Transactions

CS 475, Spring 2018
Concurrent & Distributed Systems

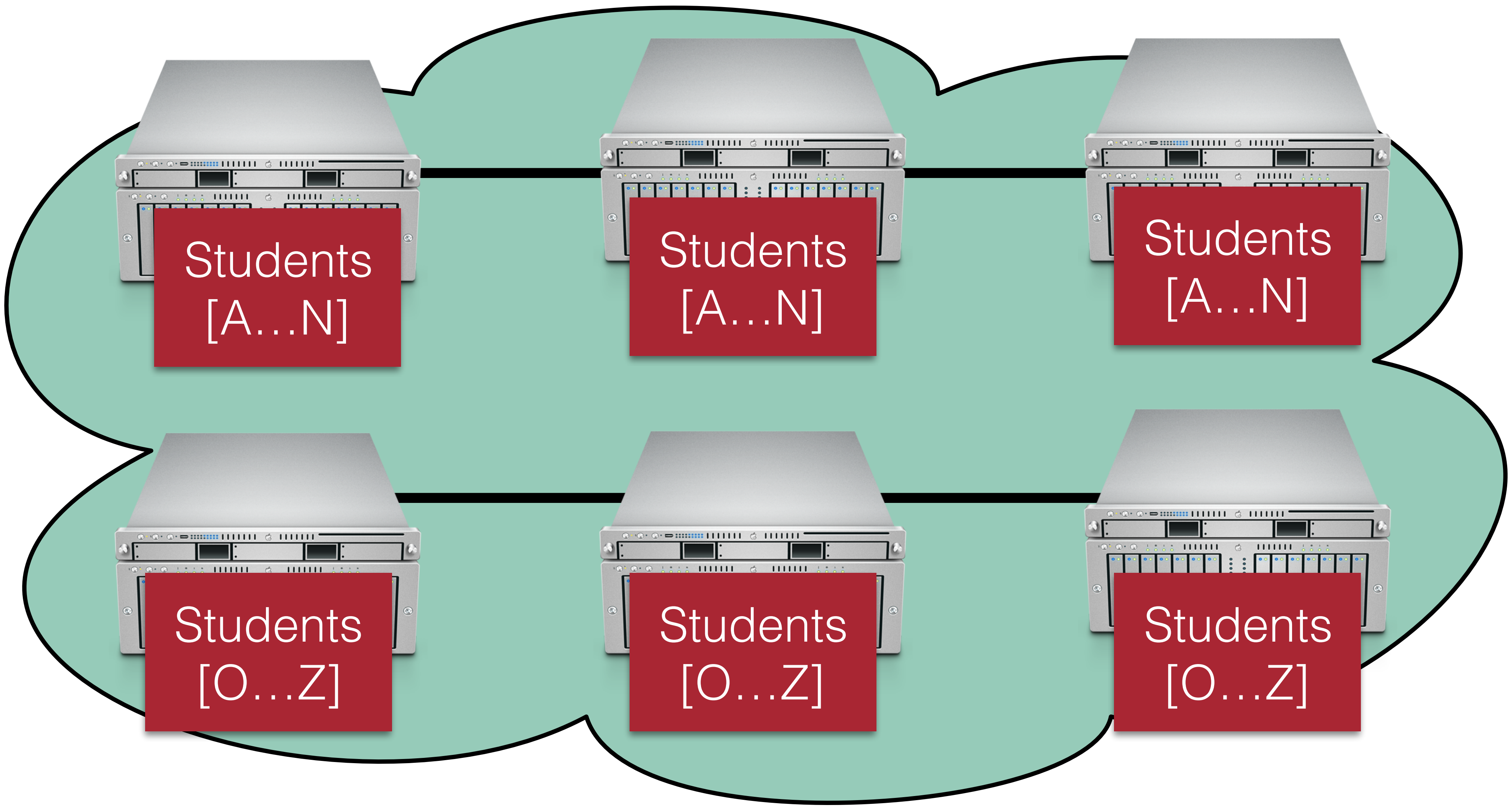
GEORGE MASON UNIVERSITY

Review: Strawman Sharding Scheme

In this class:

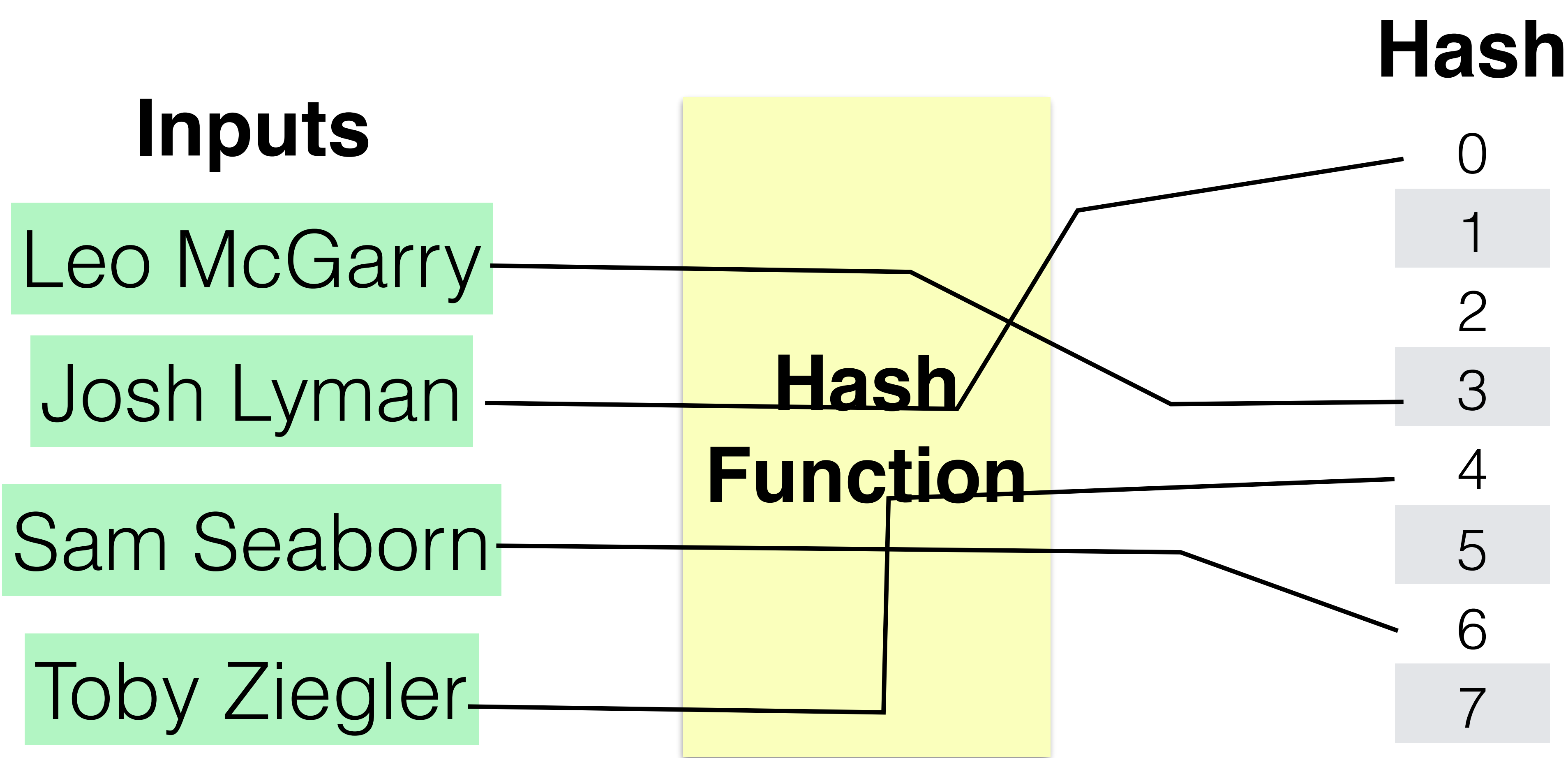
40 students

16 students



Review: Hashing

- Compresses data: maps a variable-length input to a fixed-length output
- Relatively easy to compute
- Example:



Review: Consistent Hashing

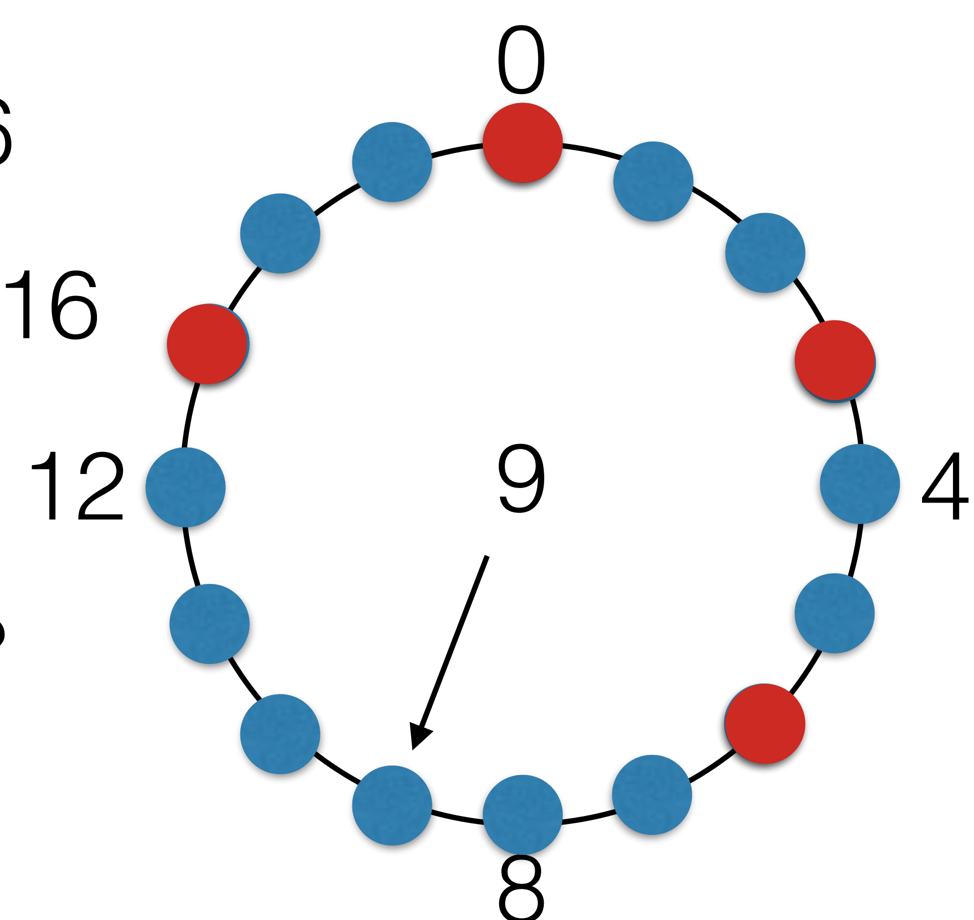
- Construction:
  - Assign each of C hash buckets to random points on mod 2^n circle, where hash key size = n
  - Map object to pseudo-random position on circle
  - Hash of object is the closest clockwise bucket

Example: hash key size is 16

Each is a value of hash % 16

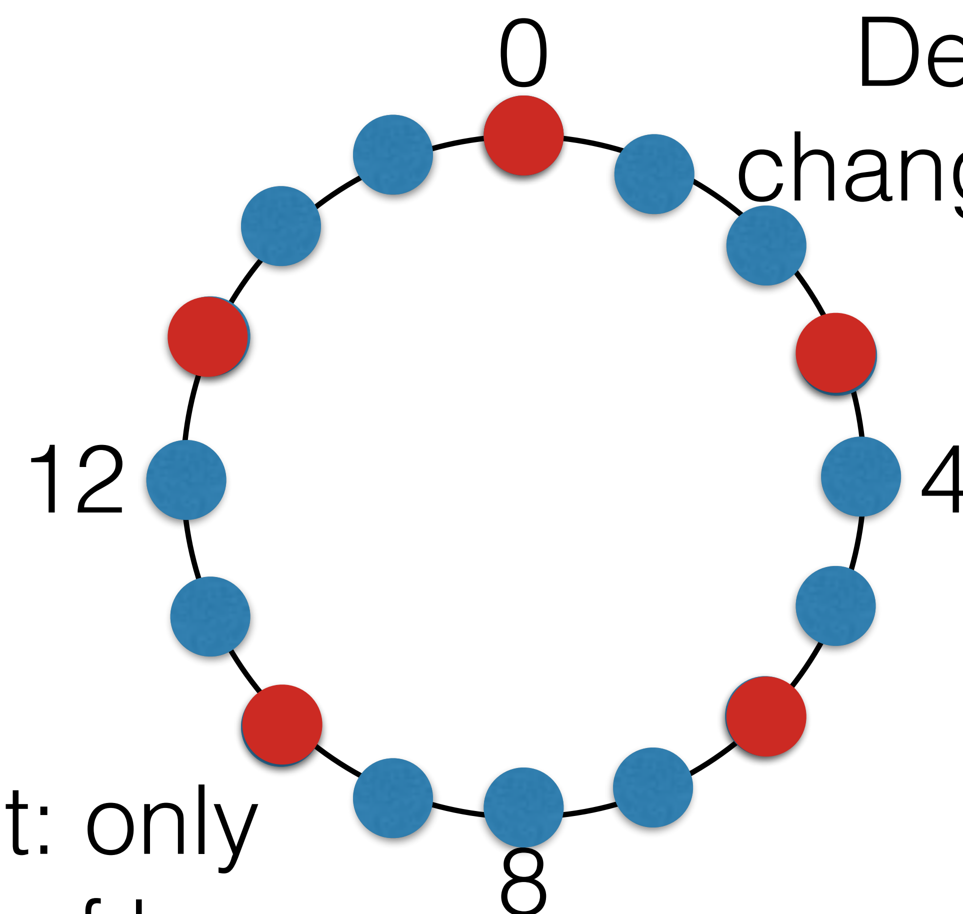
Each is a bucket

Example: bucket with key 9?



Review: Consistent Hashing

It is relatively smooth: adding a new bucket doesn't change that much



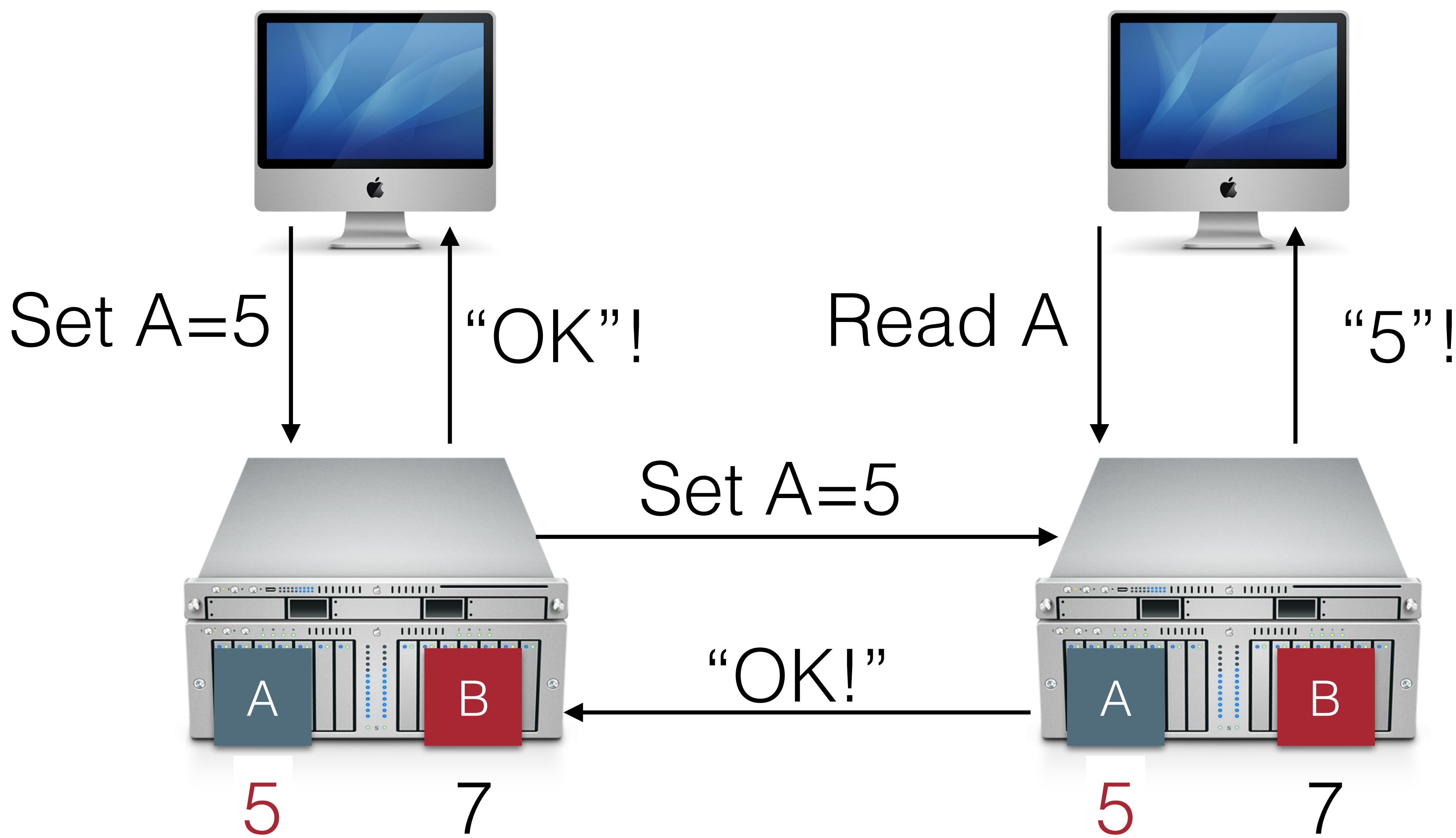
Delete bucket: only changes location of keys 1,2,3

Add new bucket: only changes location of keys 7,8,9,10

Announcements

- HW4 is out!
  - http://www.jonbell.net/gmu-cs-475-spring-2018/homework-4/
- Today:
  - Beginning to talk about fault tolerance
  - Agreement & transactions in distributed systems
- Reminder, today:
  - Video lecture (Prof Bell at secret meeting)

Fault Tolerance



Today: Transactions

```
boolean transferMoney(Person from, Person
to, float amount){
    if(from.balance >= amount)
    {
        from.balance = from.balance -
amount;
        to.balance = to.balance + amount;
        return true;
    }
    return false;
}
```

Assume running on a single machine:
What can go wrong here?

Transactions: Classic Example

```
boolean transferMoney(Person from, Person
to, float amount){
    if(from.balance >= amount)
    {
        from.balance = from.balance -
amount;
        to.balance = to.balance + amount;
}
```

transferMoney(P1, P2, 100)	transferMoney(P1, P2, 200)
P1.balance (200) >= 100	P2.balance (200) > 200
P1.balance = 200 - 100 = 0	
P2.balance = 200 + 100 = 300	
return true;	P1.balance = 100 - 200 = -100
	P2.balance = 300 + 200 = 500
	return true;

What's wrong here?
Need isolation (prevent overdrawing)

Transactions: Classic Example

```
boolean transferMoney(Person from, Person to,
float amount){
    synchronized(from){
        if(from.balance >= amount)
        {
            from.balance = from.balance -
amount;
            to.balance = to.balance + amount;
}
```

transferMoney(P1, P2, 100)	transferMoney(P1, P2, 200)
P1.balance (200) >= 100	
P1.balance = 200 - 100 = 100	
P2.balance = 200 + 100 = 300	
return true;	
	P1.balance <= 200
	return false;

Adding a lock: prevents accounts from being overdrawn

But: shouldn't we lock on `to` **also?**

Transactions: Classic Example

```
boolean transferMoney(Person from, Person to, 
float amount){
    synchronized(from, to){
        if(from.balance >= amount)
        {
            from.balance = from.balance - 
amount;
            to.balance = to.balance + amount;
}
```

transferMoney(P1, P2, 100)	**transferMoney(P1, P2, 200)**
P1.balance (200) >= 100	
P1.balance = 200 - 100 = 0	
P2.balance = 200 + 100 = 300	
return true;	
	P1.balance <= 200
	return false;

Locking on both from, to at same time

Transactions: Classic Example

```
boolean transferMoney(Person from, Person to, 
float amount){
    synchronized(from, to){
        if(from.balance >= amount)
        {
            from.balance = from.balance - 
amount;
            to.balance = to.balance + amount;
}
```

transferMoney(P1, P2, 100)	**transferMoney(P1, P2, 200)**
P1.balance (200) >= 100	
P1.balance = 200 - 100 = 0	
	P1.balance <= 200
	return false;

Problem: **`P1.balance`** was deducted **`P2.balance`** not incremented! ("Atomicity violation")

Transactions

- How can we provide some consistency guarantees **across operations**
- Transaction: unit of work (grouping) of operations
  - Begin transaction
  - Do stuff
  - Commit OR abort

Properties of Transactions

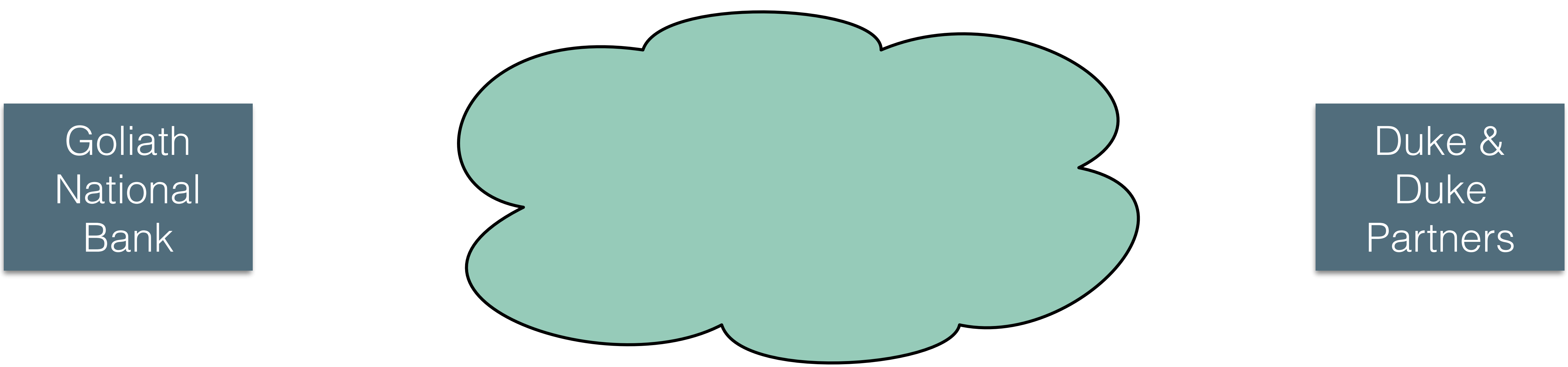
- Traditional properties: ACID
- **Atomicity**: transactions are “all or nothing”
- **Consistency**: Guarantee some basic properties of data; each transaction leaves the database in a valid state
- **Isolation**: Each transaction runs as if it is the only one; there is some valid serial ordering that represents what happens when transactions run concurrently
- **Durability**: Once committed, updates cannot be lost despite failures

Distributed Transactions

- What we are most interested in
- What happens if you need to coordinate e.g. transfers between multiple banks?

```
transferMoney(“from”: Barney@Goliath National,
     “to”: Mortimer@ Duke&Duke, “amount”=$1)

Initially: Barney.balance= $10000, Mortimer.balance=$10000
```



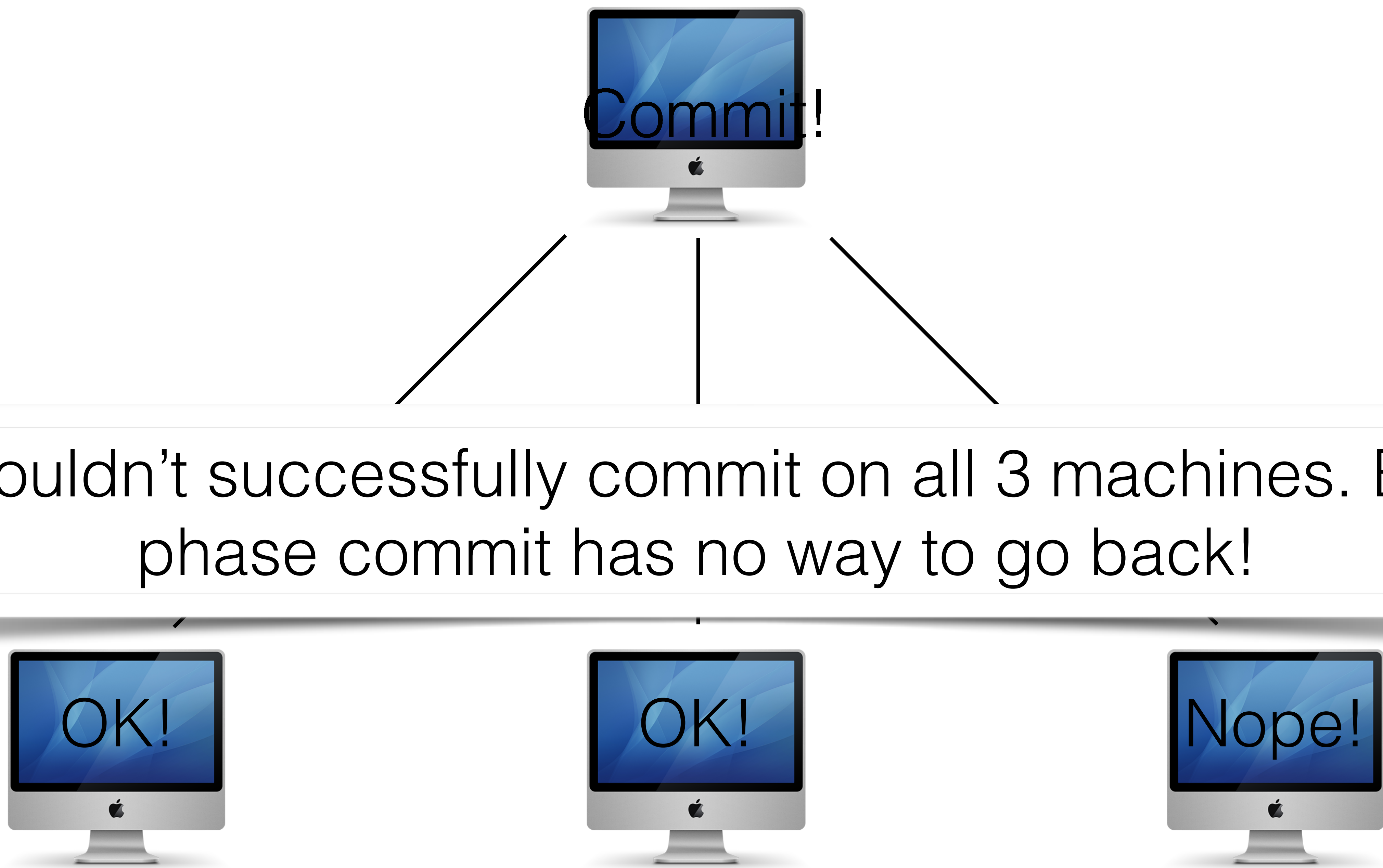
Distributed Transactions

- System model: data stored in multiple locations, multiple servers participating in a single transaction. One server pre-designated "coordinator"
- Failure model: messages can be delayed or lost, servers might crash, but have persistent storage to recover from

Distributed Transactions

- Coordinator: Begins a transaction
  - Assigns a unique transaction ID
  - Responsible for commit + abort
  - In principle, any client can be the coordinator, but all participants need to agree on who is the coordinator
- Participants: everyone else who has the data used in the transaction

1-Phase Commit (no transactions)



We couldn't successfully commit on all 3 machines. But 1-phase commit has no way to go back!

1-Phase Non-Transaction Commit

- Naive protocol: coordinator broadcasts out "commit!" continuously until participants all say "OK!"
- Problem: what happens when a participants fails during commit? How do the other participants know that they shouldn't have really committed and they need to abort?

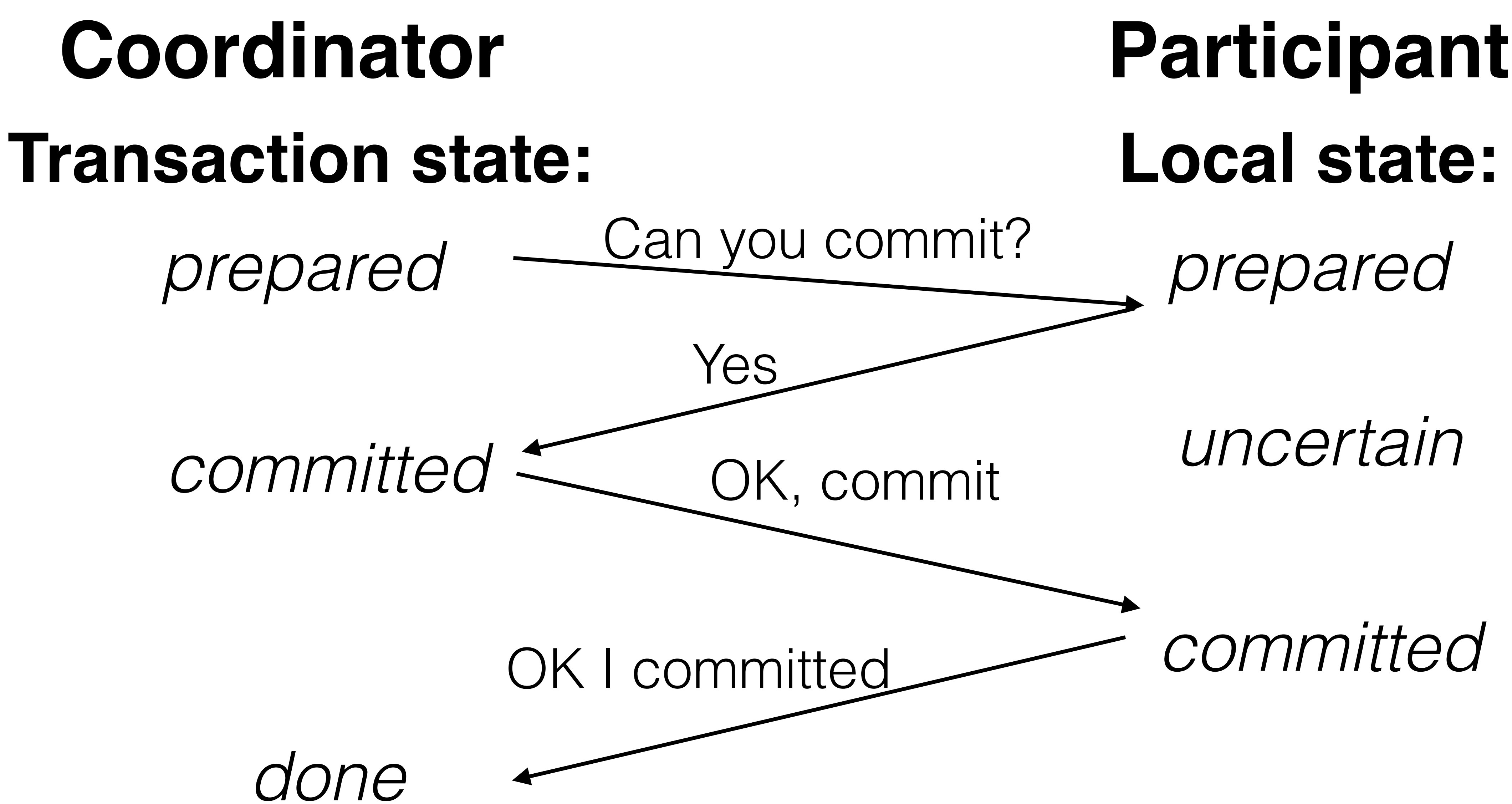
2-Phase Commit

- Separate the commit into two steps:
- 1: Voting
  - Each participant prepares to commit and votes of whether or not it can commit
- 2: Committing
  - Once voting succeeds, every participant commits or aborts

2PC: Voting

- Coordinator asks each participant: can you commit for this transaction?
- Each participant prepares to commit BEFORE answering yes
  - e.g. save transaction to disk for later recovery
  - Can not abort after saying yes
- Outcome of transaction is unknown until the coordinator receives all votes and says “do abort” or “do commit”

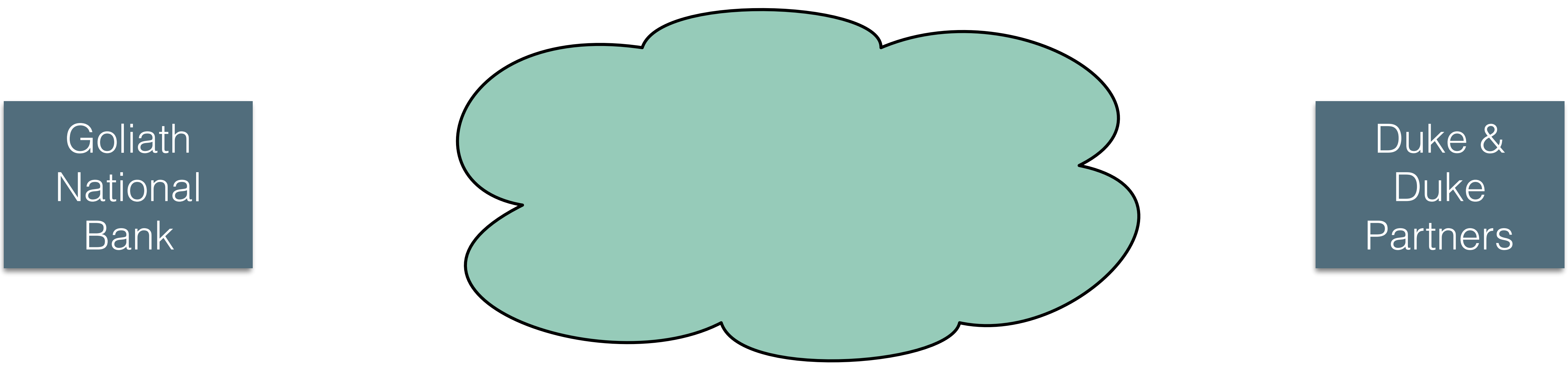
2PC Event Sequence



2PC Example

```
transferMoney("from": Barney@Goliath National,
     "to": Mortimer@ Duke&Duke, "amount"=$1)

Initially: Barney.balance= $10000, Mortimer.balance=$10000
```



Requirements:

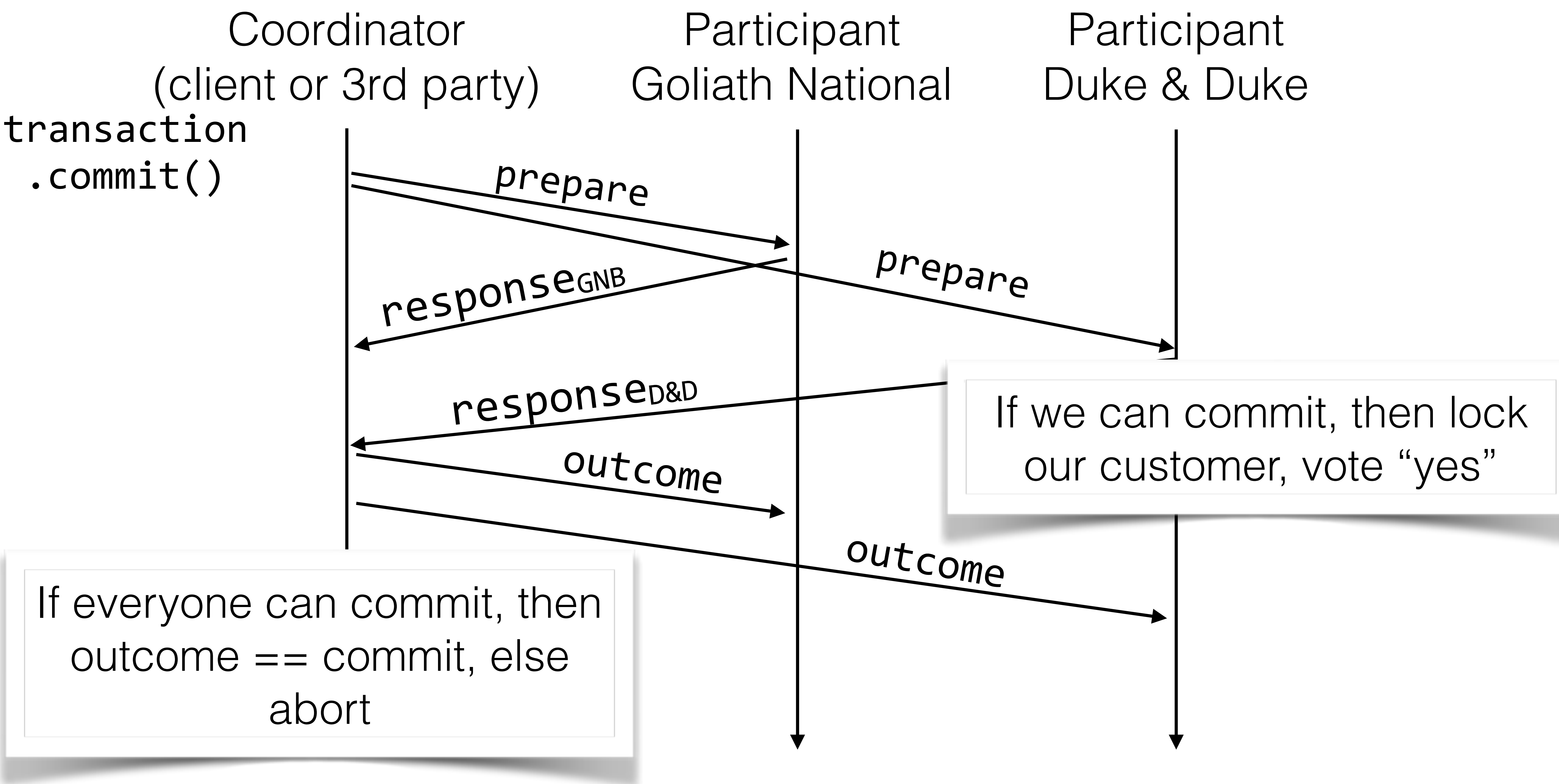
1. Atomicity (transfer happens or doesn't)
2. Concurrency control (serializability)

2PC Example

For simplicity, let's assume transfer is:

```
int transfer(src, dst, amt) {
    transaction = begin();
    src.bal -= amt;
    dst.bal += amt;
    return transaction.commit();
}
```

2PC Example



Coordinator
(client or 3rd party)
Participant
Goliath National
Participant
Duke & Duke
transaction
.commit()
prepare
prepare
responseGNB
responseD&D
outcome
outcome
If we can commit, then lock our customer, vote "yes"
If everyone can commit, then outcome == commit, else abort

Fault Recovery

- How do we recover transaction state if we crash?
- Goal:
  - Committed transactions are not lost
  - Non-committed transactions either continue where they were or aborted

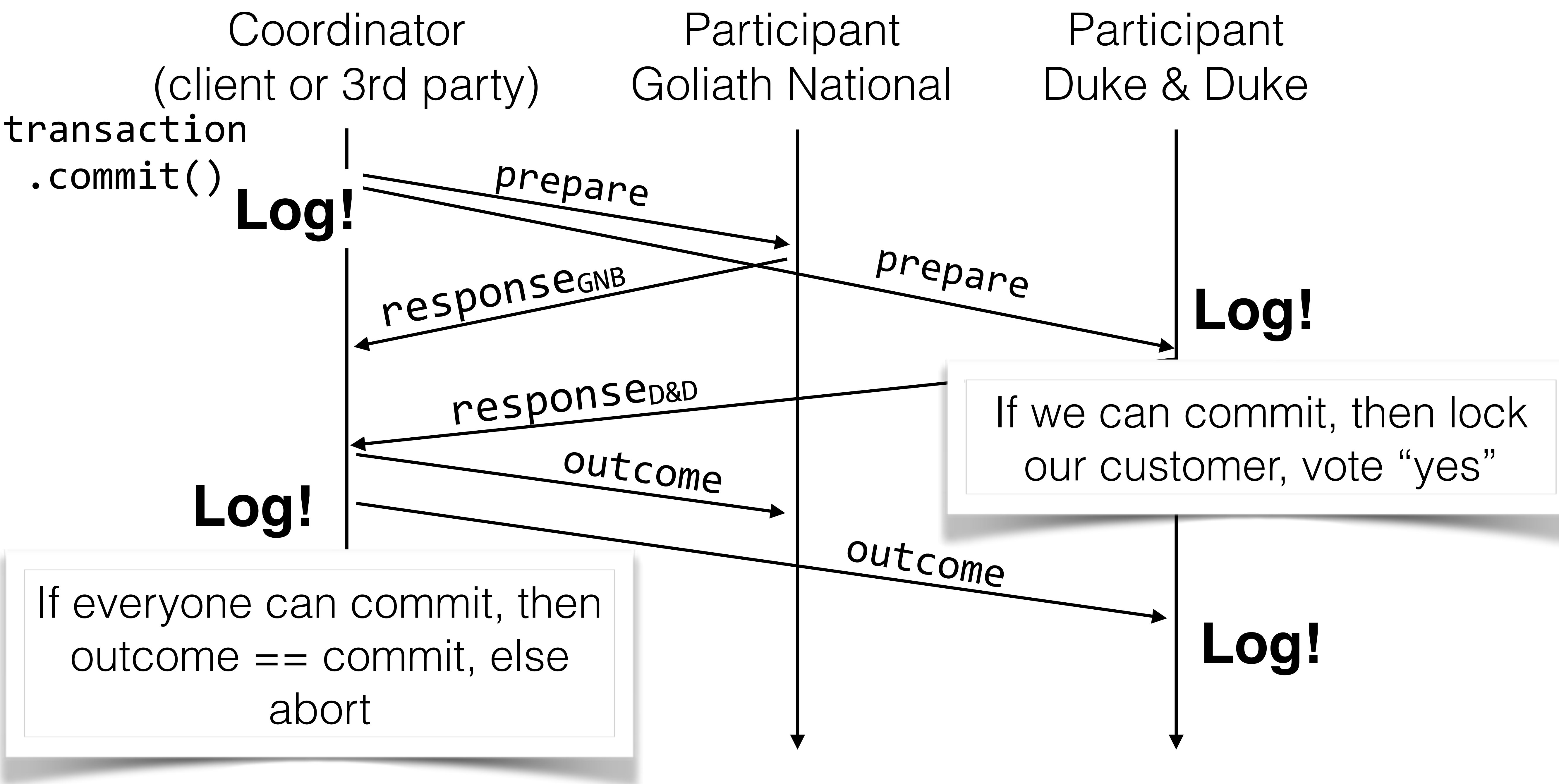
Recovery in 2PC

- What to log?
  - State changes in protocol
  - Participants: prepared; uncertain; committed/aborted
  - Coordinator: prepared; committed/aborted; done
  - These messages are idempotent - can be repeated
- Recovery depends on failure
  - Crash + reboot + recover
  - Timeout + recover

Crash + Reboot Recovery

- Nodes can’t back out once commit is decided
- If coordinator crashes just AFTER deciding “commit”
  - Must remember this decision, replay
- If participant crashes after saying “yes, commit”
  - Must remember this decision, replay
- Hence, all nodes need to log their progress in the protocol

2PC Example with logging



Recovery on Reboot

- If coordinator finds no “commit” message on disk, abort
- If coordinator finds “commit” message, commit
- If participant finds no “yes, ok” message, abort
- If participant finds “yes, ok” message, then replay that message and continue protocol

Timeouts in 2PC

- Example:
  - Coordinator times out waiting for Goliath National Bank's response
  - Bank times out waiting for coordinator's outcome message
- Causes?
  - Network
  - Overloaded hosts
  - Both are very realistic…

Coordinator Timeouts

- If coordinator times out waiting to hear from a bank
  - Coordinator hasn’t sent any commit messages yet
  - Can safely abort - send abort message
  - Preserves correctness, sacrifices performance (maybe didn’t need to abort!)
  - If either bank decided to commit, it’s fine - they will eventually abort

Handling Bank Timeouts

- What if the bank doesn't hear back from coordinator?
- If bank voted "no", it's OK to abort
- If bank voted "yes"
  - It can't decide to abort (maybe both banks voted "yes" and coordinator heard this)
  - It can't decide to commit (maybe other bank voted yes)
- Does bank just wait for ever?

Handling Bank Timeouts

- Can resolve SOME timeout problems with guaranteed correctness in event bank voted “yes” to commit
- Bank asks other bank for status (if it heard from coordinator)
- If other bank heard “commit” or “abort” then do that
- If other bank didn’t hear
  - but other voted “no”: both banks abort
  - but other voted “yes”: no decision possible!

2PC Timeouts

- We can solve a lot (but not all of the cases) by having the participants talk to each other
- But, if coordinator fails, there are cases where everyone stalls until it recovers
- Can the coordinator fail?… yes
- We’ll come back to this “discuss amongst yourselves” kind of transactions next week