Carnegie Mellon University

22 | Introduction to Distributed Databases

Intro to Database Systems
15-445/15-645
Fall 2019

AP
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Computer Science
Carnegie Mellon University

ADMINISTRIVIA

Homework #5: Monday Dec 3rd @ 11:59pm

Project #4: Monday Dec 10th @ 11:59pm

Extra Credit: Wednesday Dec 10th @ 11:59pm

Final Exam: Monday Dec 9th @ 5:30pm

ADMINISTRIVIA

Monday Dec 2th – Oracle Lecture
→ Shasank Chavan (VP In-Memory Databases)

Wednesday Dec 4th – Potpourri + Review
→ Vote for what system you want me to talk about.
→ https://cmudb.io/f19-systems

Sunday Nov 24th – Extra Credit Check
→ Submit your extra credit assignment early to get feedback from me.

UPCOMING DATABASE EVENTS

Oracle Research Talk

→ Tuesday December 4^{th} @ 12:00pm

→ CIC 4^{th} Floor

PARALLEL VS. DISTRIBUTED

Parallel DBMSs:

→ Nodes are physically close to each other.
→ Nodes connected with high-speed LAN.
→ Communication cost is assumed to be small.

Distributed DBMSs:

→ Nodes can be far from each other.
→ Nodes connected using public network.
→ Communication cost and problems cannot be ignored.

DISTRIBUTED DBMSs

Use the building blocks that we covered in single-node DBMSs to now support transaction processing and query execution in distributed environments.

→ Optimization & Planning
→ Concurrency Control
→ Logging & Recovery

TODAY'S AGENDA

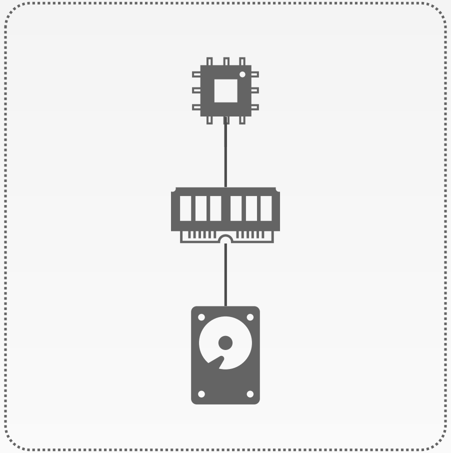
System Architectures
Design Issues
Partitioning Schemes
Distributed Concurrency Control

SYSTEM ARCHITECTURE

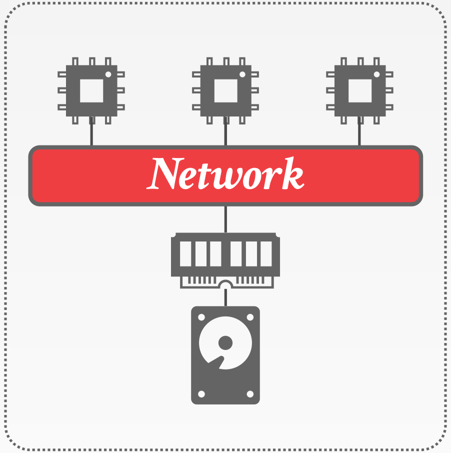
A DBMS's system architecture specifies what shared resources are directly accessible to CPUs.

This affects how CPUs coordinate with each other and where they retrieve/store objects in the database.

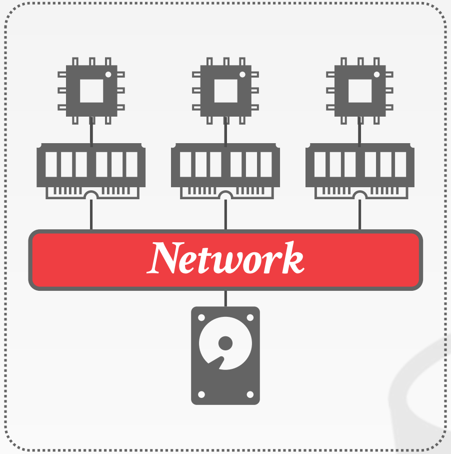
SYSTEM ARCHITECTURE



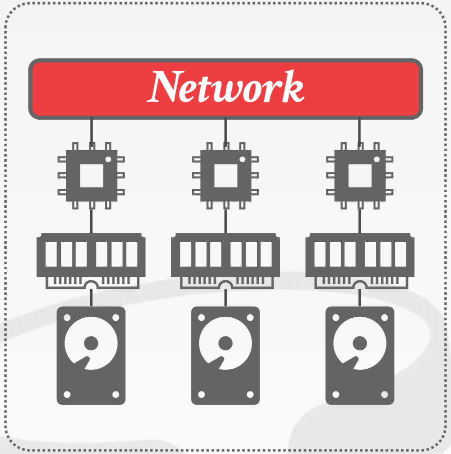
Shared Everything



Shared Memory



Shared Disk



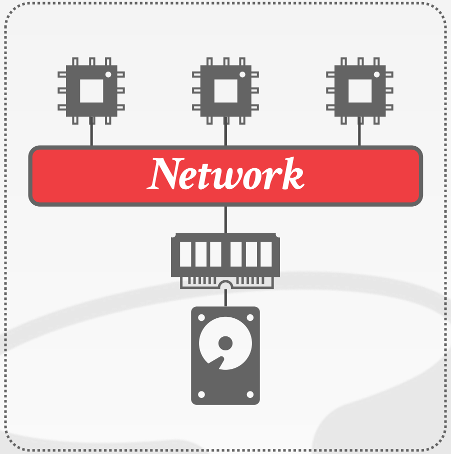
Shared Nothing

SHARED MEMORY

CPUs have access to common memory address space via a fast interconnect.

→ Each processor has a global view of all the in-memory data structures.

→ Each DBMS instance on a processor has to "know" about the other instances.

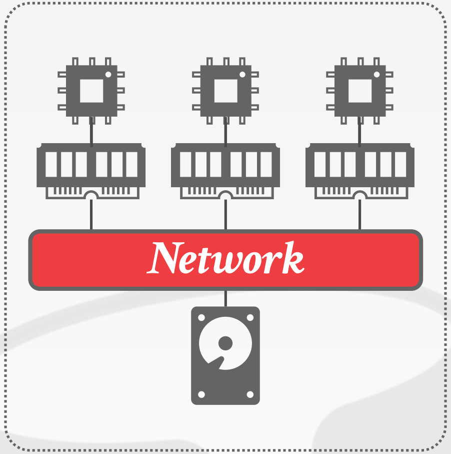


SHARED DISK

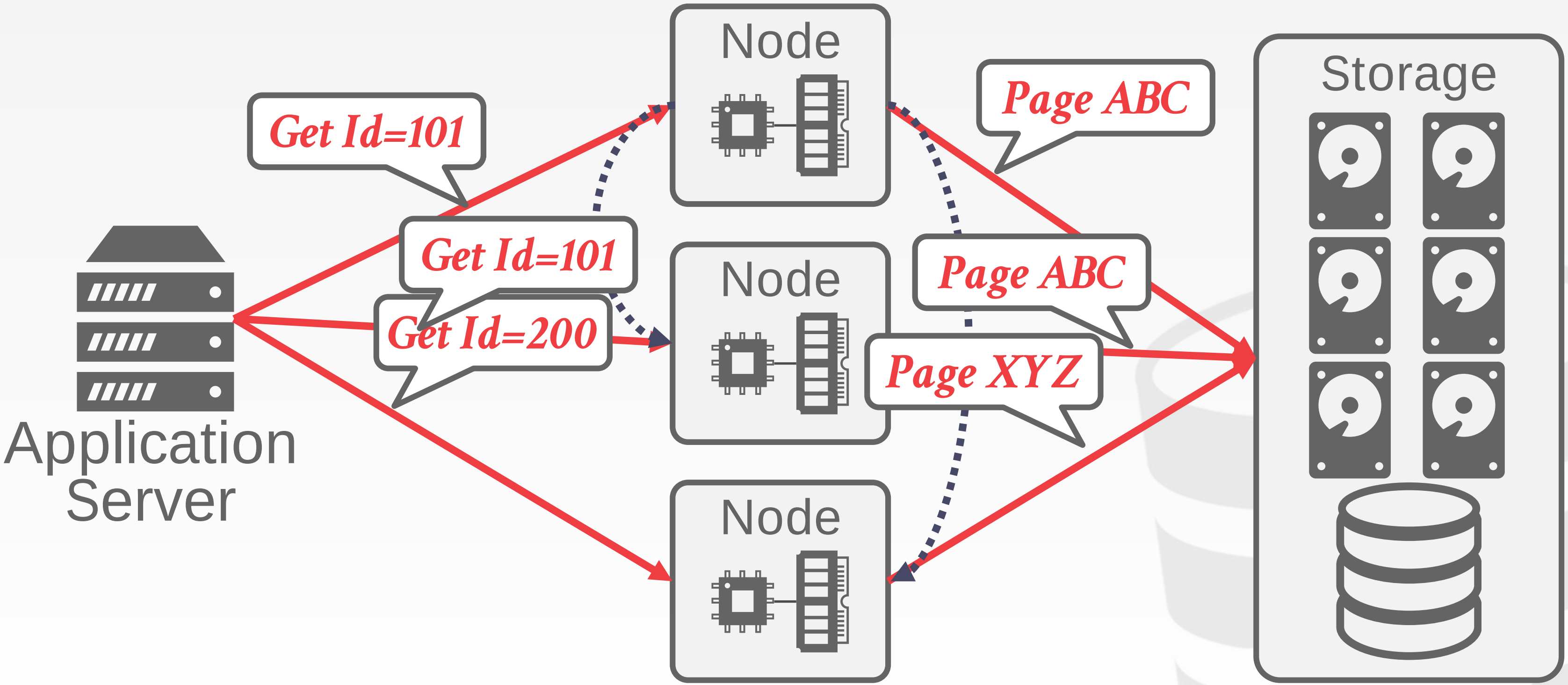
All CPUs can access a single logical disk directly via an interconnect, but each have their own private memories.

→ Can scale execution layer independently from the storage layer.

→ Must send messages between CPUs to learn about their current state.



SHARED DISK EXAMPLE

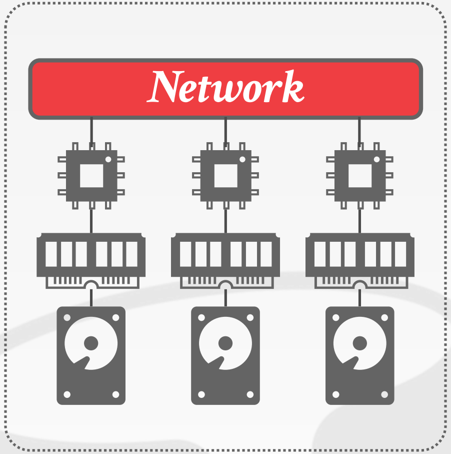


SHARED NOTHING

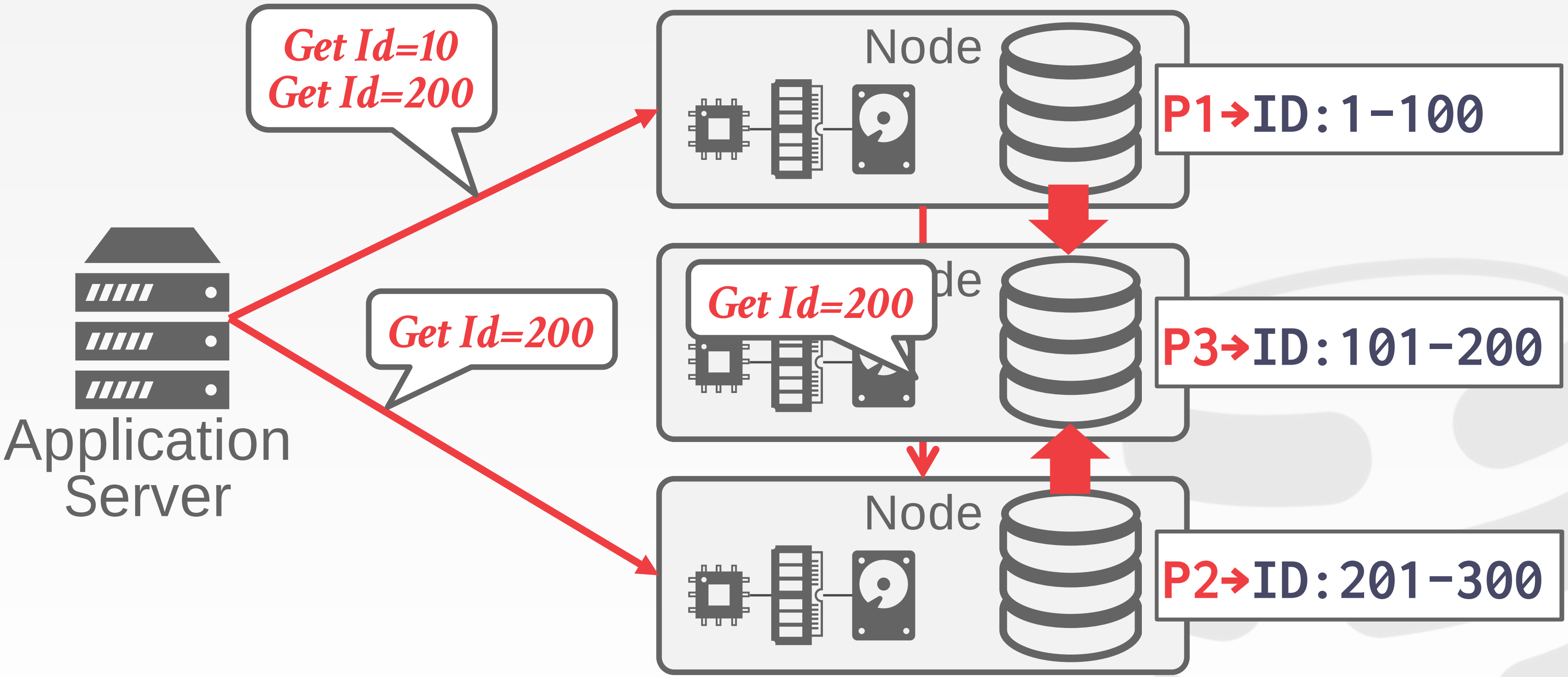
Each DBMS instance has its own CPU, memory, and disk.

Nodes only communicate with each other via network.

→ Hard to increase capacity.
→ Hard to ensure consistency.
→ Better performance & efficiency.



SHARED NOTHING EXAMPLE



EARLY DISTRIBUTED DATABASE SYSTEMS

MUFFIN – UC Berkeley (1979)

SDD-1 – CCA (1979)

System R* – IBM Research (1984)

Gamma – Univ. of Wisconsin (1986)

NonStop SQL – Tandem (1987)

Stonebraker

Bernstein

Mohan

DeWitt

Gray

DESIGN ISSUES

How does the application find data?

How to execute queries on distributed data?

→ Push query to data.

→ Pull data to query.

How does the DBMS ensure correctness?

HOMOGENOUS VS. HETEROGENOUS

Approach #1: Homogenous Nodes

→ Every node in the cluster can perform the same set of tasks (albeit on potentially different partitions of data).

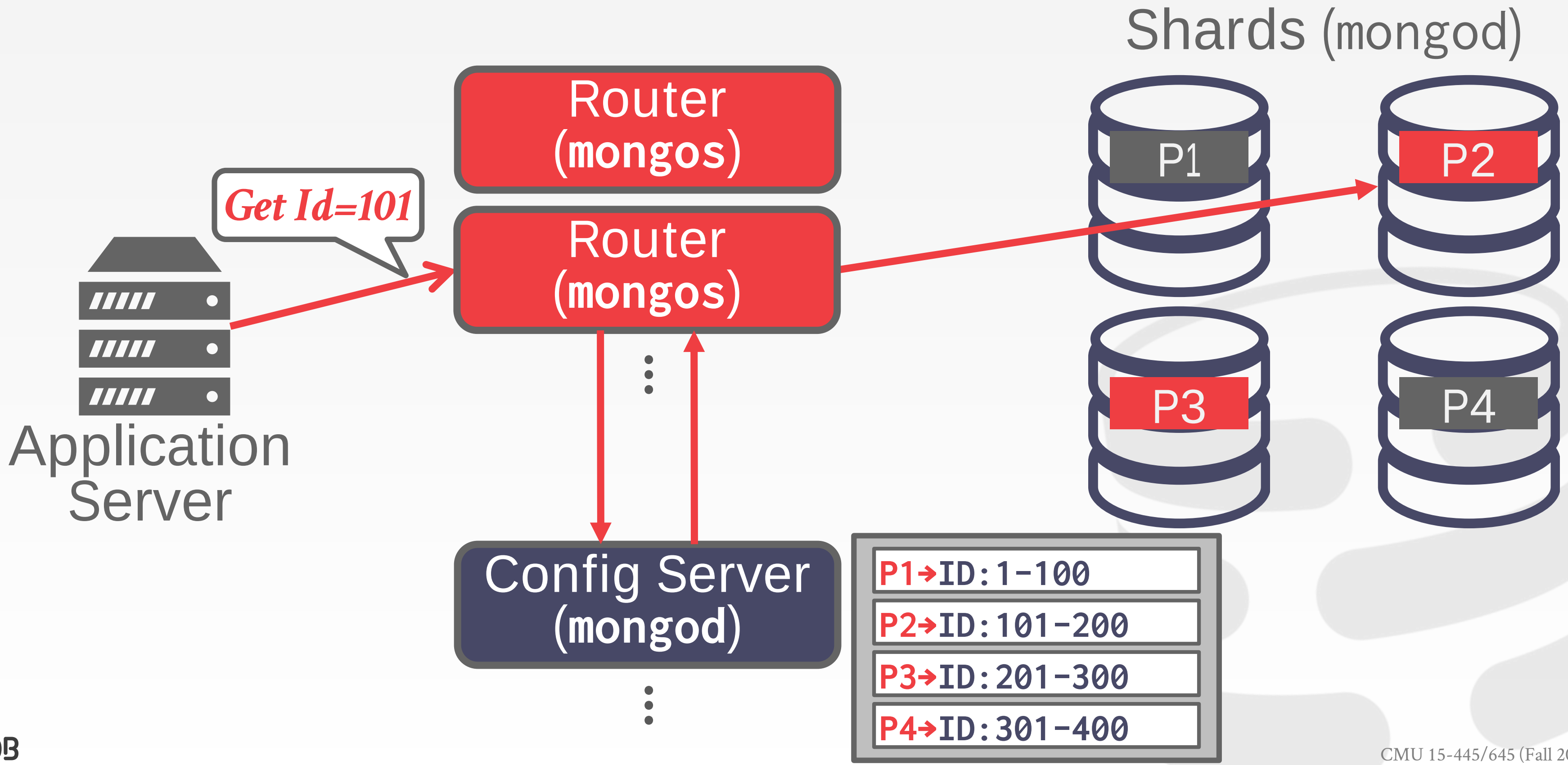
→ Makes provisioning and failover "easier".

Approach #2: Heterogenous Nodes

→ Nodes are assigned specific tasks.

→ Can allow a single physical node to host multiple "virtual" node types for dedicated tasks.

MONGODB HETEROGENOUS ARCHITECTURE



DATA TRANSPARENCY

Users should not be required to know where data is physically located, how tables are **partitioned** or **replicated**.

A SQL query that works on a single-node DBMS should work the same on a distributed DBMS.

DATABASE PARTITIONING

Split database across multiple resources:
→ Disks, nodes, processors.
→ Sometimes called "sharding"

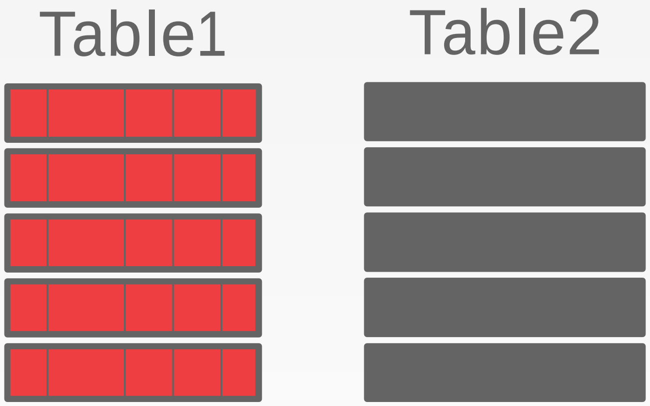
The DBMS executes query fragments on each partition and then combines the results to produce a single answer.

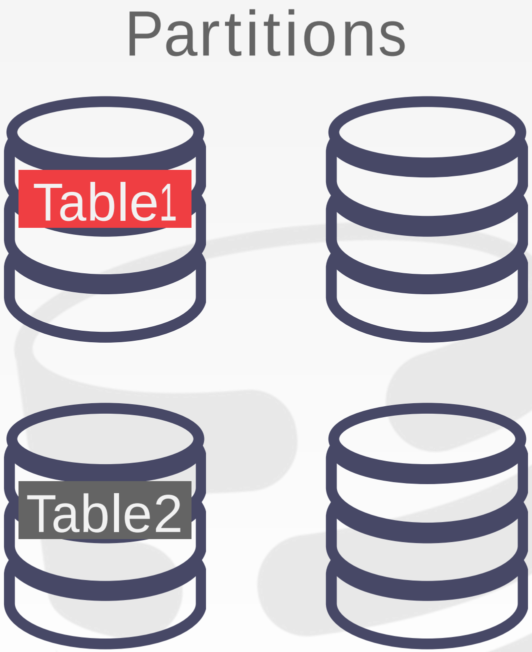
NAÏVE TABLE PARTITIONING

Each node stores one and only table.

Assumes that each node has enough storage space for a table.

NAÏVE TABLE PARTITIONING





Ideal Query:

```
SELECT * FROM table
```

HORIZONTAL PARTITIONING

Split a table's tuples into disjoint subsets.

→ Choose column(s) that divides the database equally in terms of size, load, or usage.

→ Hash Partitioning, Range Partitioning

The DBMS can partition a database **physical** (shared nothing) or **logically** (shared disk).

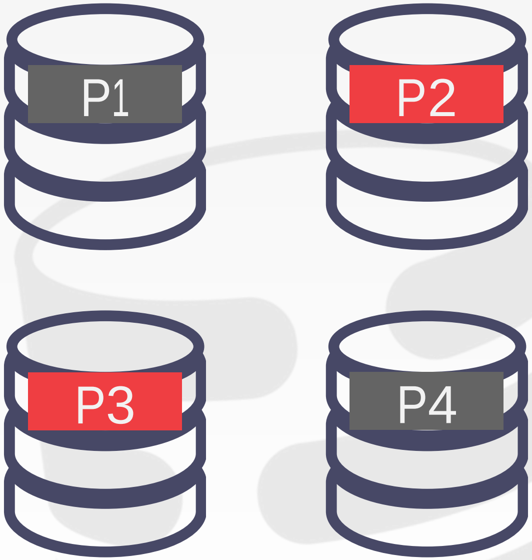
HORIZONTAL PARTITIONING

Partitioning Key

Table1

101	a	XXX	2019-11-29	hash(a)%4 = P2
102	b	XXY	2019-11-28	hash(b)%4 = P4
103	c	XYZ	2019-11-29	hash(c)%4 = P3
104	d	XYX	2019-11-27	hash(d)%4 = P2
105	e	XYY	2019-11-29	hash(e)%4 = P1

Partitions



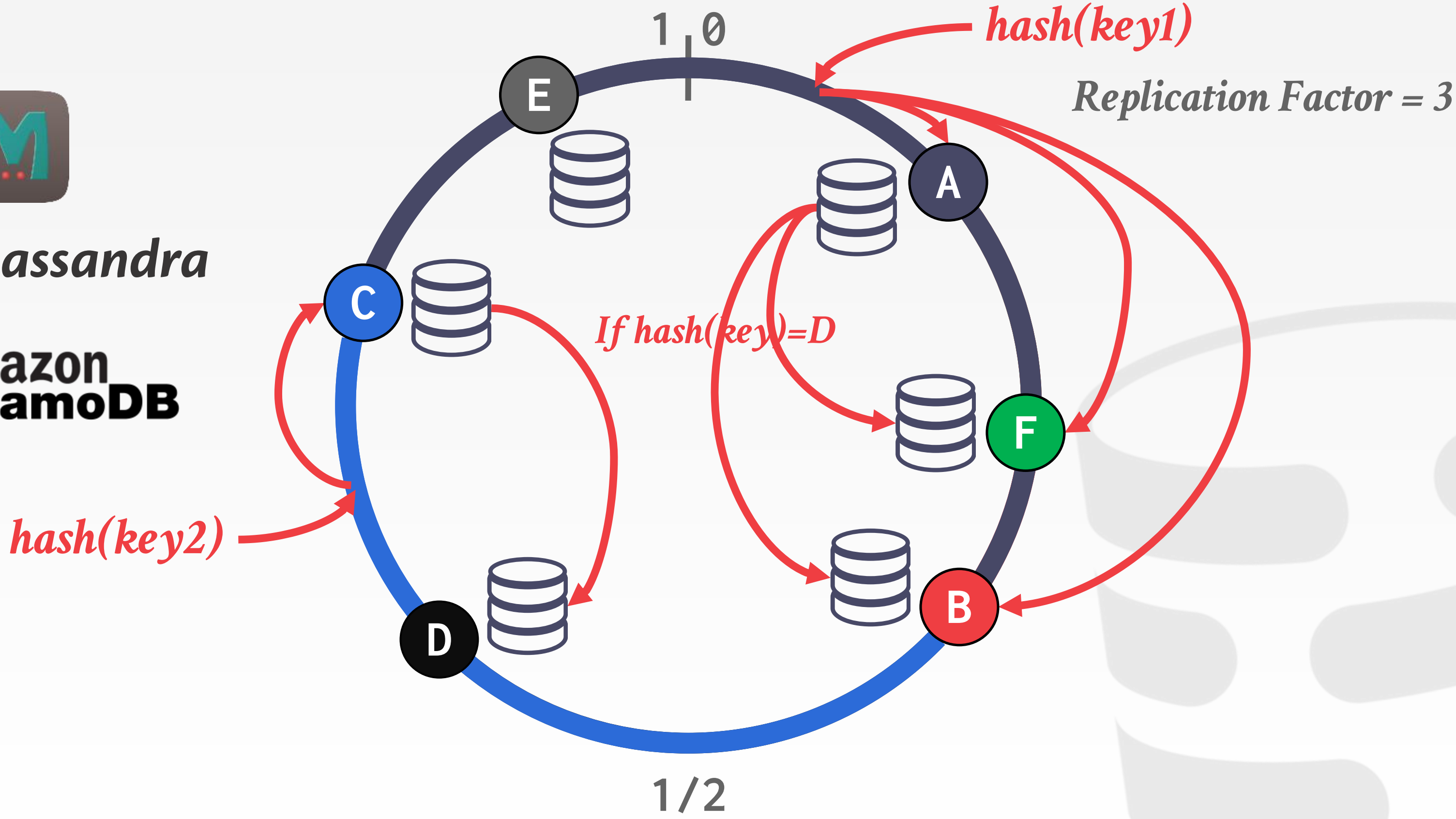
Ideal Query:

```
SELECT * FROM table
 WHERE partitionKey = ?
```

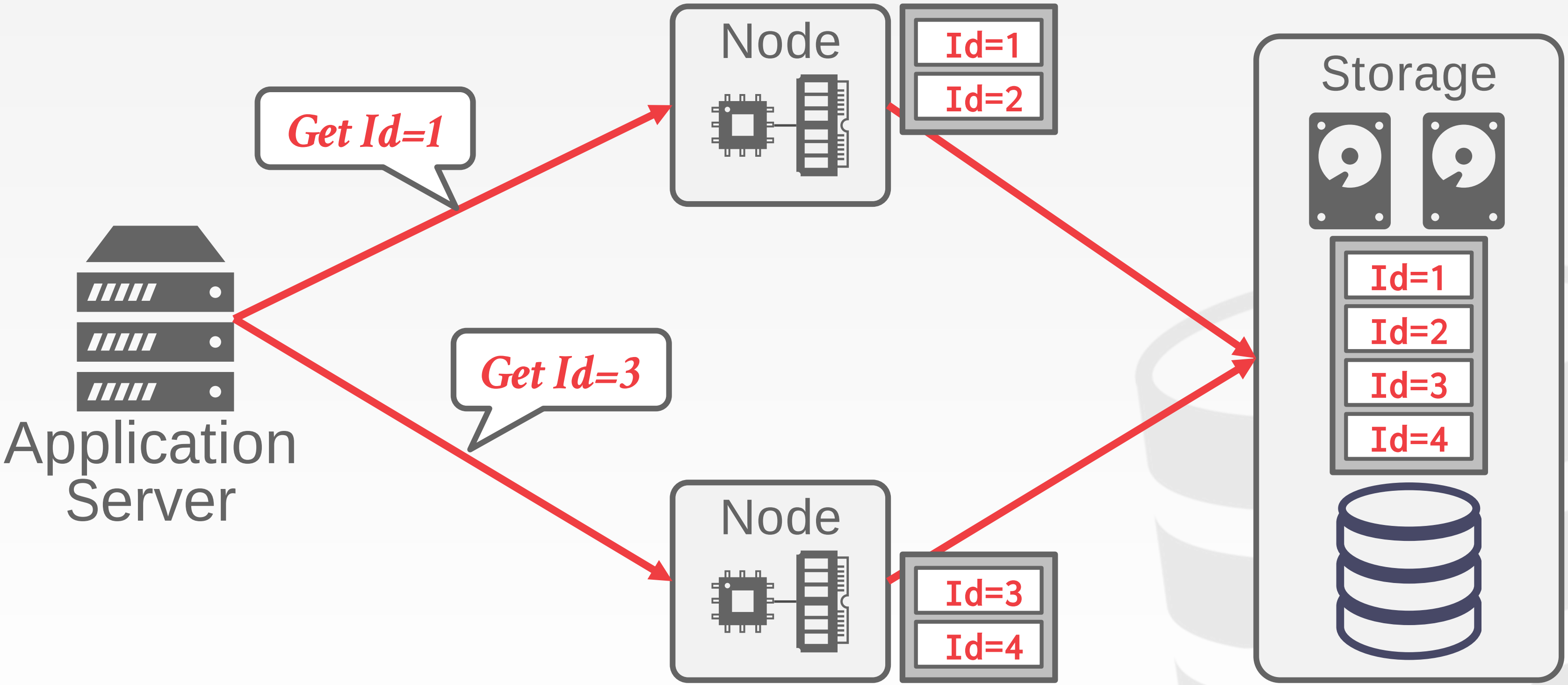
CONSISTENT HASHING

cassandra

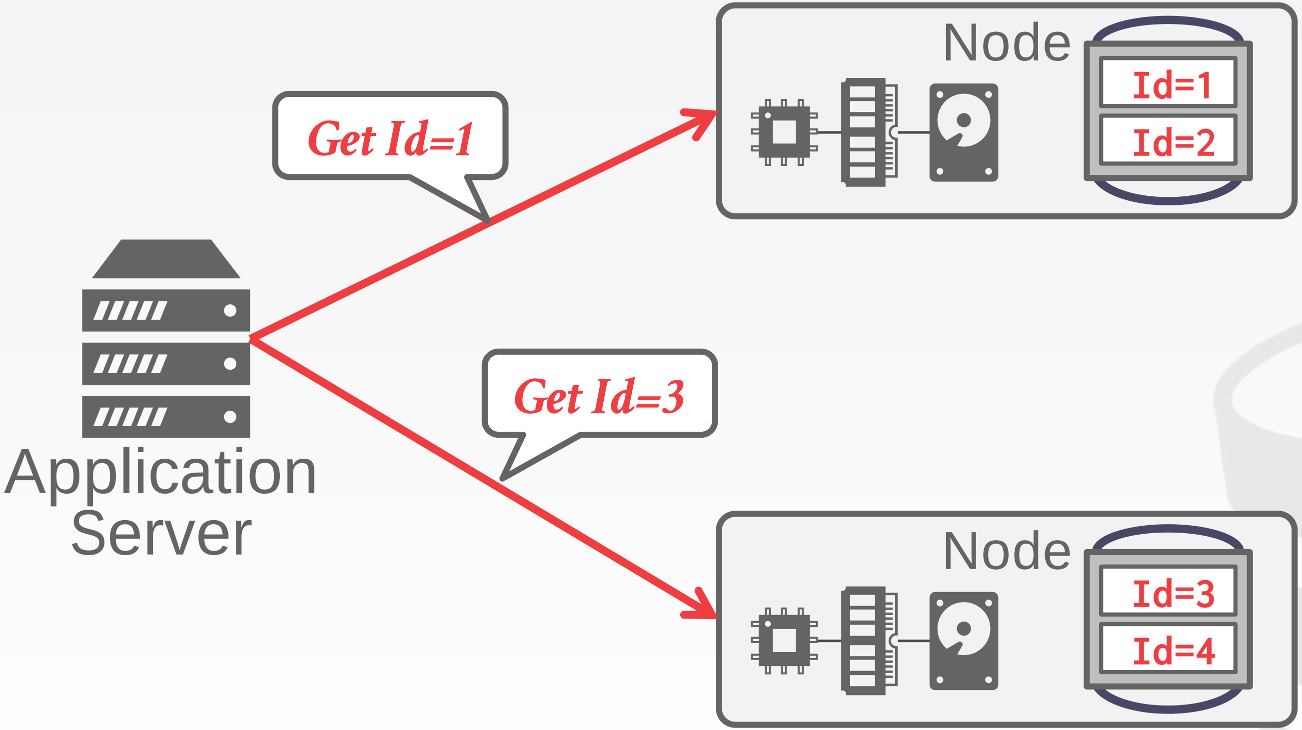
amazon DynamoDB



LOGICAL PARTITIONING



PHYSICAL PARTITIONING



SINGLE-NODE VS. DISTRIBUTED

A **single-node** txn only accesses data that is contained on one partition.

→ The DBMS does not need coordinate the behavior concurrent txns running on other nodes.

A **distributed** txn accesses data at one or more partitions.

→ Requires expensive coordination.

TRANSACTION COORDINATION

If our DBMS supports multi-operation and distributed txns, we need a way to coordinate their execution in the system.

Two different approaches:

→ **Centralized**: Global "traffic cop".
→ **Decentralized**: Nodes organize themselves.

TP MONITORS

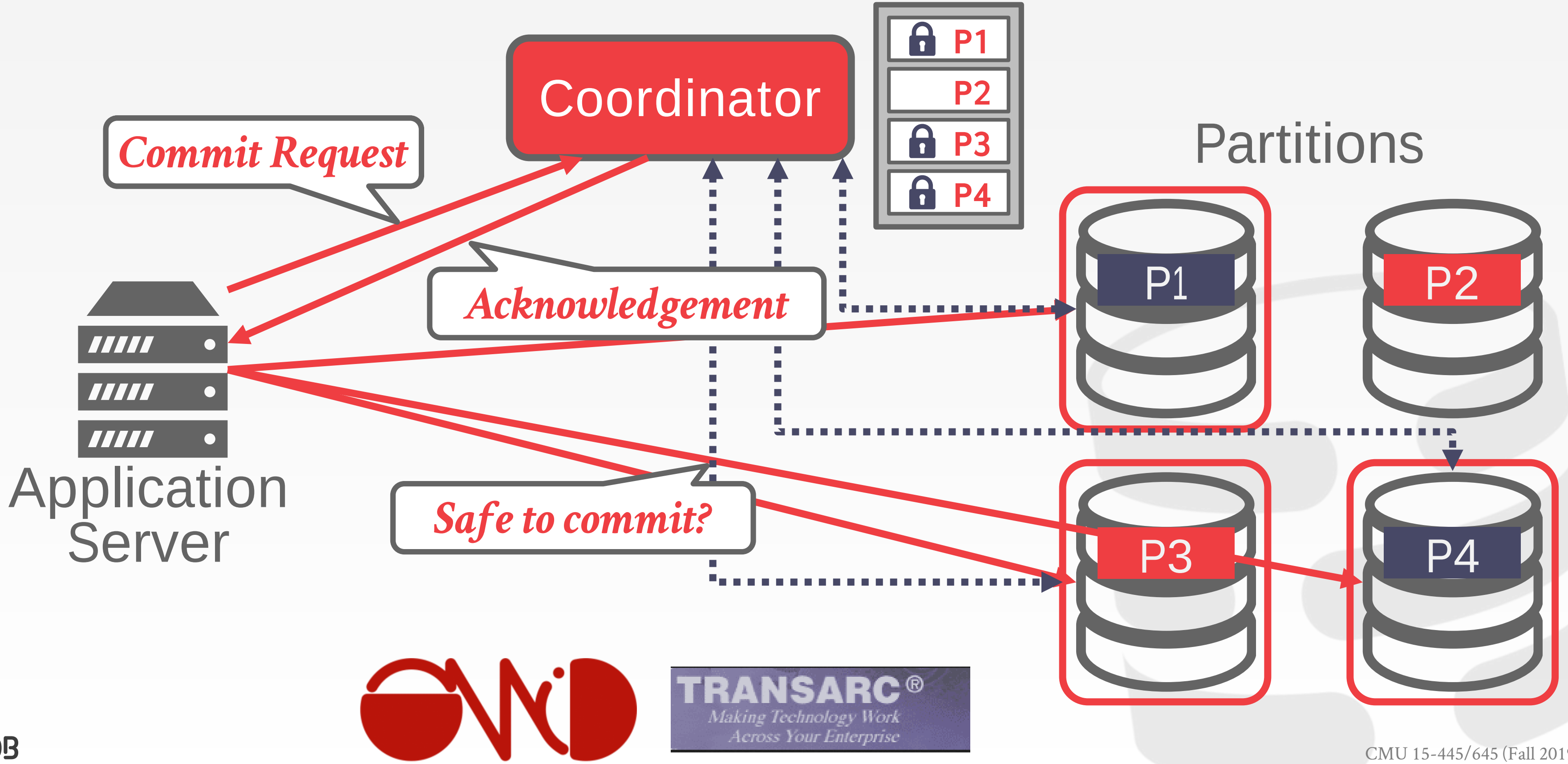
Example of a centralized coordinator.

Originally developed in the 1970-80s to provide txns between terminals and mainframe databases.

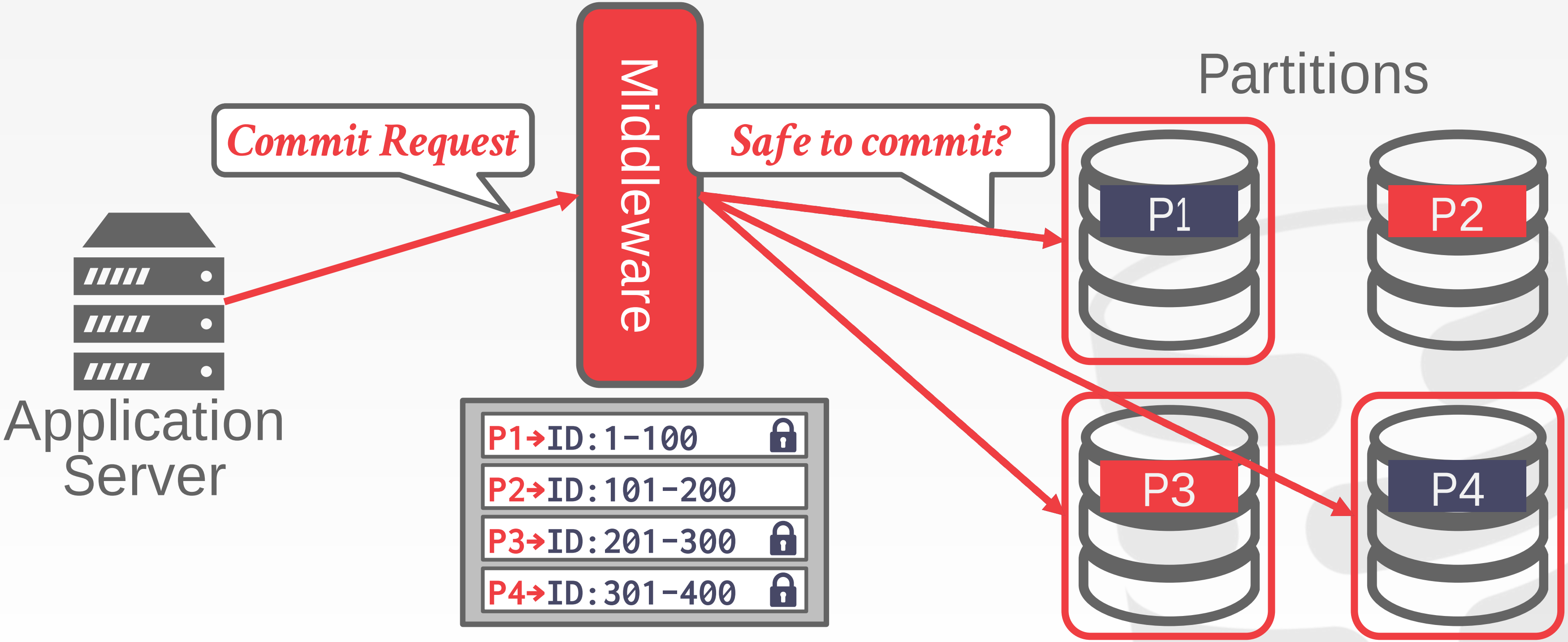
→ Examples: ATMs, Airline Reservations.

Many DBMSs now support the same functionality internally.

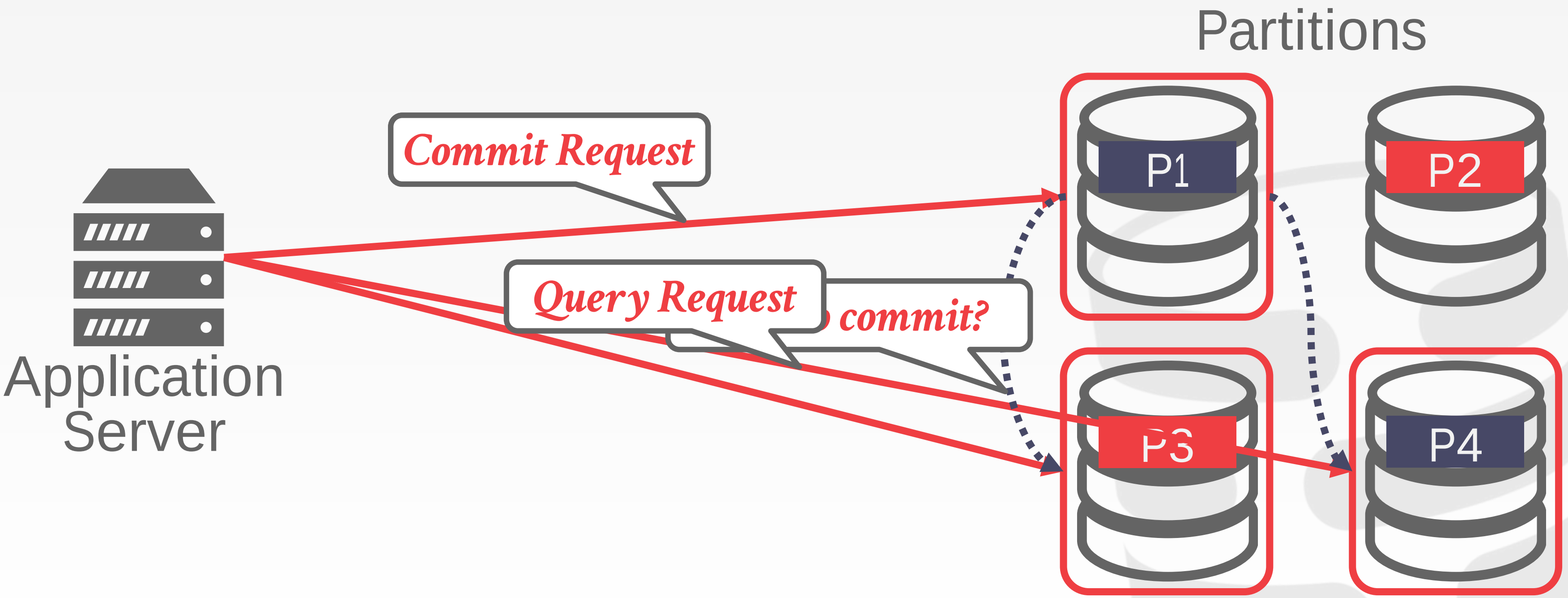
CENTRALIZED COORDINATOR



CENTRALIZED COORDINATOR



DECENTRALIZED COORDINATOR



DISTRIBUTED CONCURRENCY CONTROL

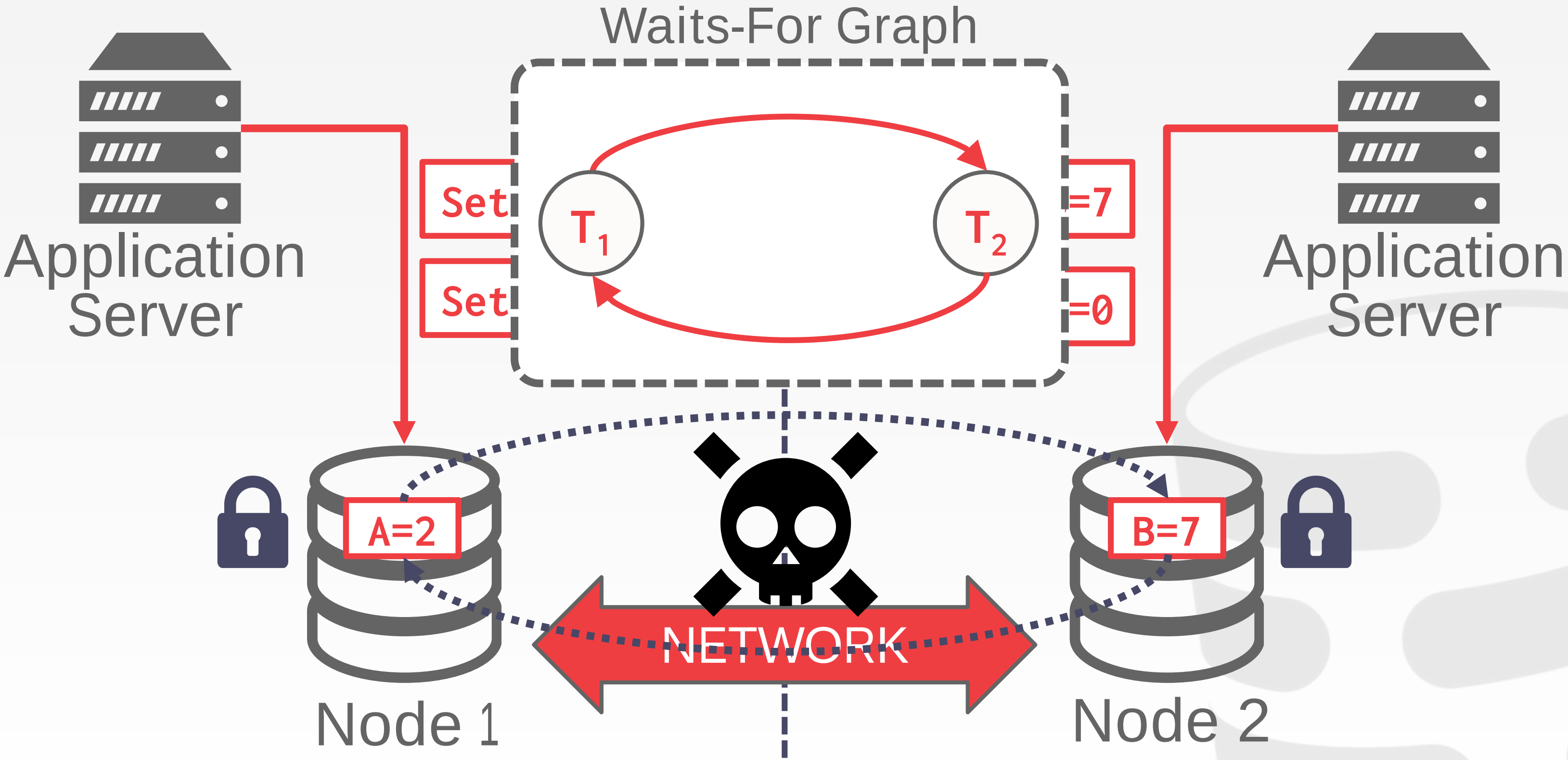
Need to allow multiple txns to execute simultaneously across multiple nodes.

→ Many of the same protocols from single-node DBMSs can be adapted.

This is harder because of:

→ Replication.
→ Network Communication Overhead.
→ Node Failures.
→ Clock Skew.

DISTRIBUTED 2PL



CONCLUSION

I have barely scratched the surface on distributed database systems…

It is **hard** to get right.

More info (and humiliation):

→ Kyle Kingsbury's Jepsen Project

NEXT CLASS

Distributed OLTP Systems

Replication

CAP Theorem

Real-World Examples