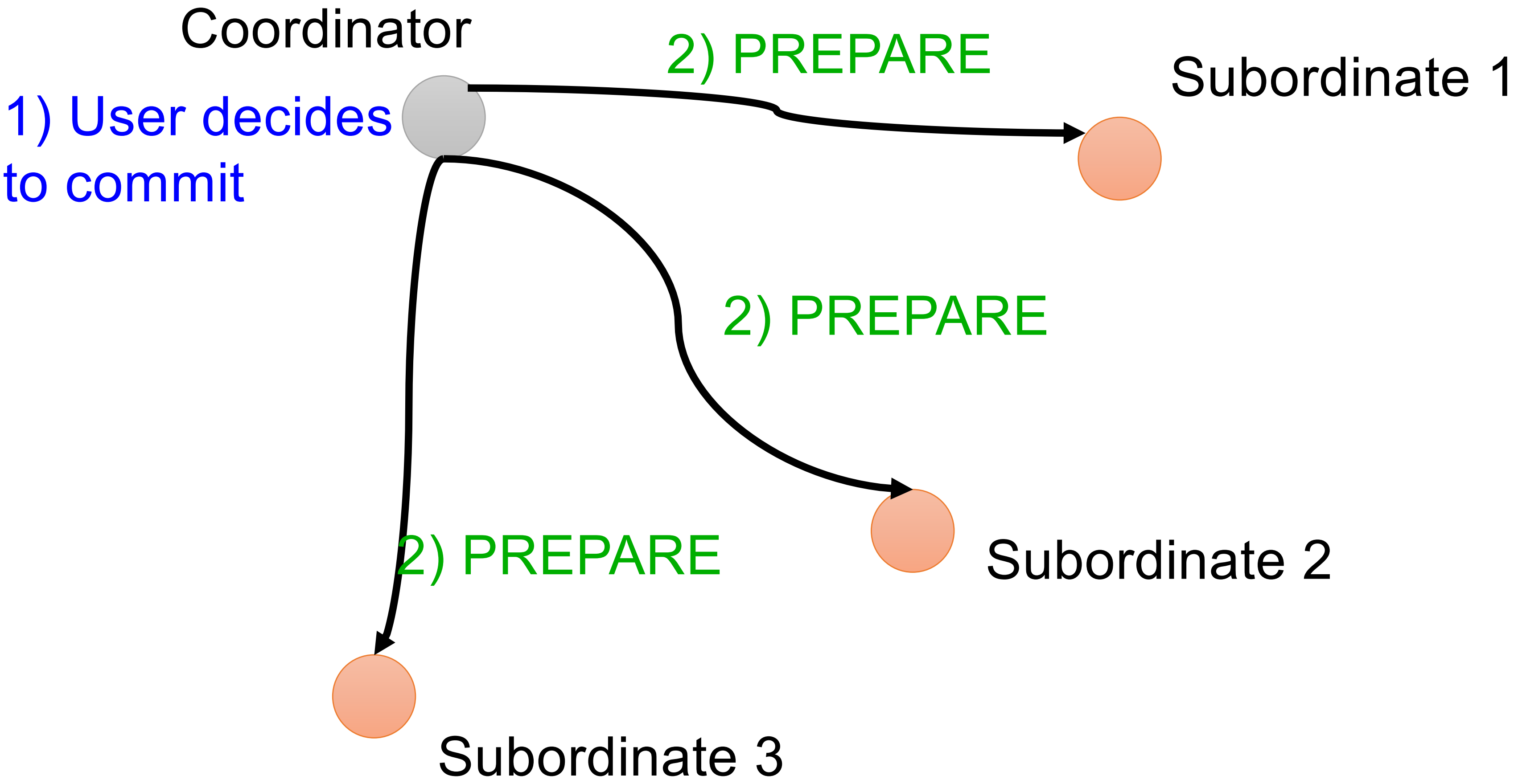
Subordinate 1

2) PREPARE

Subordinate 2

Subordinate 3

2PC: Phase 1, Prepare



Coordinator

1) User decides to commit

2) PREPARE

Subordinate 1

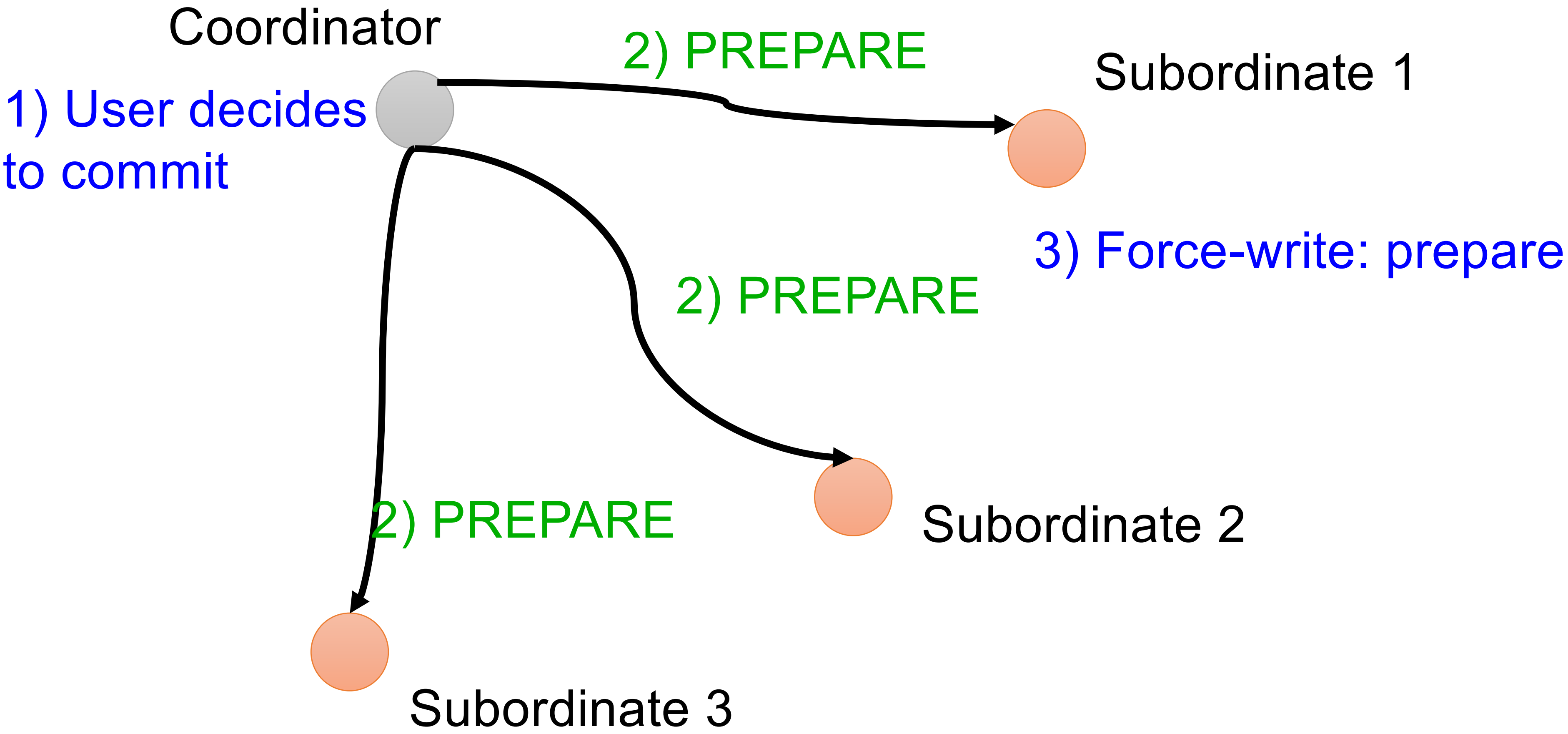
2) PREPARE

Subordinate 2

2) PREPARE

Subordinate 3

2PC: Phase 1, Prepare



Coordinator

1) User decides to commit

2) PREPARE

Subordinate 1

3) Force-write: prepare

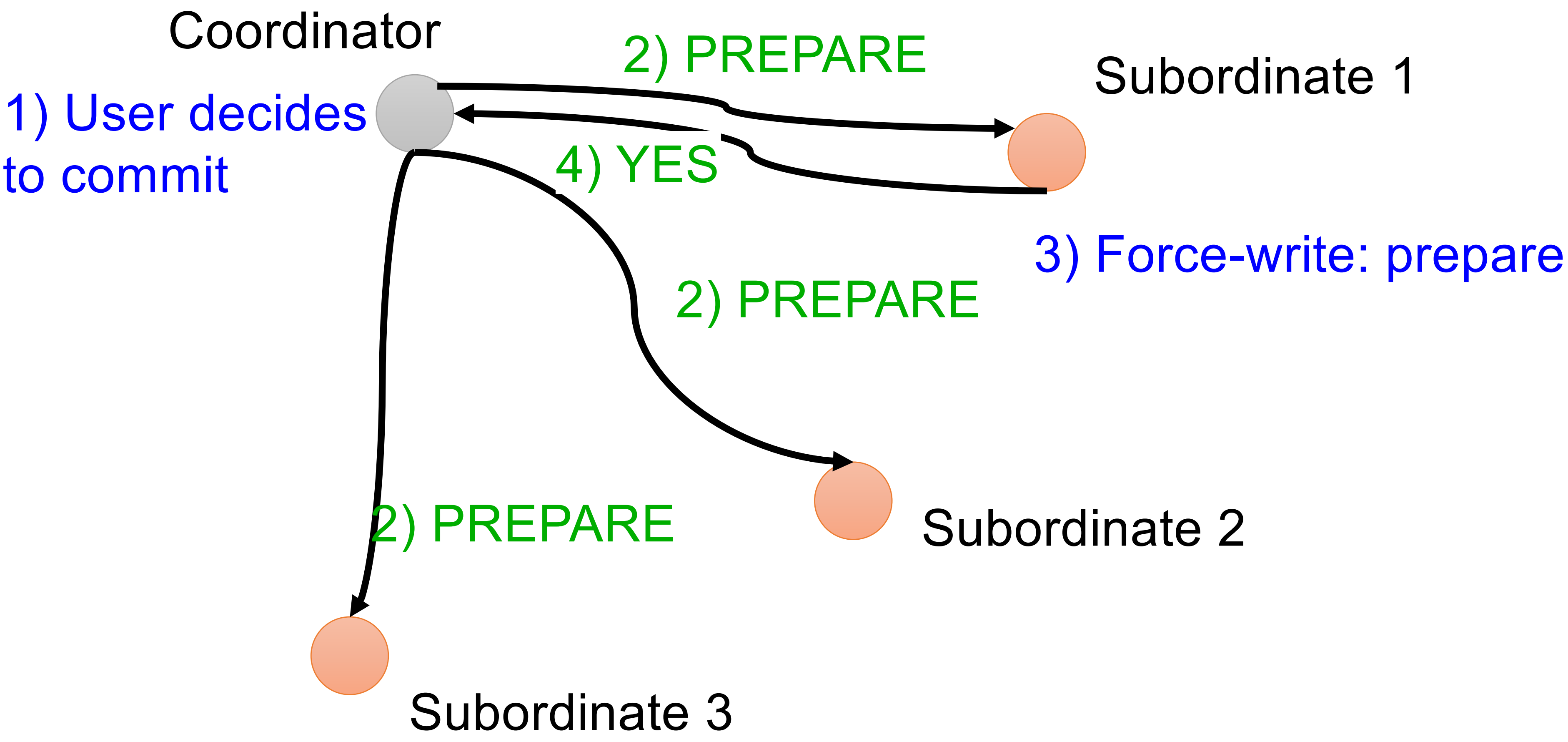
2) PREPARE

Subordinate 2

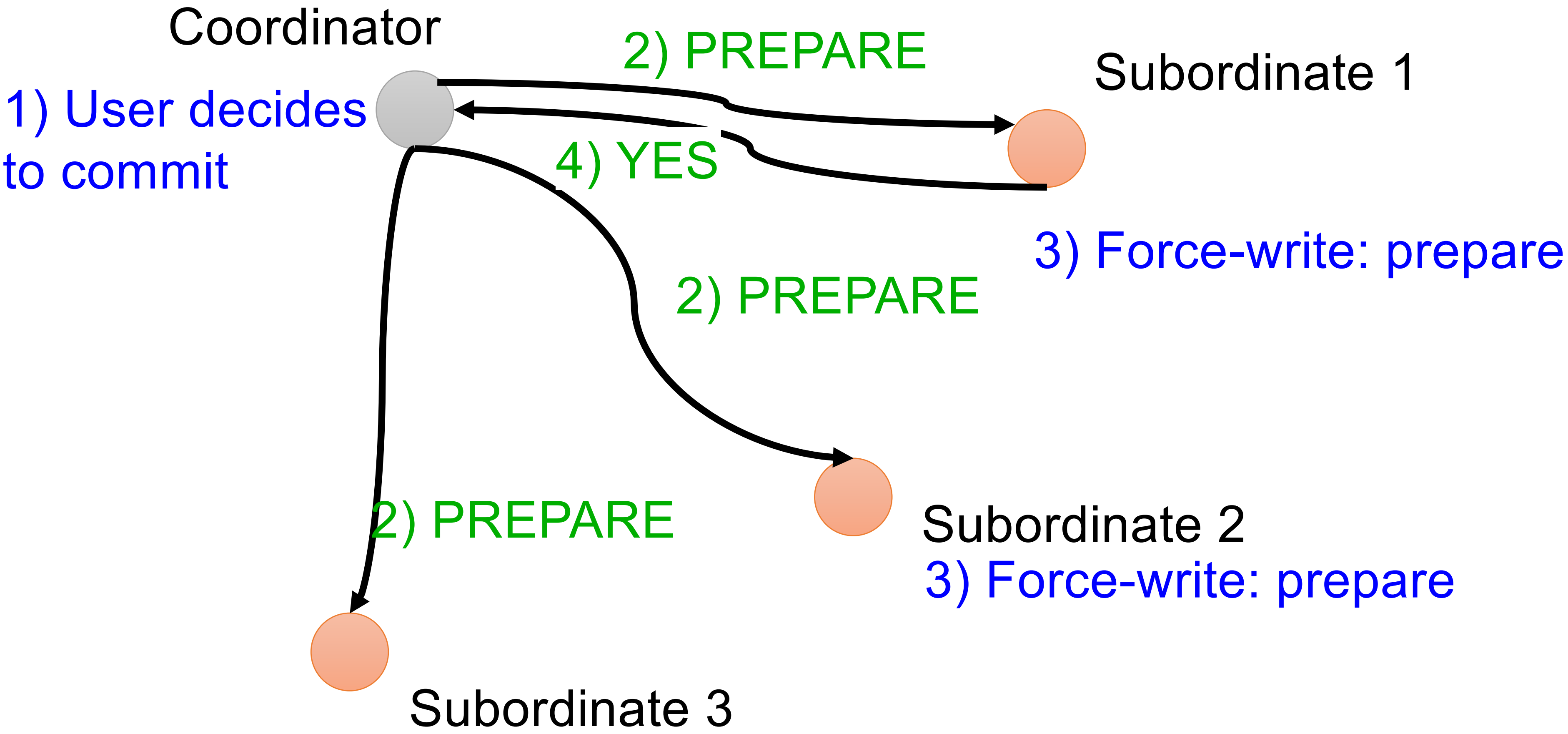
2) PREPARE

Subordinate 3

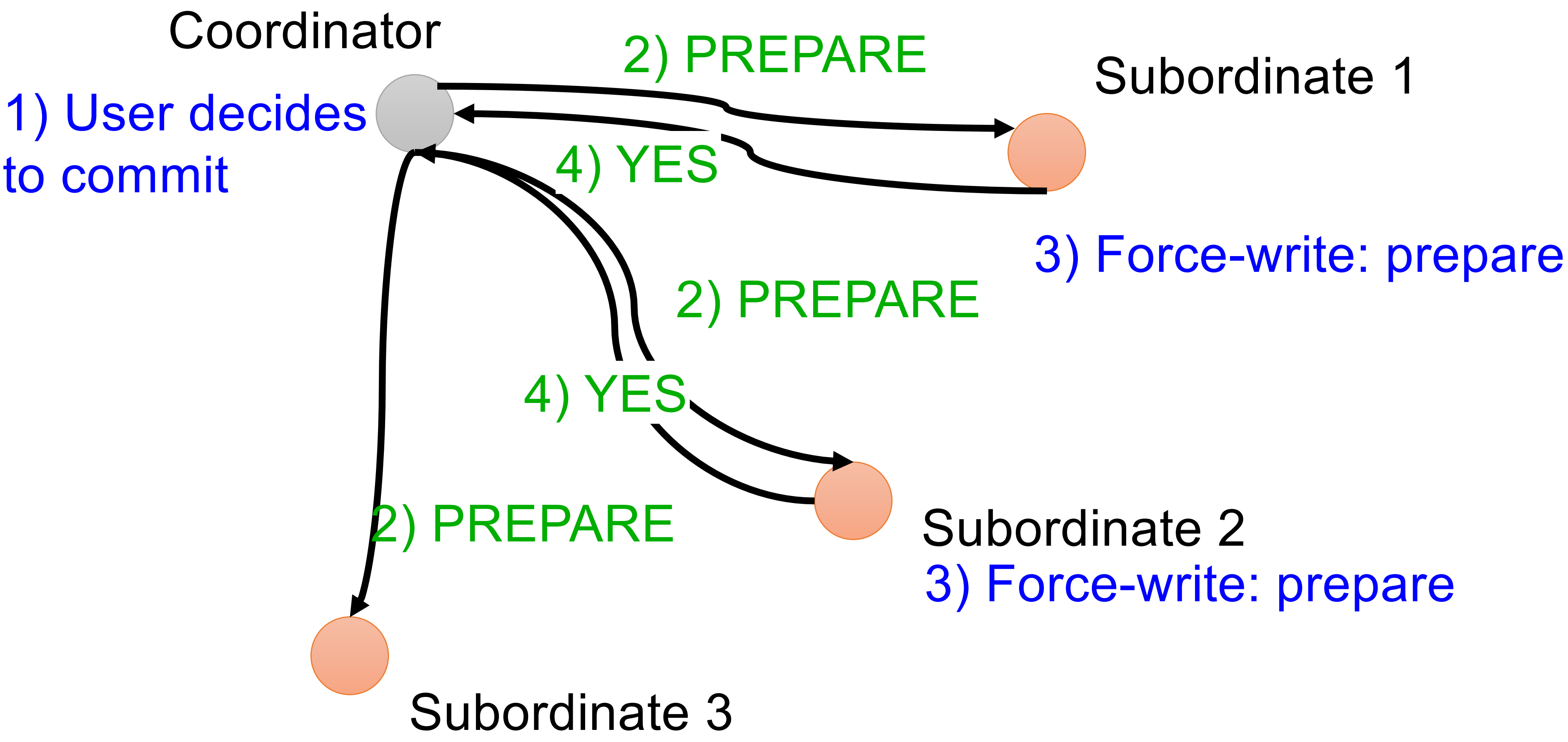
2PC: Phase 1, Prepare



2PC: Phase 1, Prepare



2PC: Phase 1, Prepare



Coordinator

1) User decides to commit

2) PREPARE

4) YES

Subordinate 1

3) Force-write: prepare

2) PREPARE

4) YES

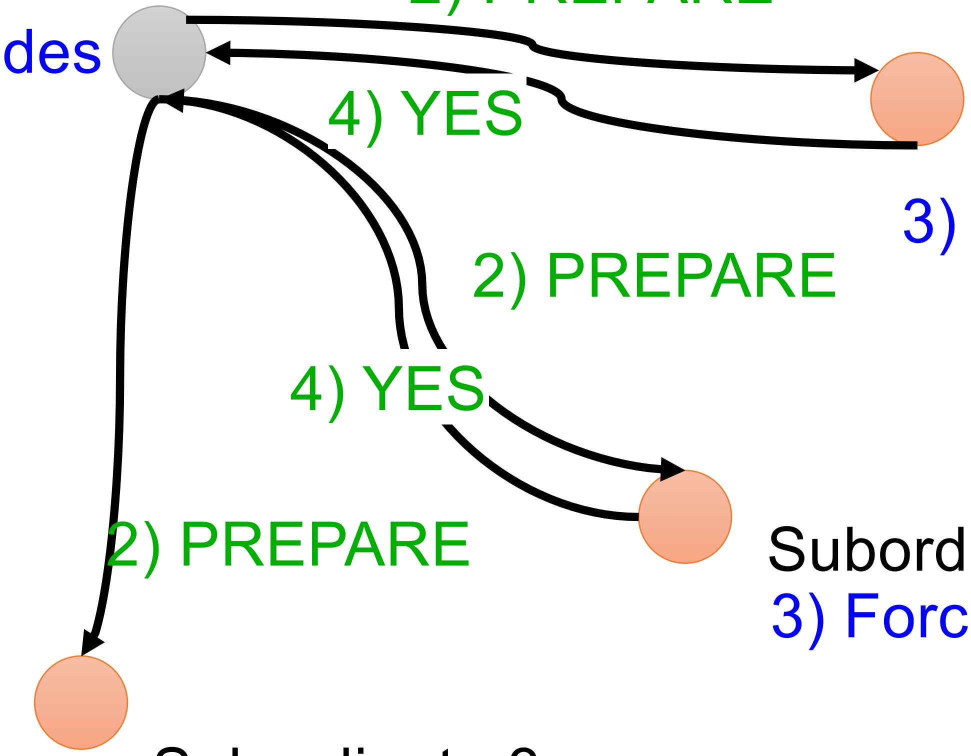
Subordinate 2

3) Force-write: prepare

2) PREPARE

Subordinate 3

2PC: Phase 1, Prepare



Coordinator

1) User decides to commit

2) PREPARE

Subordinate 1

4) YES

3) Force-write: prepare

2) PREPARE

4) YES

2) PREPARE

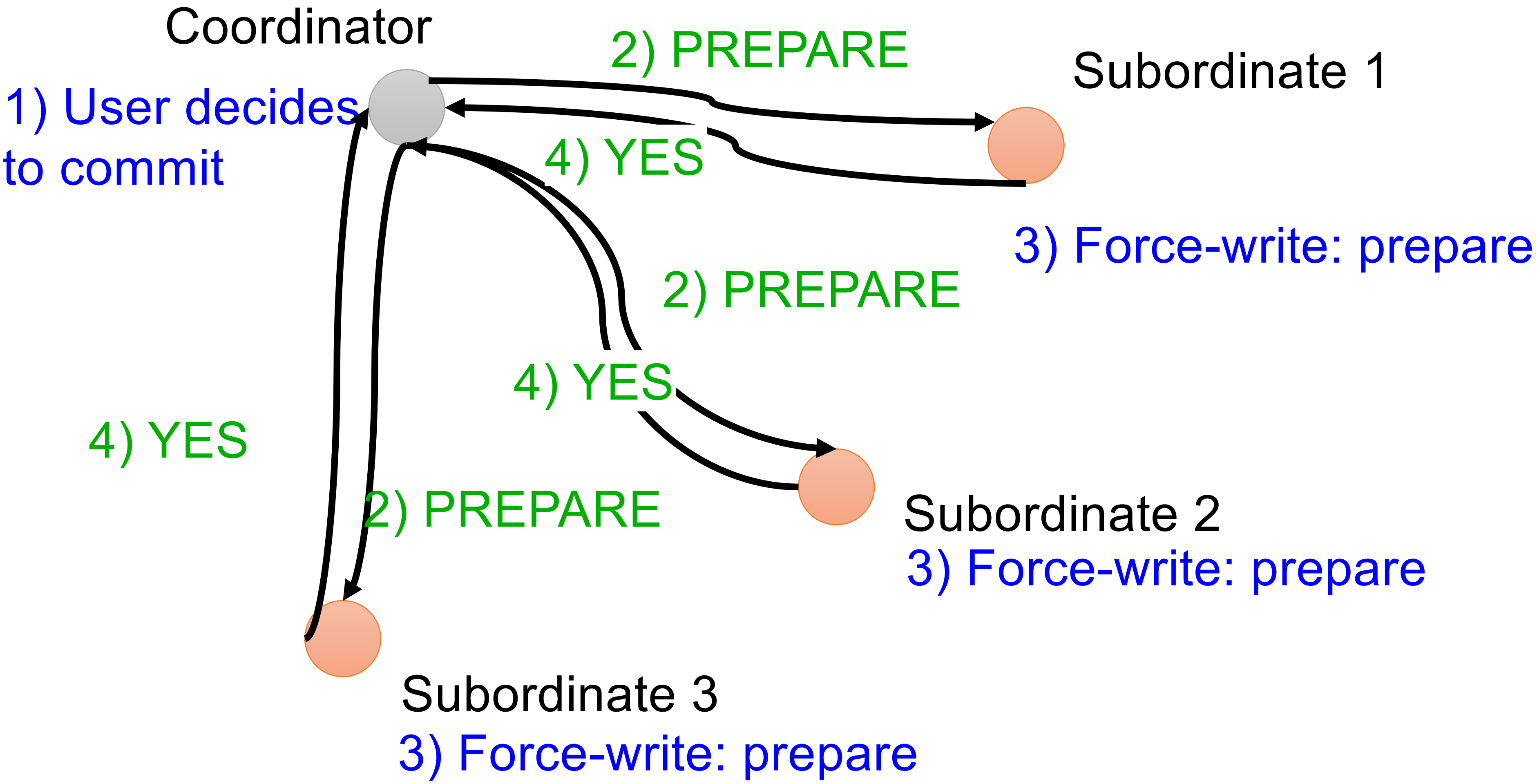
Subordinate 2

3) Force-write: prepare

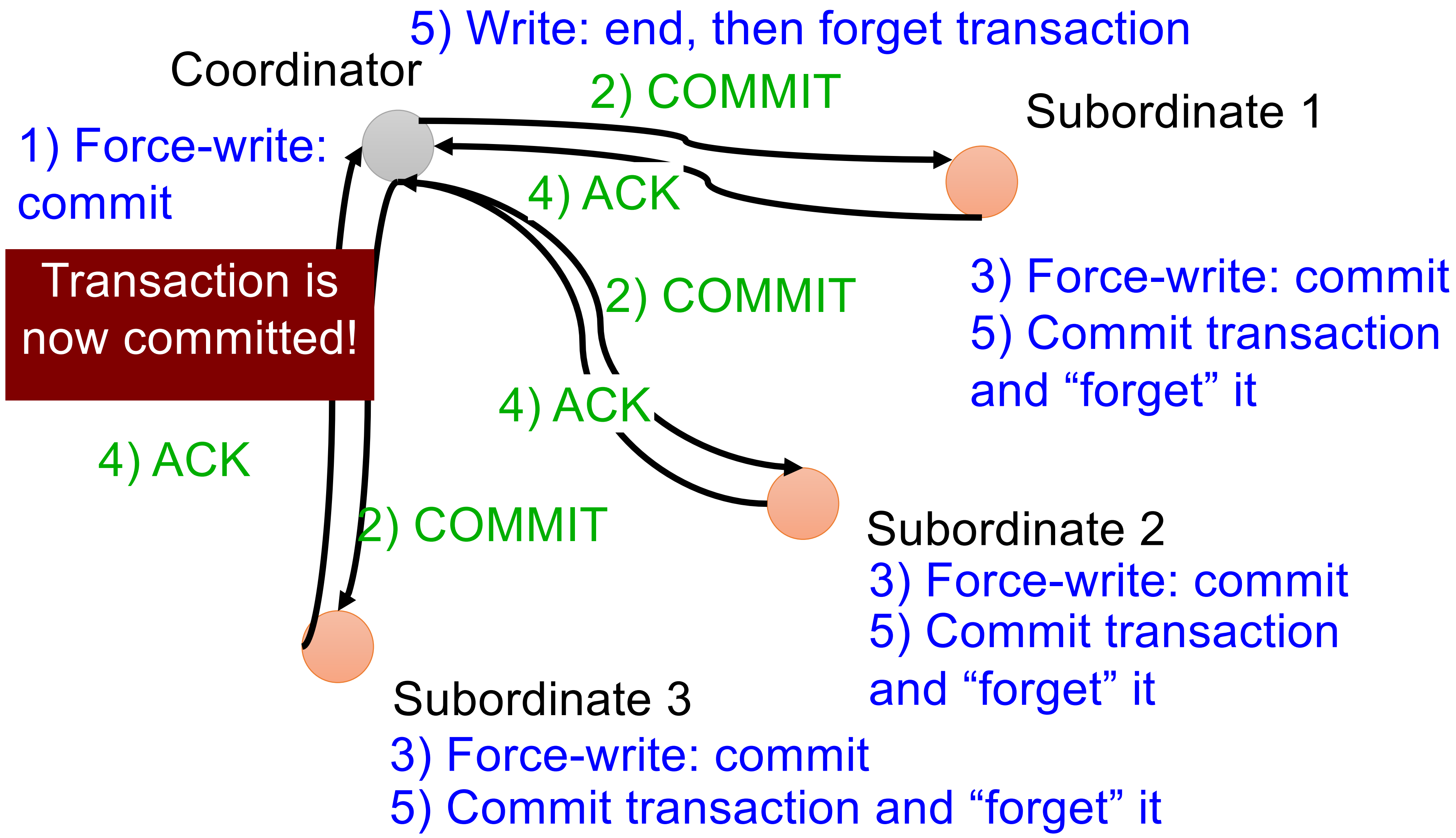
Subordinate 3

3) Force-write: prepare

2PC: Phase 1, Prepare



2PC: Phase 2, Commit



Coordinator

5) Write: end, then forget transaction

1) Force-write: commit

Transaction is now committed!

2) COMMIT

4) ACK

Subordinate 1

3) Force-write: commit
5) Commit transaction and “forget” it

2) COMMIT

4) ACK

Subordinate 2

3) Force-write: commit
5) Commit transaction and “forget” it

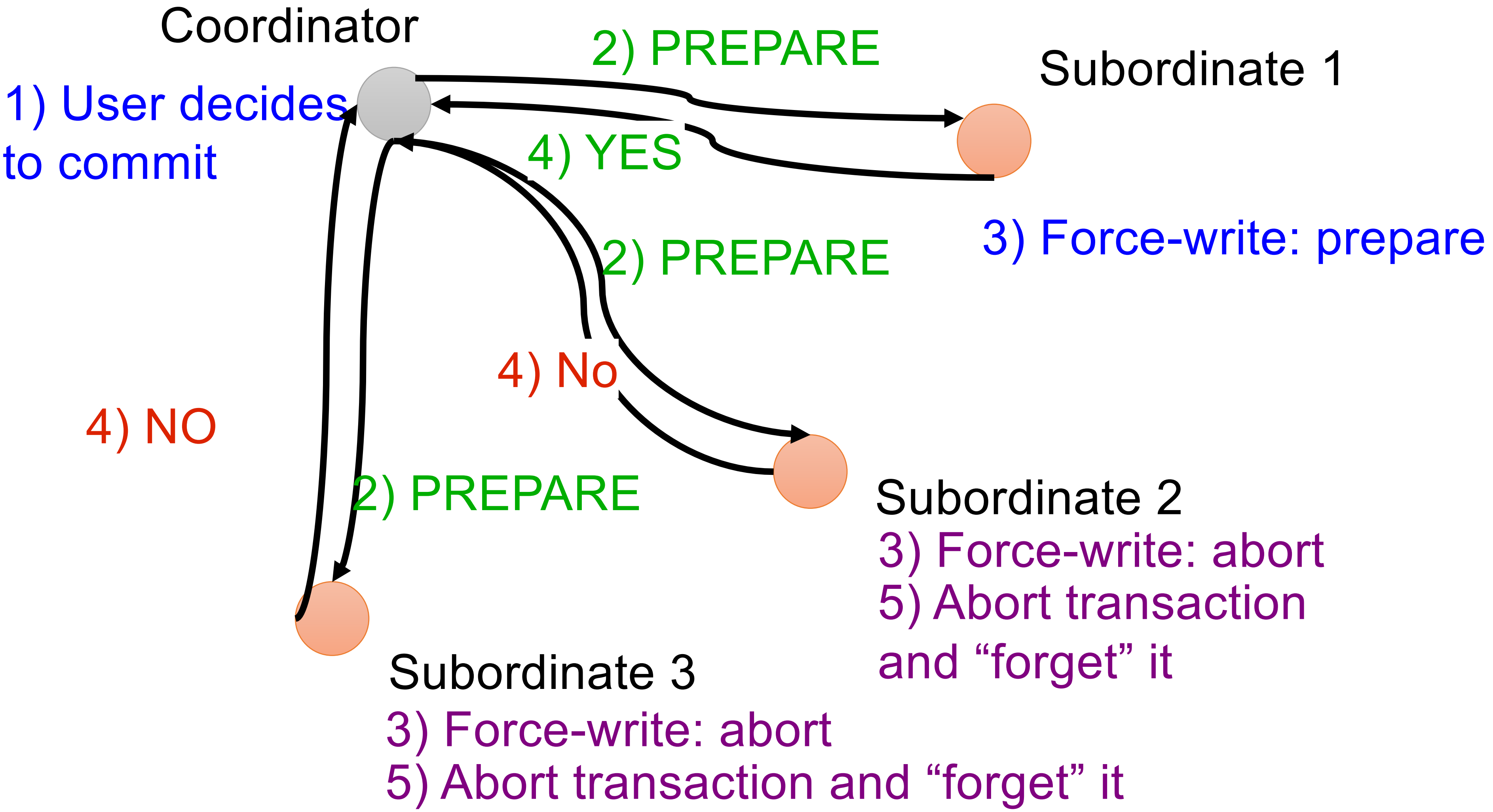
4) ACK

2) COMMIT

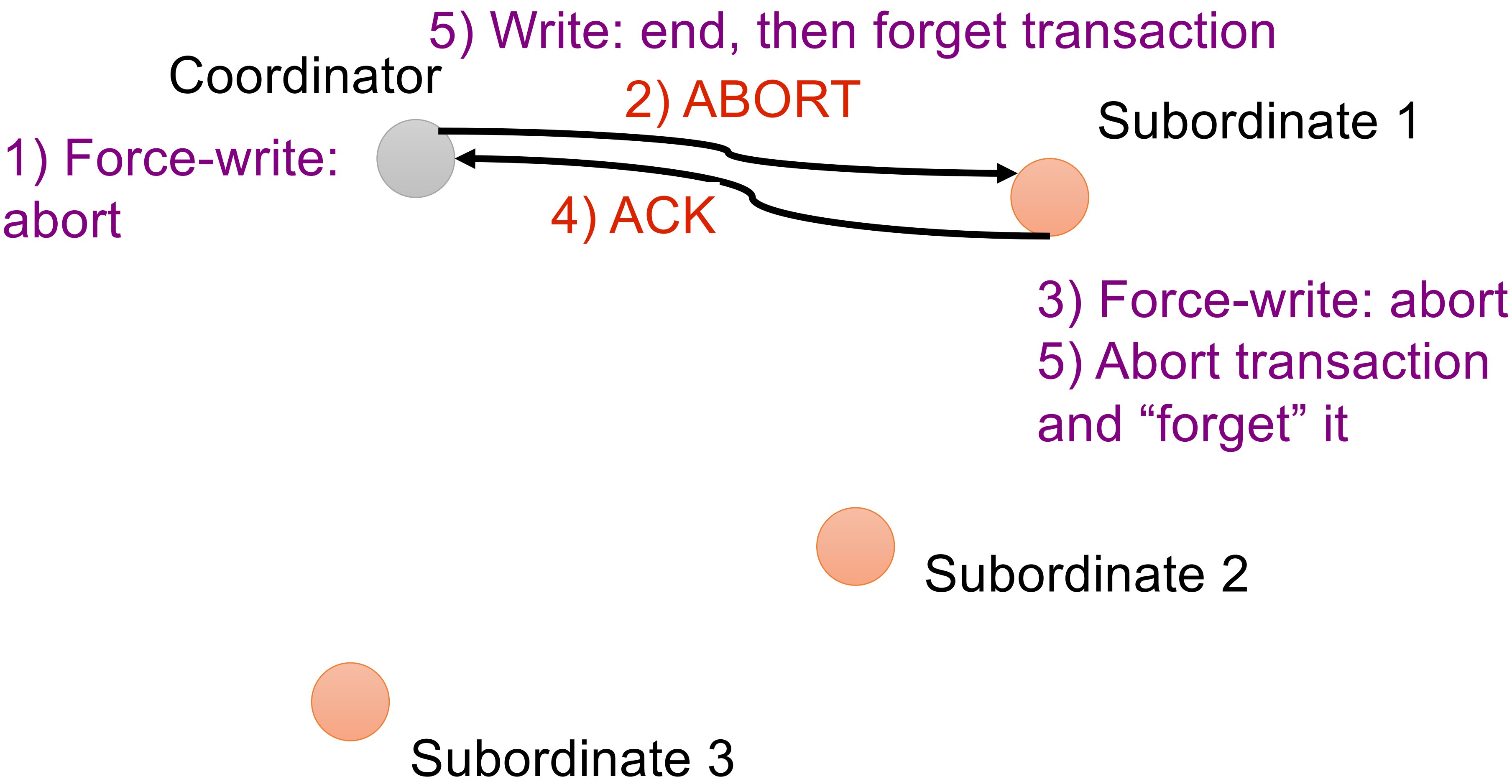
Subordinate 3

3) Force-write: commit
5) Commit transaction and “forget” it

2PC with Abort – Phase 1



2PC with Abort – Phase 2



5) Write: end, then forget transaction

Coordinator

1) Force-write: abort

2) ABORT

4) ACK

Subordinate 1

3) Force-write: abort
5) Abort transaction and "forget" it

Subordinate 2

Subordinate 3

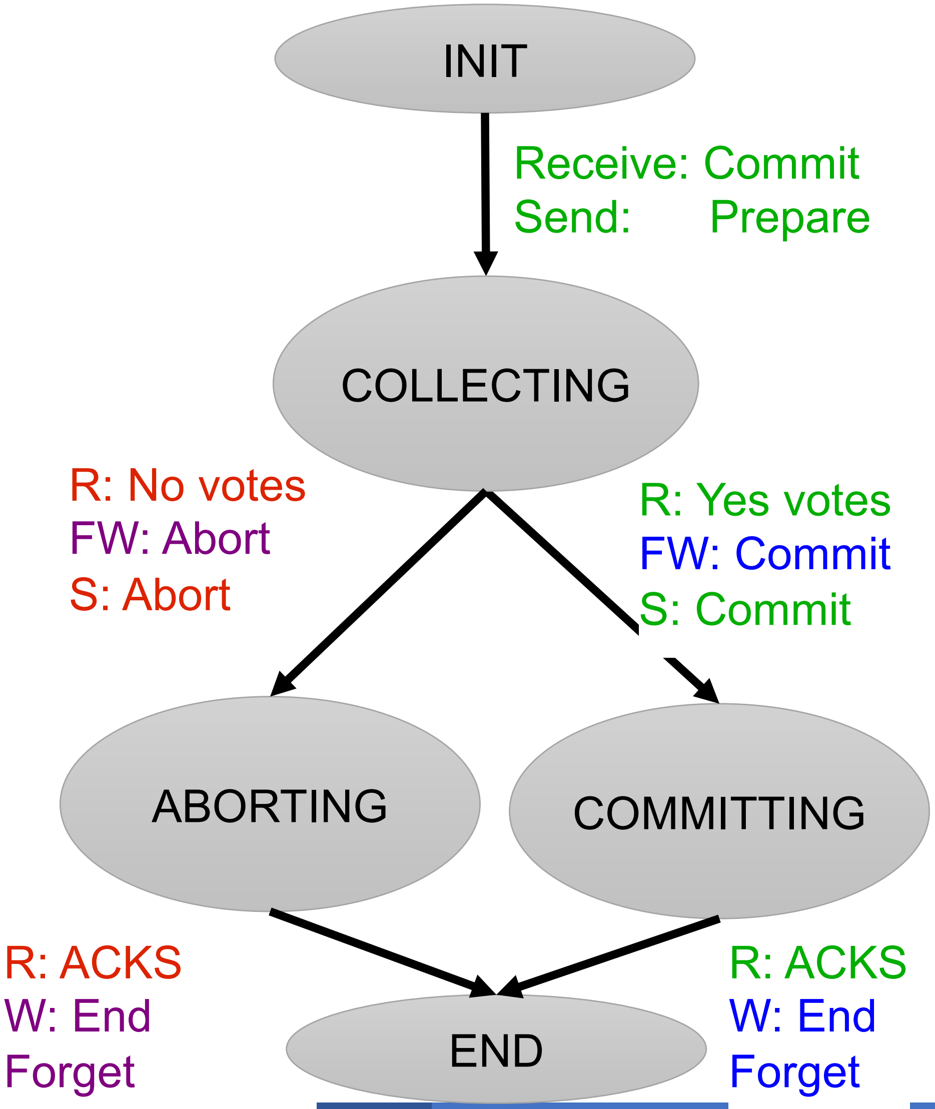
Recap

- Phase 1, Prepare: collect votes
  - What if no response? Presume abort

- Phase 2, send decision commit/abort
  - Wait for ack then write END and forget

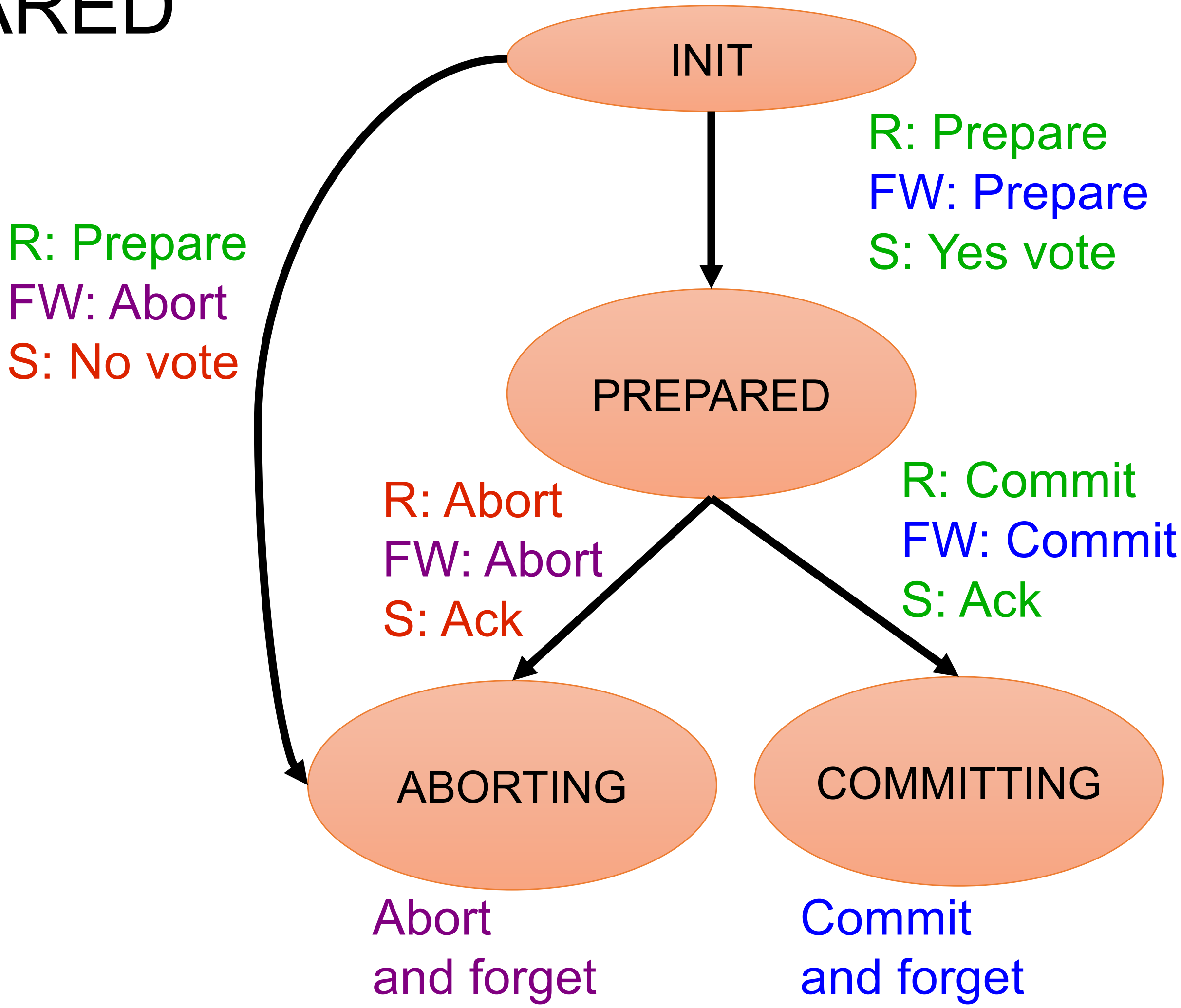
Coordinator State Machine

- All states involve waiting for messages



Subordinate State Machine

- INIT and PREPARED involve waiting



Handling Site Failures

What to do if there is no response

- Approach 1: no site failure detection
  - Subordinate can only do retrying & blocking
- Approach 2: timeouts, since unilateral abort is ok
  - Subordinate: init state: can timeout;
    prepared state is still blocking
  - Coordinator: collecting state can timeout
    committing state is blocking
- 2PC is a blocking protocol

Recovery

A subordinate fails. During recovery:

- If the last entry in the log is <COMMIT T> then the transaction is committed: REDO

Recovery

A subordinate fails. During recovery:

- If the last entry in the log is <COMMIT T> then the transaction is committed: REDO

- If the last entry in the log is <ABORT T>

Recovery

A subordinate fails. During recovery:

- If the last entry in the log is <COMMIT T> then the transaction is committed: REDO
- If the last entry in the log is <ABORT T> then the transaction is aborted: UNDO

Recovery

A subordinate fails. During recovery:

- If the last entry in the log is <COMMIT T> then the transaction is committed: REDO
- If the last entry in the log is <ABORT T> then the transaction is aborted: UNDO
- If no COMMIT/ABORT/PREPARE is found

Recovery

A subordinate fails. During recovery:

- If the last entry in the log is <COMMIT T> then the transaction is committed: REDO
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- If no COMMIT/ABORT/PREPARE is found, then presume ABORT (why is this OK?)

Recovery

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- If no COMMIT/ABORT/PREPARE is found, then presume ABORT (why is this OK?)
- If the last entry is <PREPARE T> then it's hard:

Recovery

A subordinate fails. During recovery:

- If the last entry in the log is <COMMIT T> then the transaction is committed: REDO
- If the last entry in the log is <ABORT T> then the transaction is aborted: UNDO
- If no COMMIT/ABORT/PREPARE is found, then presume ABORT (why is this OK?)
- If the last entry is <PREPARE T> then it's hard: must re-contact coordinator to find out whether ABORT or COMMIT

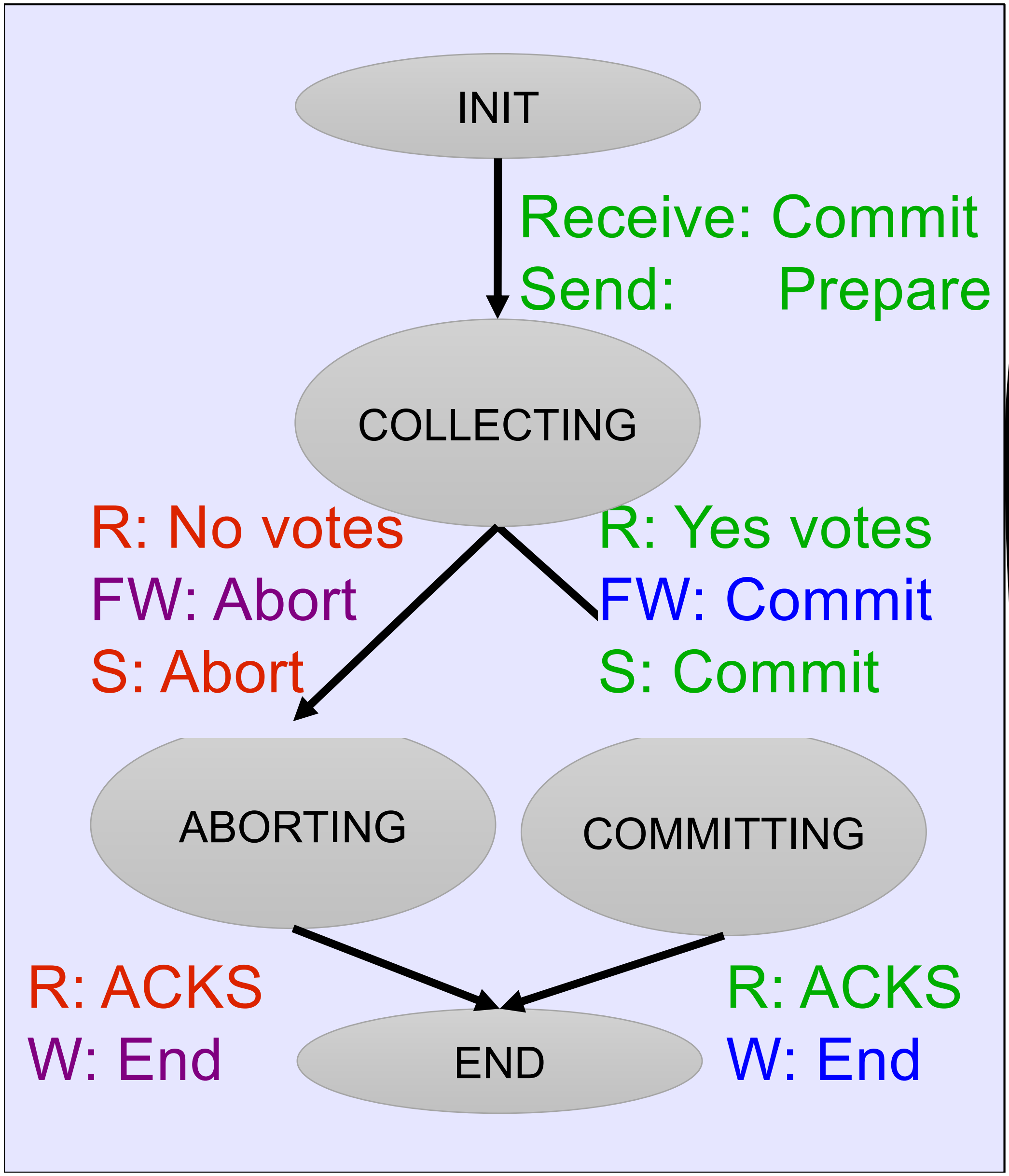
Observations

- Coordinator keeps transaction in transactions table until it receives all acks
  - To ensure subordinates know to commit or abort
  - So acks enable coordinator to “forget” about transaction
- After crash, if recovery process finds no log records for a transaction, the transaction is presumed to have aborted
- Read-only subtransactions: no changes ever need to be undone nor redone

Presumed Abort Protocol

- Optimization goals
  - Fewer messages and fewer force-writes
- Principle
  - If nothing known about a transaction, assume ABORT
- Aborting transactions need no force-writing
- Avoid log records for read-only transactions
  - Reply with a READ vote instead of YES vote

2PC State Machines (repeat)



INIT

Receive: Commit
Send: Prepare

COLLECTING

R: No votes
FW: Abort
S: Abort

R: Yes votes
FW: Commit
S: Commit

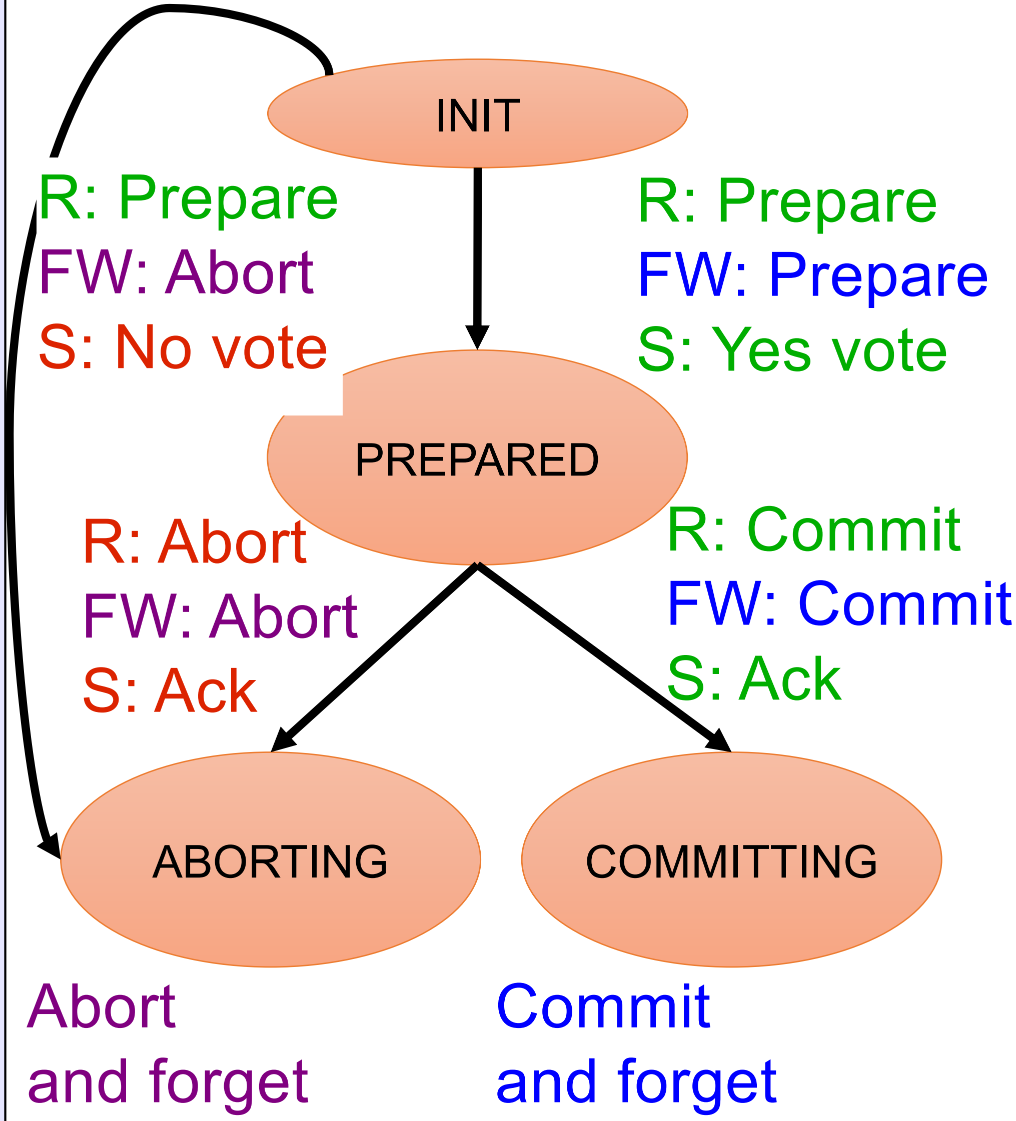
ABORTING

COMMITTING

R: ACKS
W: End

R: ACKS
W: End

END



INIT

R: Prepare
FW: Abort
S: No vote

R: Prepare
FW: Prepare
S: Yes vote

PREPARED

R: Abort
FW: Abort
S: Ack

R: Commit
FW: Commit
S: Ack

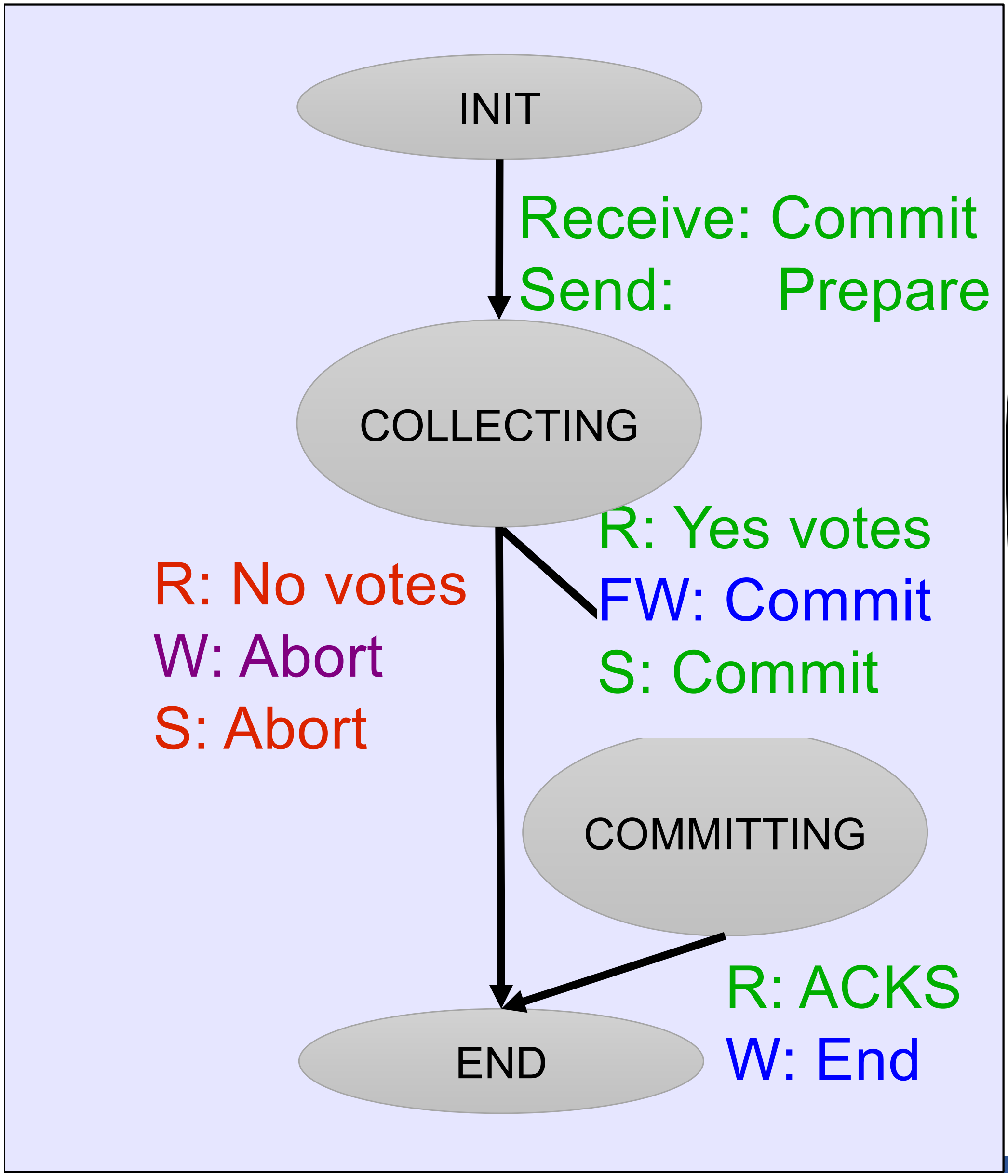
ABORTING

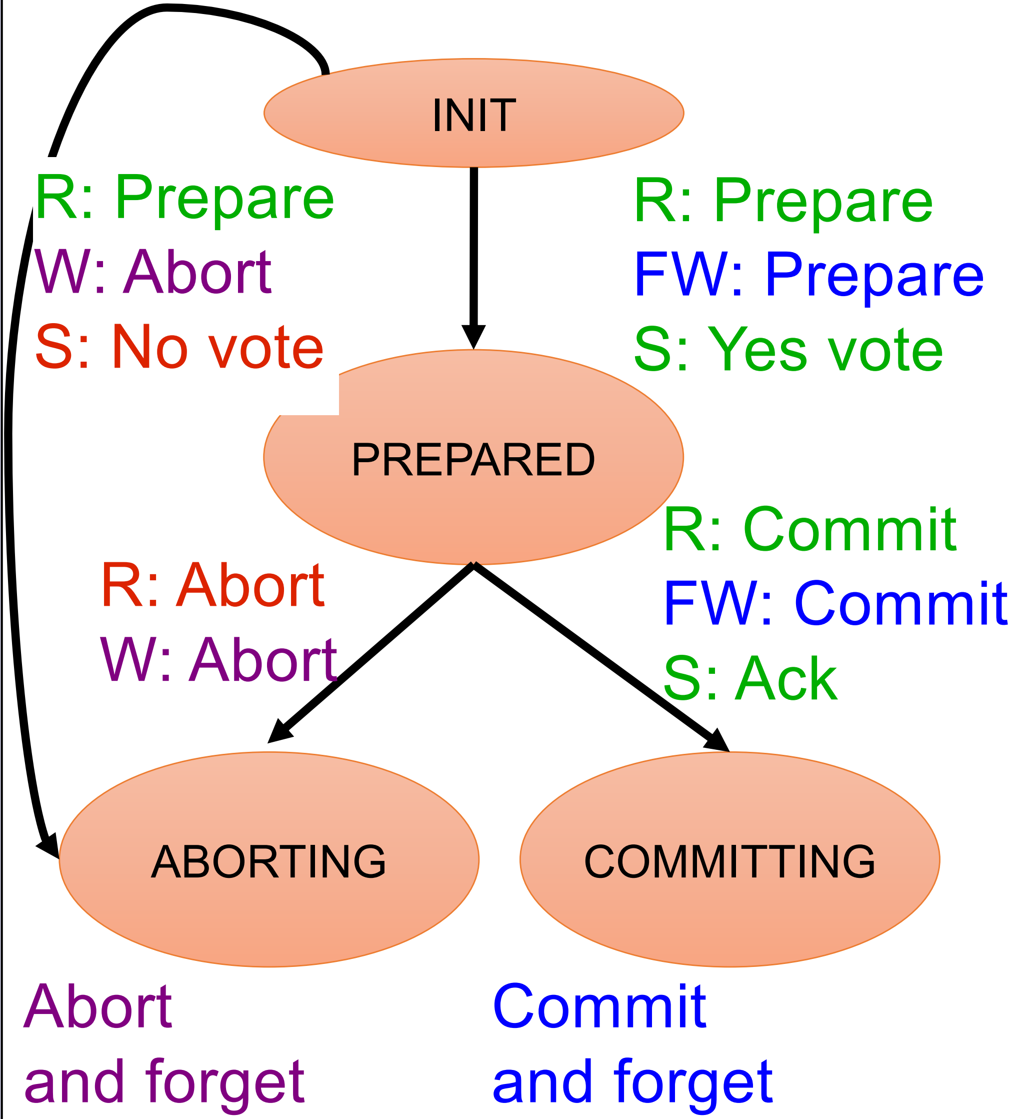
COMMITTING

Abort
and forget

Commit
and forget

Presumed Abort State Machines





Summary: Two-Phase Commit Protocol

- One coordinator and many subordinates
  - Phase 1: prepare
    - All subordinates must flush tail of write-ahead log to disk before ack
    - Must ensure that if coordinator decides to commit, they can commit!
  - Phase 2: commit or abort
  - Log records for 2PC include transaction and coordinator ids
  - Coordinator also logs ids of all subordinates

- Principle
  - Whenever a process makes a decision: vote yes/no or commit/abort
  - Or whenever a subordinate wants to respond to a message: ack
  - First force-write a log record (to make sure it survives a failure)
  - Only then send message about decision

- "Forget" completed transactions at the very end
  - Once synchronized, or transaction has committed or aborted, all nodes can stop logging any more information about that transaction

Discussion

- Data replication: simple case of distributed TXN: ensure that all replicas performed the update
- But 2PC is slow: waiting for the slowest link
- Major shortcoming: need reliable coordinator
- Paxos: gives up the coordinator, even slower…

- NoSQL: give up strong consistency (i.e. ACID)
- Mostly for data replication:“eventual consistency”
- Programming nightmare: how to write a TXN?