NOSQL DATABASES

Adopted from

Part I- NoSQL Databases
Lecture 26, April 21, 2015

Mohammad Hammoud

جامعة كارنيجي ميلون في قطر
Carnegie Mellon University Qatar

Today…

- Last Session:
  - Recovery Management

- Today's Session:
  - NoSQL databases

- Announcements:
  - PS4 grades are out
  - On Thursday, April 23rd we will practice on Hive (during recitation)
  - PS5 (the "last" assignment) is due on Thursday, April 23rd by midnight
  - P4: Write a survey on SQL vs. NoSQL databases (*optional*)- due on Friday, April 24th by midnight
  - The final exam is on Monday April 27th, from 8:30AM to 11:30AM in room 1190 (*all materials are included- open book, open notes*)

Outline

- Types of Data ✓
- Scaling Databases & the 2PC Protocol
- The CAP Theorem and the BASE Properties
- NoSQL Databases

Types of Data

- Data can be broadly classified into four types:
  1. Structured Data:
     - Have a predefined model, which organizes data into a form that is relatively easy to store, process, retrieve and manage
     - E.g., relational data
  2. Unstructured Data:
     - Opposite of structured data
     - E.g., Flat binary files containing text, video or audio
     - Note: data is not completely devoid of a structure (e.g., an audio file may still have an encoding structure and some metadata associated with it)

Types of Data

- Data can be broadly classified into four types:
  3. Dynamic Data:
     - Data that changes relatively frequently
     - E.g., office documents and transactional entries in a financial database

  4. Static Data:
     - Opposite of dynamic data
     - E.g., Medical imaging data from MRI or CT scans

Why Classifying Data?

- Segmenting data into one of the following 4 quadrants can help in designing and developing a pertaining storage solution

	Dynamic	Static
Unstructured	Media Production, eCAD, mCAD, Office Docs	Media Archive, Broadcast, Medical Imaging
Structured	Transaction Systems, ERP, CRM	BI, Data Warehousing

- Relational databases are usually used for structured data

- File systems or *NoSQL databases* can be used for (static), unstructured data (*more on these later*)

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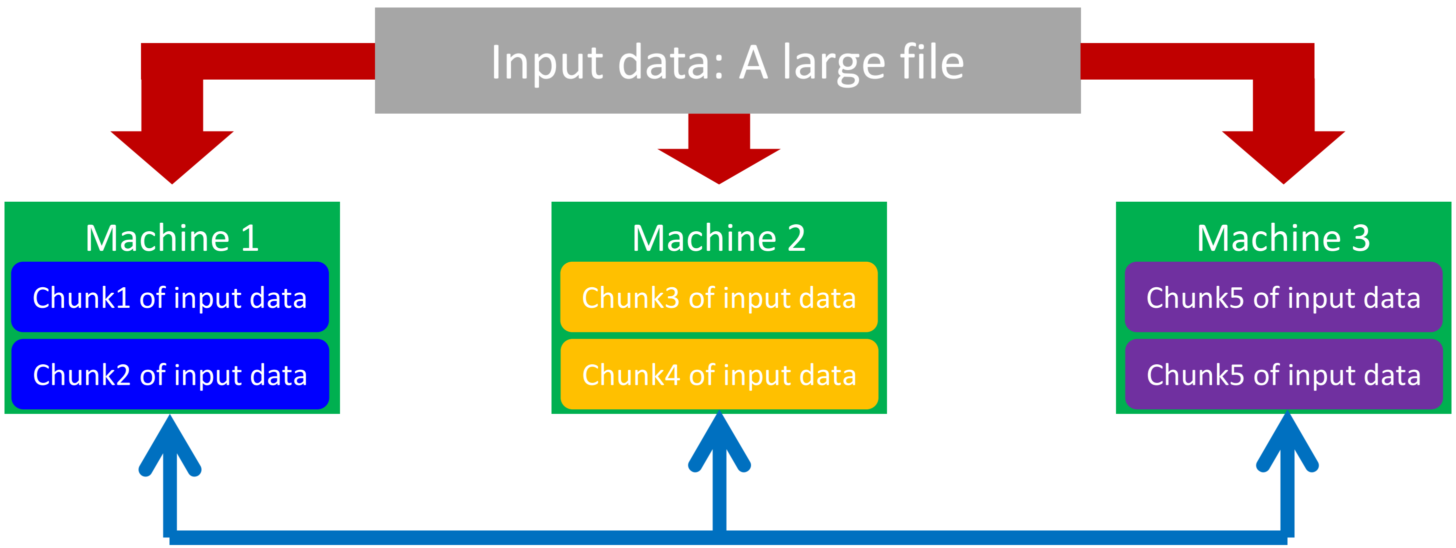
Scaling Traditional Databases

- Traditional RDBMSs can be either scaled:
  - Vertically (or Up)
    - Can be achieved by hardware upgrades (e.g., faster CPU, more memory, or larger disk)
    - Limited by the amount of CPU, RAM and disk that can be configured on a single machine
  - Horizontally (or Out)
    - Can be achieved by adding more machines
    - Requires database *sharding* and probably *replication*
    - Limited by the Read-to-Write ratio and communication overhead

Why Sharding Data?

- Data is typically *sharded* (or *striped*) to allow for concurrent/parallel accesses



E.g., Chunks 1, 3 and 5 can be accessed in parallel

Amdahl's Law

- How much faster will a parallel program run?
  - Suppose that the sequential execution of a program takes T_1 time units and the parallel execution on p processors/machines takes T_p time units
  - Suppose that out of the entire execution of the program, s fraction of it is not parallelizable while $1\text{-}s$ fraction is parallelizable
  - Then the speedup (***Amdahl's formula***):

$$\frac{T_1}{T_p} = \frac{T_1}{(T_1 \times s + T_1 \times \frac{1-s}{p})} = \frac{1}{s + \frac{1-s}{p}}$$

Amdahl's Law: An Example

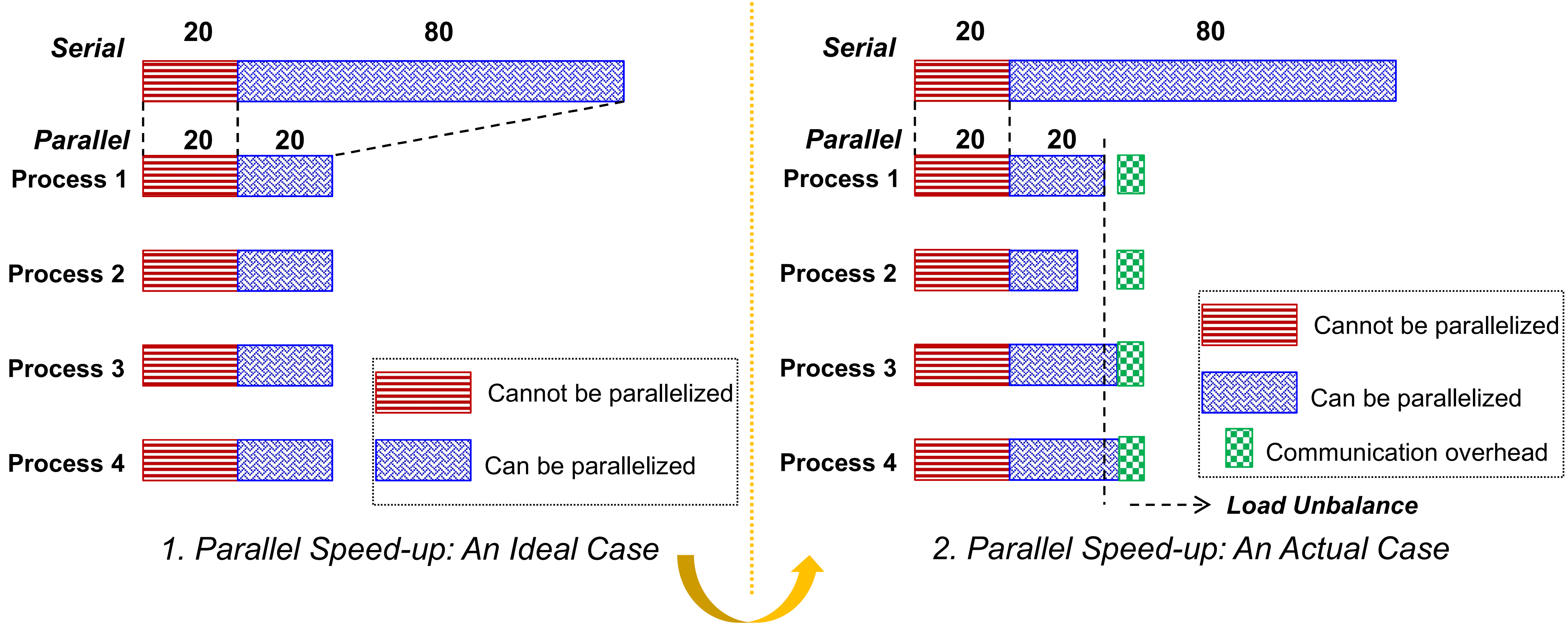
- Suppose that:
  - 80% of your program can be parallelized
  - 4 machines are used to run your parallel version of the program
- The speedup you can get according to Amdahl's law is:

$$\frac{1}{s+\frac{1-s}{p}} = \frac{1}{0.2+\frac{0.8}{4}} = 2.5 \text{ times}$$

Although you use 4 processors you cannot get a speedup more than 2.5 times!

Real Vs. Actual Cases

- Amdahl's argument is too simplified
- In reality, communication overhead and potential workload imbalance exist upon running parallel programs



Some Guidelines

- Here are some guidelines to effectively benefit from parallelization:
  1. Maximize the fraction of your program that can be parallelized
  2. Balance the workload of parallel processes
  3. Minimize the time spent for communication

Why Replicating Data?

- Replicating data across servers helps in:
  - Avoiding performance bottlenecks
  - Avoiding single point of failures
  - And, hence, enhancing scalability and availability

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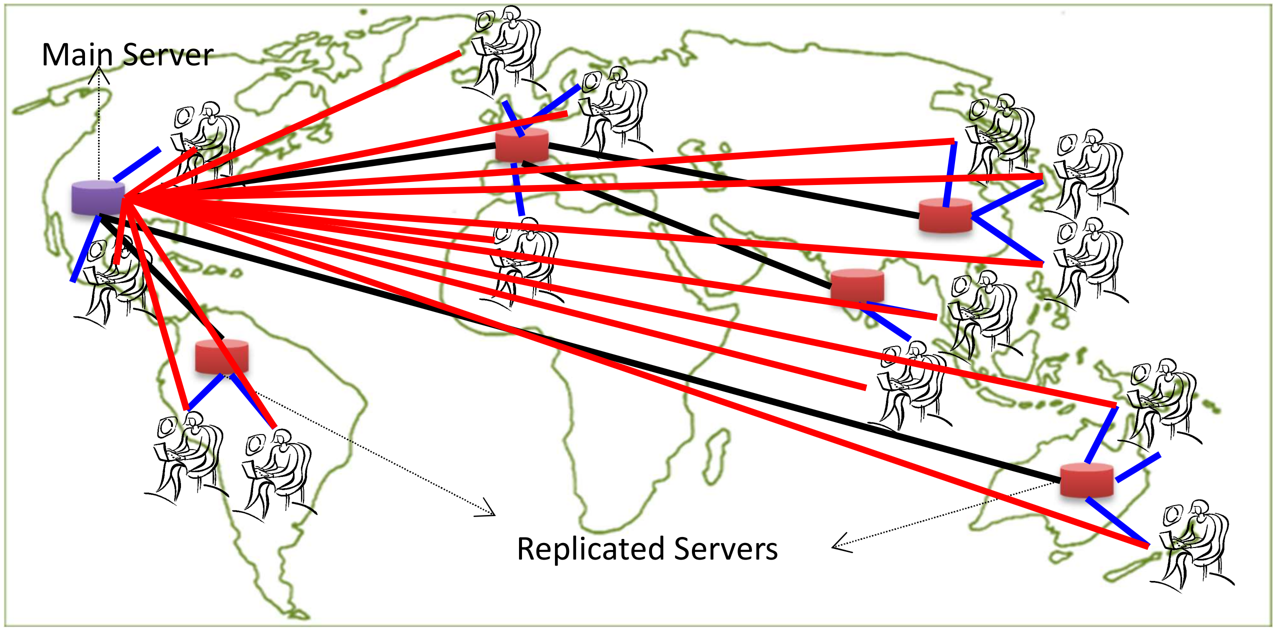
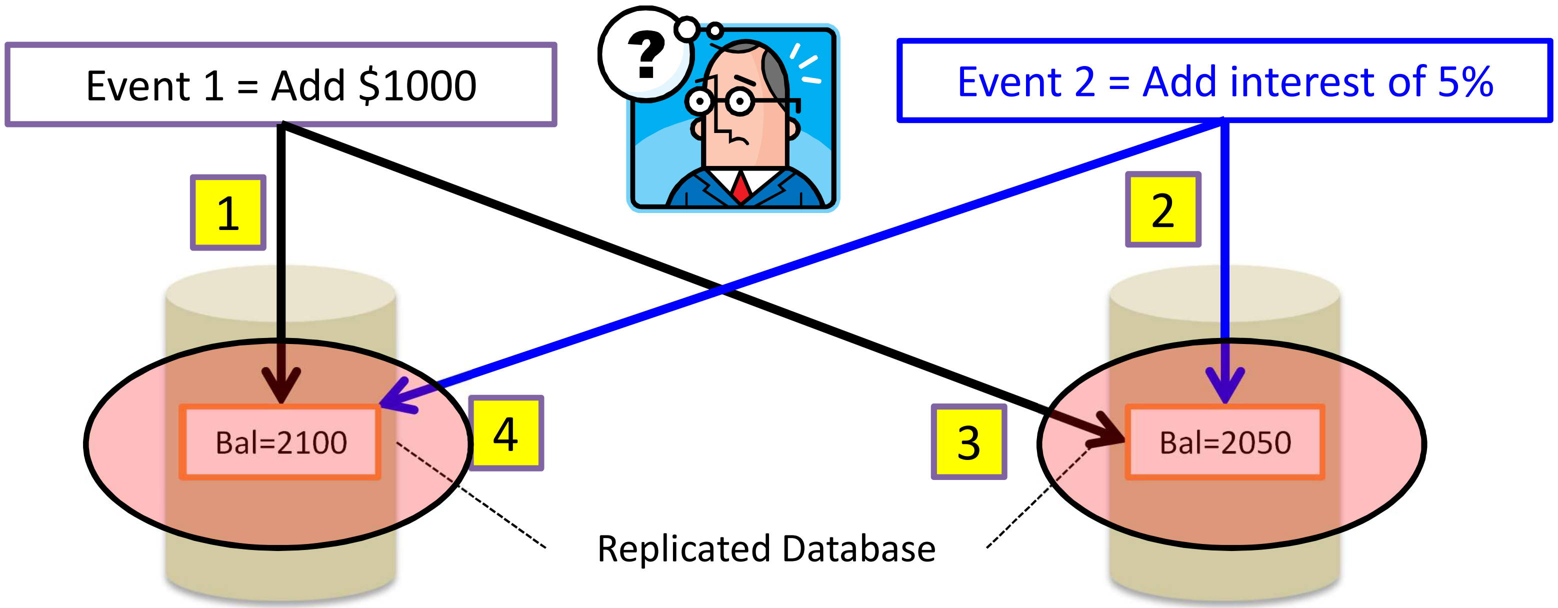


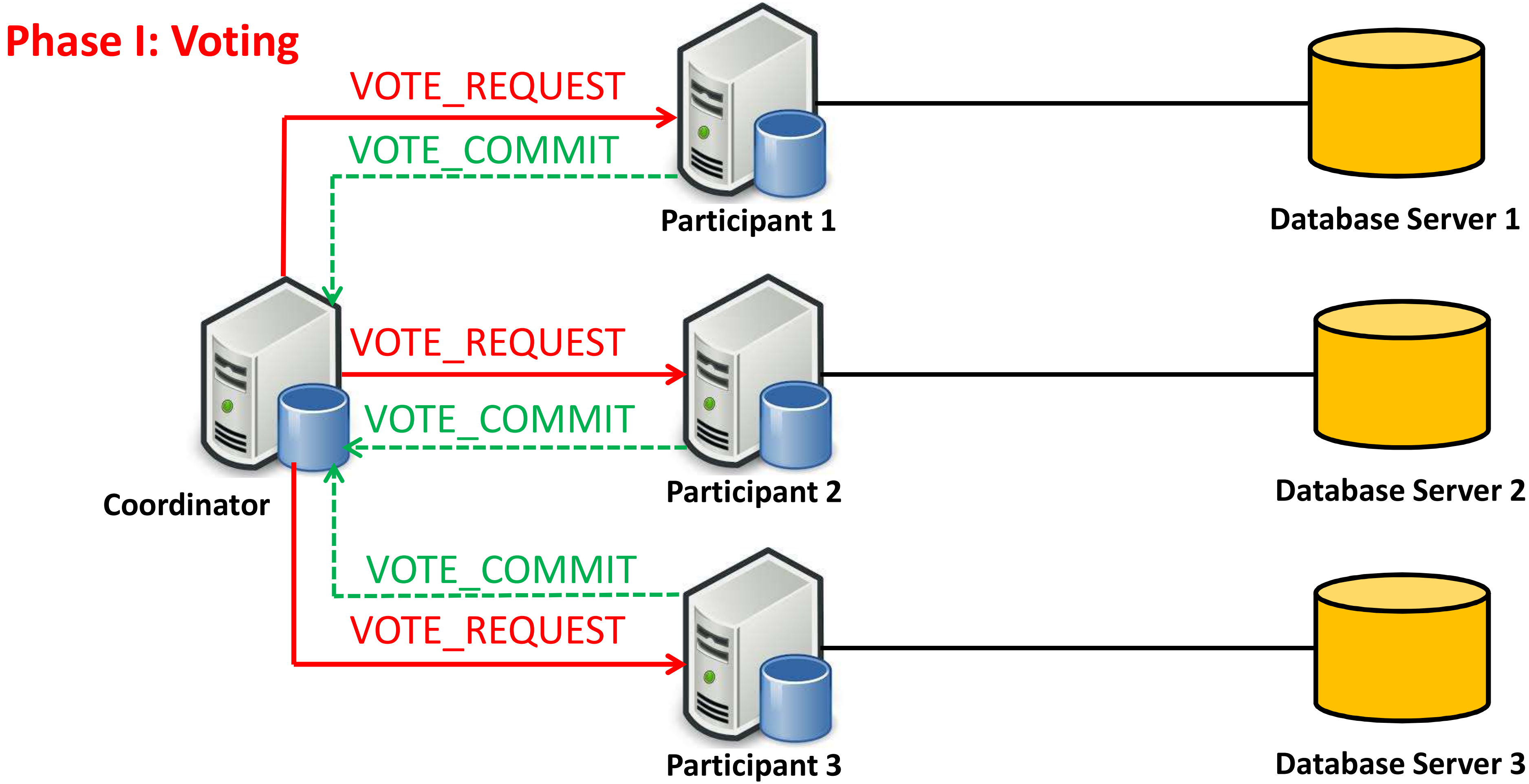
But, Consistency Becomes a Challenge

- An example:
  - In an e-commerce application, the bank database has been replicated across two servers
  - Maintaining consistency of replicated data is a challenge



The Two-Phase Commit Protocol

- The two-phase commit protocol (2PC) can be used to ensure atomicity and consistency



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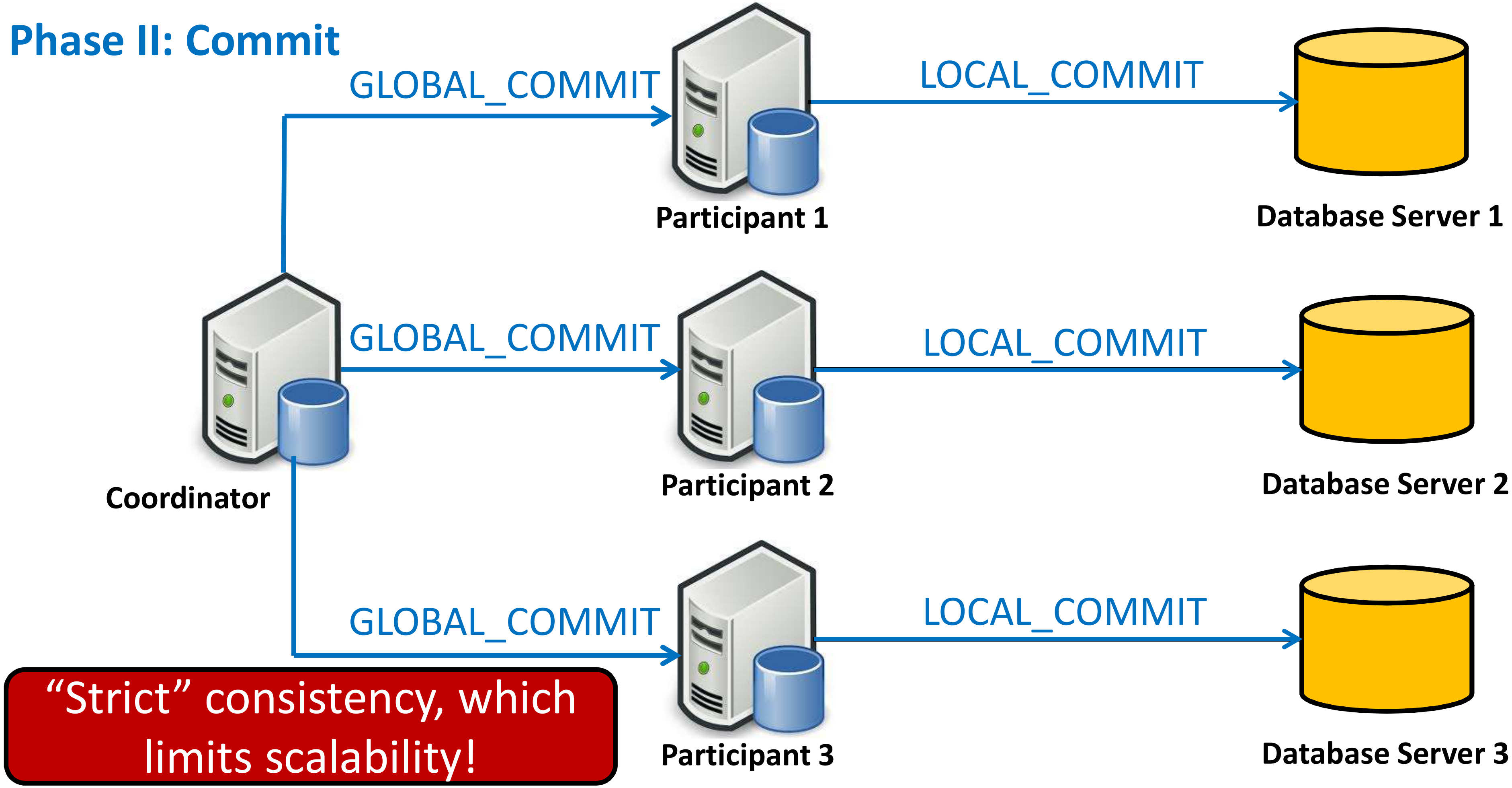

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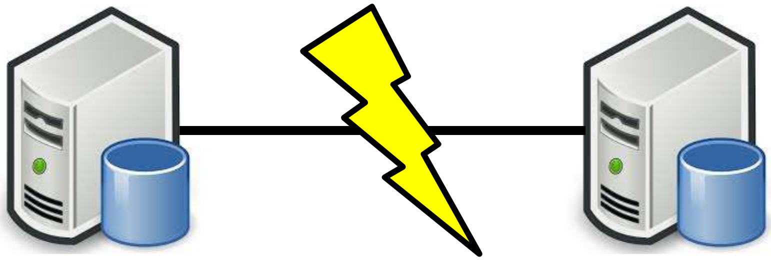
The CAP Theorem

- The limitations of distributed databases can be described in the so called the CAP theorem
  - **C**onsistency: every node always sees the same data at any given instance (i.e., strict consistency)
  - **A**vailability: the system continues to operate, even if nodes in a cluster crash, or some hardware or software parts are down due to upgrades
  - **P**artition Tolerance: the system continues to operate in the presence of network partitions

CAP theorem: any distributed database with shared data, can have ***at most two*** of the three desirable properties, C, A or P

The CAP Theorem (*Cont'd*)

- Let us assume two nodes on opposite sides of a network partition:



- Availability + Partition Tolerance forfeit Consistency

- Consistency + Partition Tolerance entails that one side of the partition must act as if it is unavailable, thus forfeiting Availability

- Consistency + Availability is only possible if there is no network partition, thereby forfeiting Partition Tolerance

Large-Scale Databases

- When companies such as Google and Amazon were designing large-scale databases, 24/7 Availability was a key
  - A few minutes of downtime means lost revenue
- When *horizontally* scaling databases to 1000s of machines, the likelihood of a node or a network failure increases tremendously
- Therefore, in order to have strong guarantees on Availability and Partition Tolerance, they had to sacrifice “strict” Consistency (*implied by the CAP theorem*)

Trading-Off Consistency

- Maintaining consistency should balance between the strictness of consistency versus availability/scalability
  - Good-enough consistency ***depends on your application***

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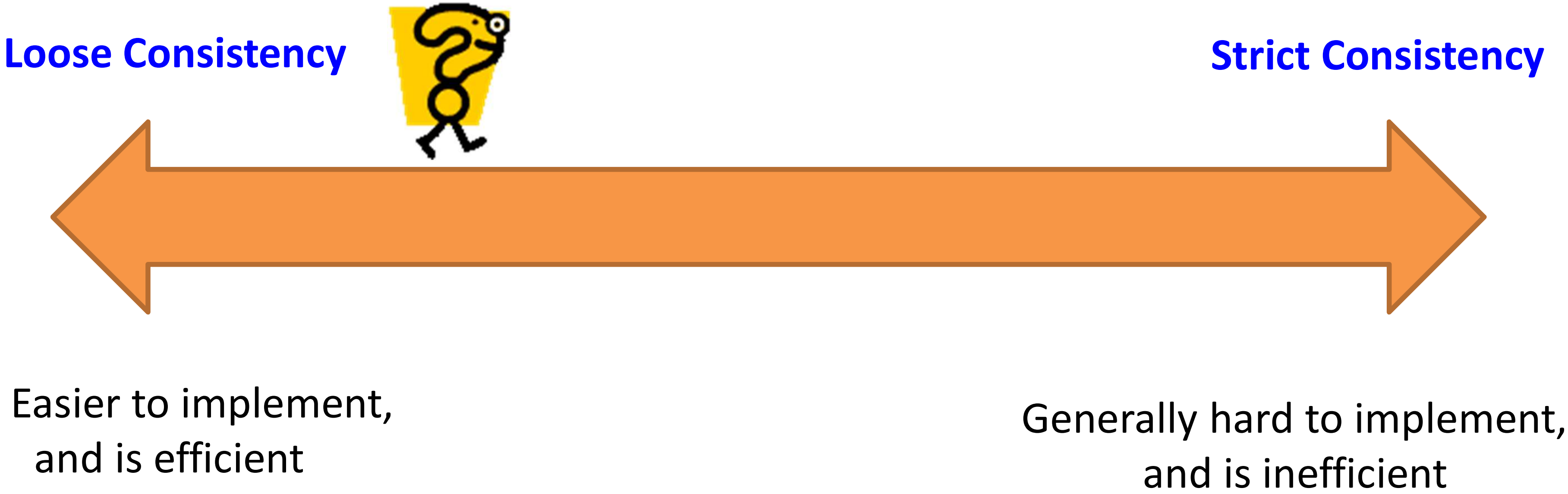

The BASE Properties

- The CAP theorem proves that it is impossible to guarantee strict Consistency and Availability while being able to tolerate network partitions

- This resulted in databases with relaxed ACID guarantees

- In particular, such databases apply the BASE properties:
  - **B**asically **A**vailable: the system guarantees Availability
  - **S**oft-State: the state of the system may change over time
  - **E**ventual Consistency: the system will *eventually* become consistent

Eventual Consistency

- A database is termed as *Eventually Consistent* if:
  - All replicas will *gradually* become consistent in the absence of updates

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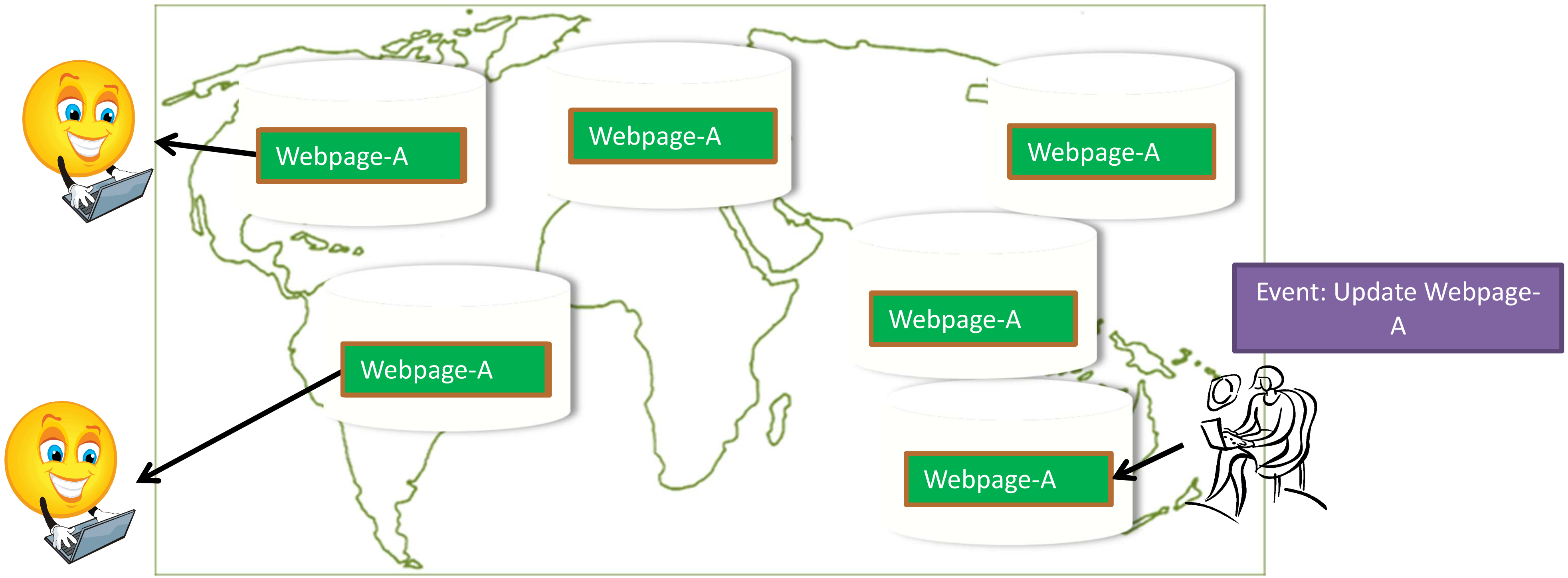
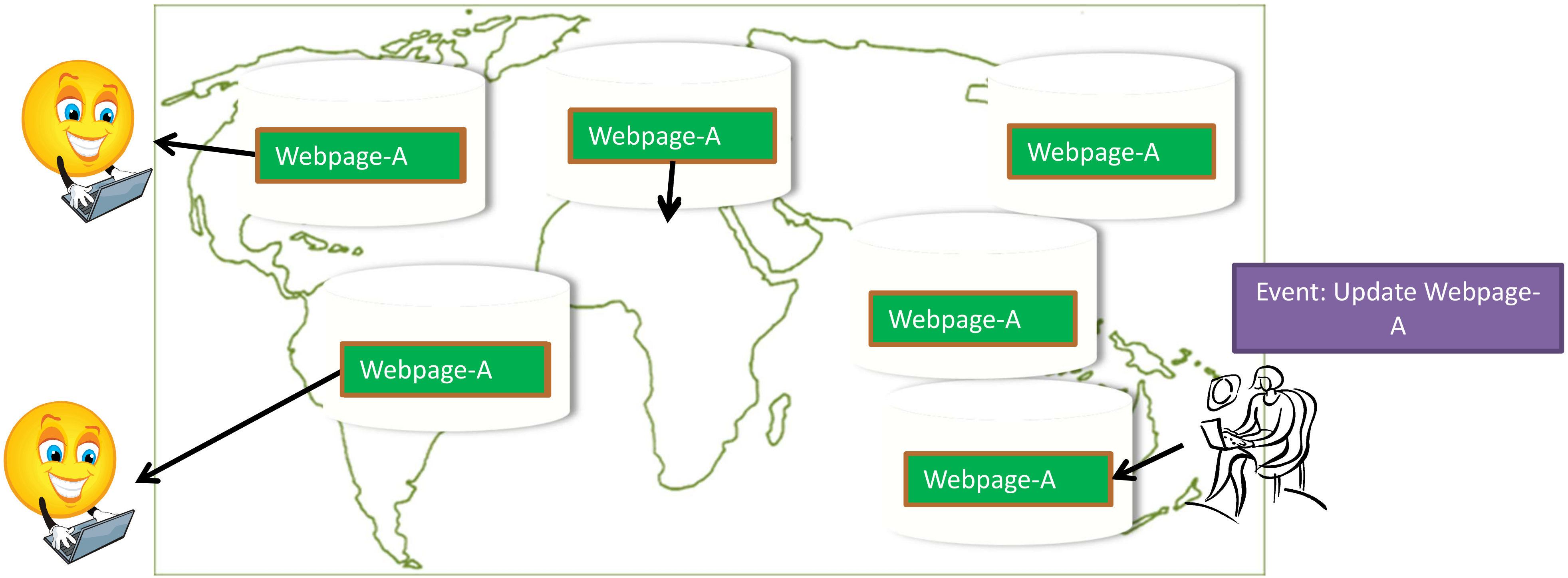


Eventual Consistency: A Main Challenge

- But, what if the client accesses the data from different replicas?



Protocols like Read Your Own Writes (RYOW) can be applied!

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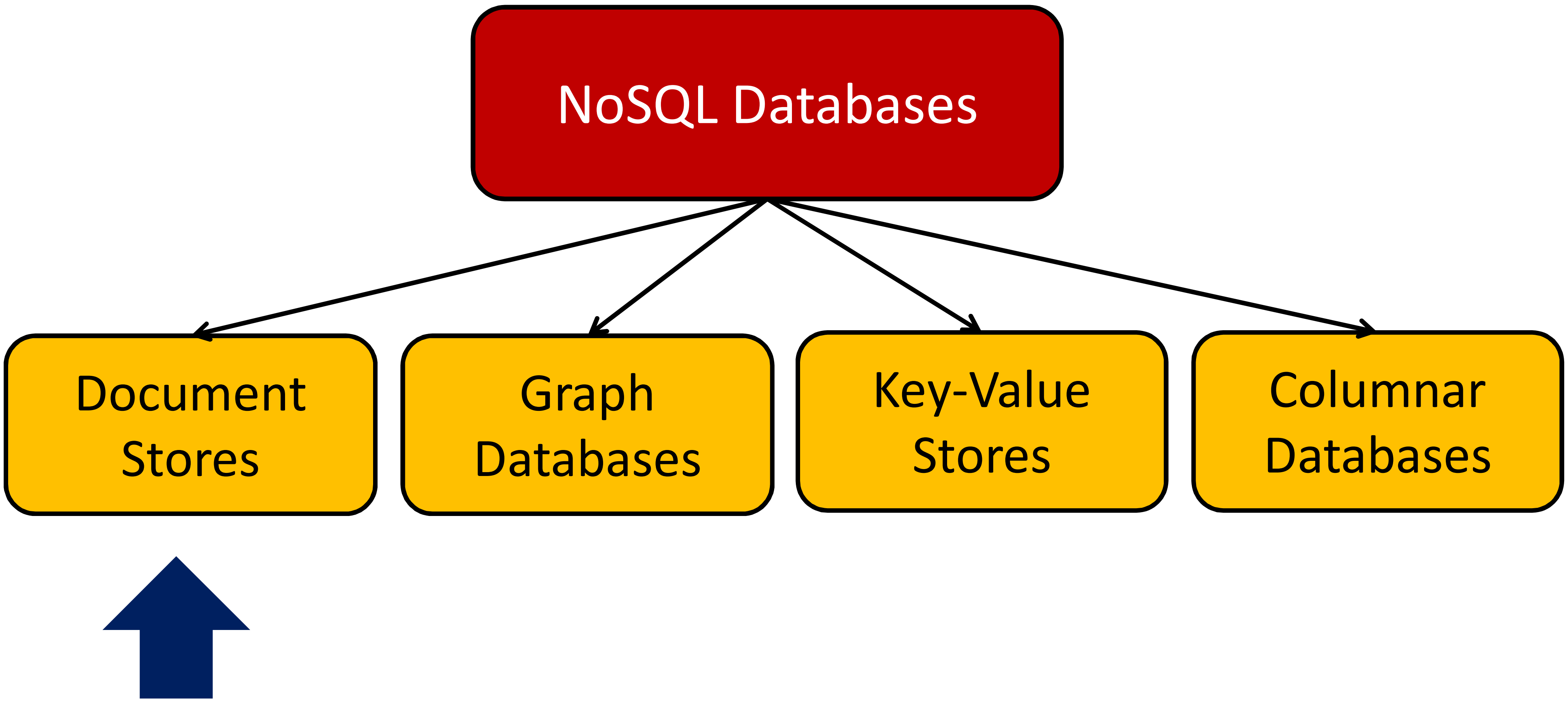
NoSQL Databases

- To this end, a new class of databases emerged, which mainly follow the BASE properties
  - These were dubbed as NoSQL databases
  - E.g., Amazon’s Dynamo and Google’s Bigtable

- Main characteristics of NoSQL databases include:
  - No strict schema requirements
  - No strict adherence to ACID properties
  - Consistency is traded in favor of Availability

Types of NoSQL Databases

- Here is a limited taxonomy of NoSQL databases:



Document Stores

- Documents are stored in some standard format or encoding (e.g., XML, JSON, PDF or Office Documents)
  - These are typically referred to as Binary Large Objects (BLOBs)

- Documents can be indexed
  - This allows document stores to outperform traditional file systems

- E.g., MongoDB and CouchDB (both can be queried using MapReduce)

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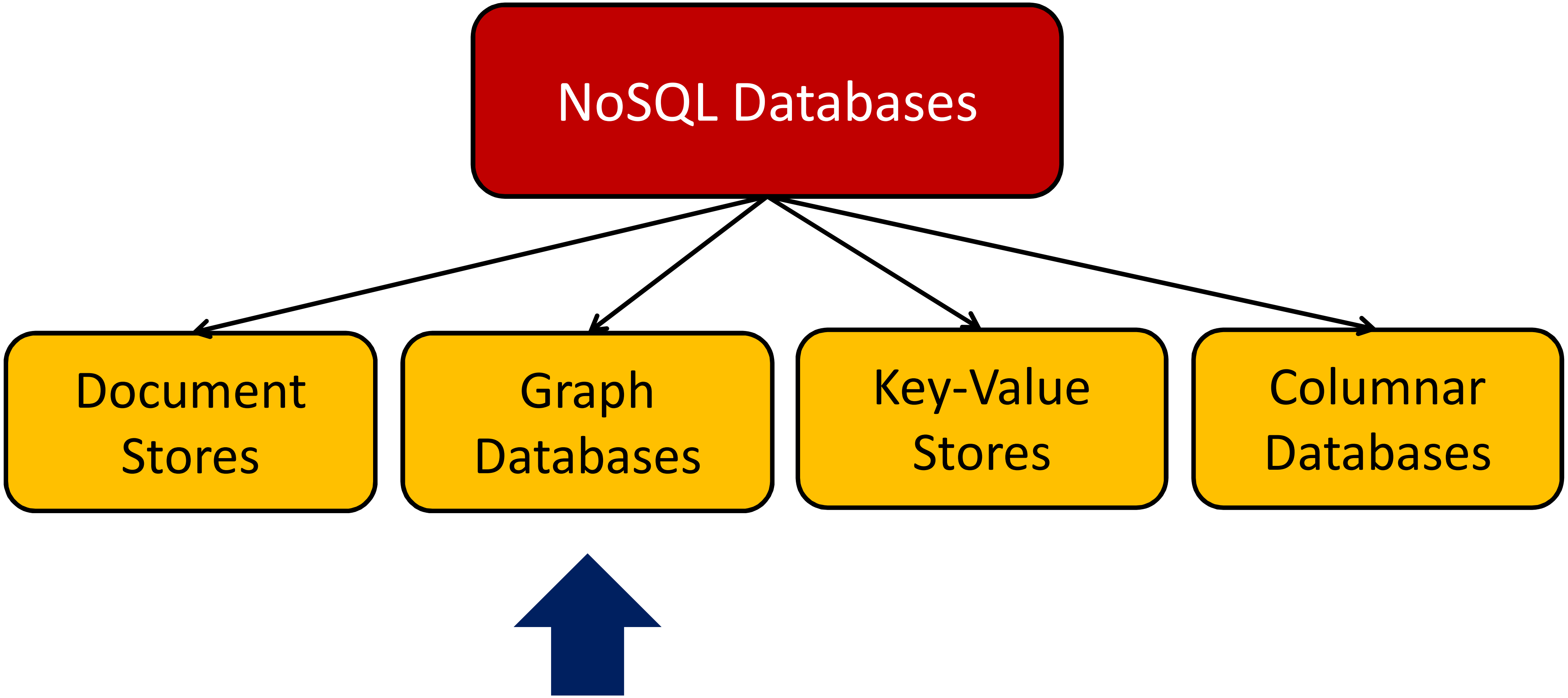
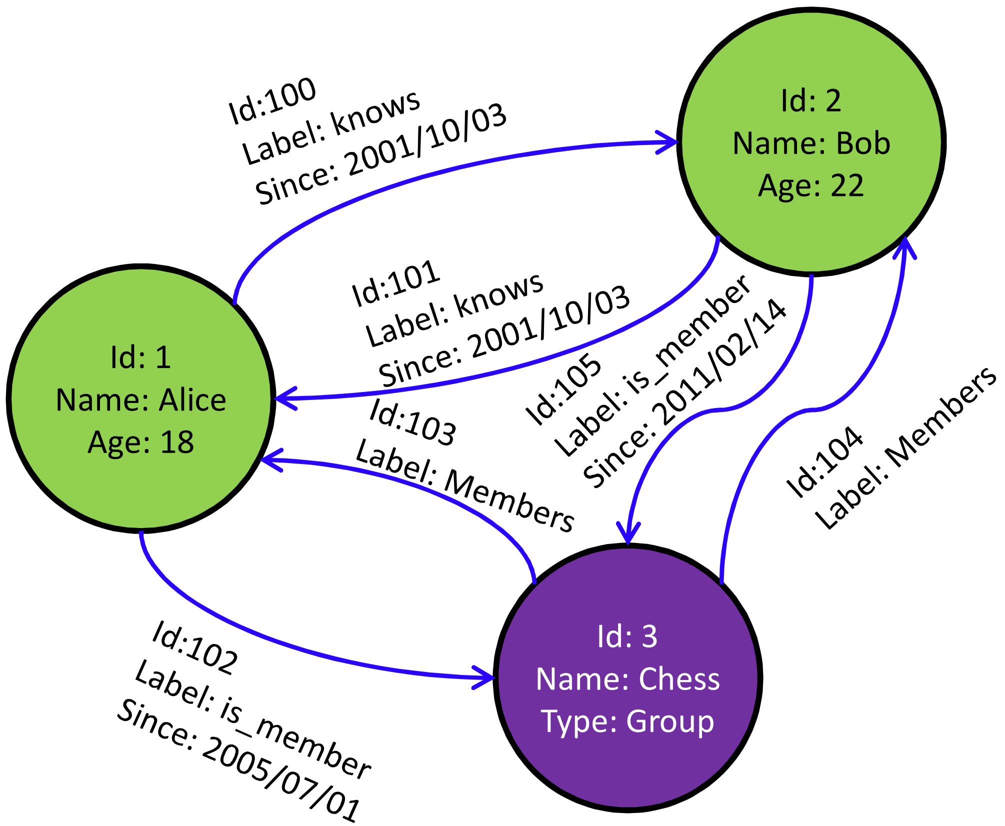


Graph Databases

- Data are represented as vertices and edges



- Graph databases are powerful for graph-like queries (e.g., find the shortest path between two elements)

- E.g., Neo4j and VertexDB

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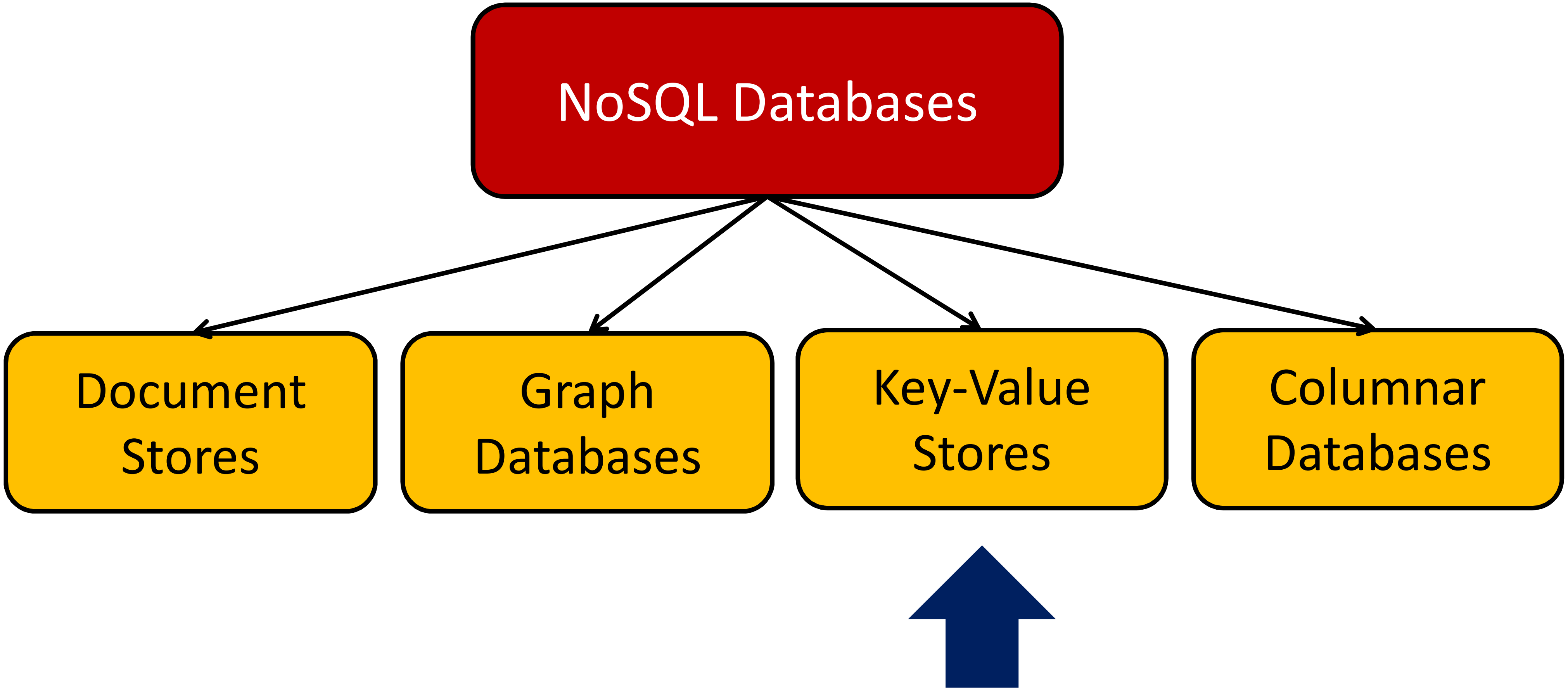

Key-Value Stores

- Keys are mapped to (possibly) more complex value (e.g., lists)
- Keys can be stored in a hash table and can be distributed easily
- Such stores typically support regular CRUD (create, read, update, and delete) operations
  - That is, no joins and aggregate functions
- E.g., Amazon DynamoDB and Redis

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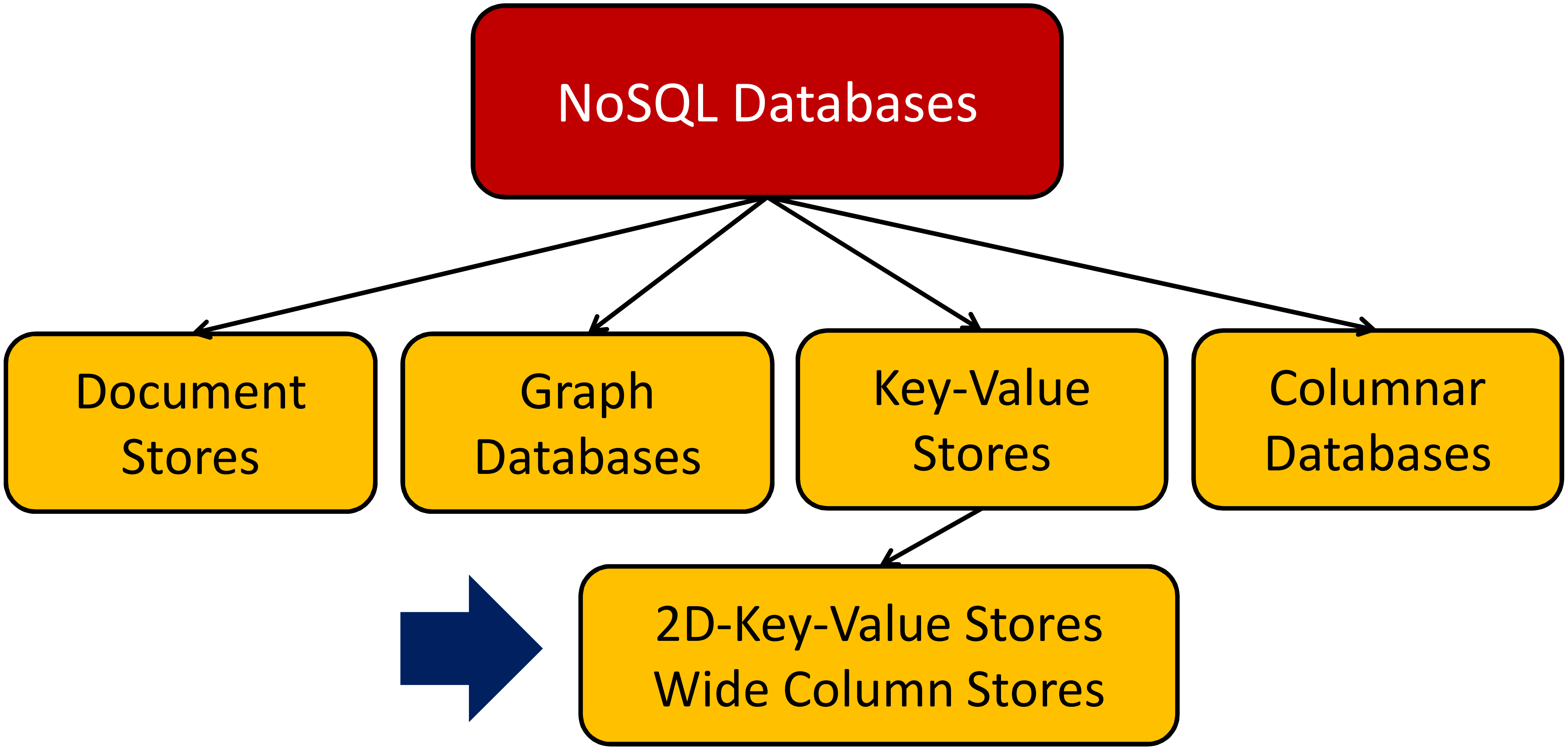

Wide Column Stores

- Wide column stores, also called extensible record stores
  - Store data in records with an ability to hold very large numbers of dynamic columns.
  - Since the column names as well as the record keys are not fixed, and since a record can have billions of columns, **wide column stores can be seen as two-dimensional key-value stores**.
- Wide column stores share the chracteristic of being schema-free with document stores,
  - however the implementation is very different.
- Wide column stores must not be confused with the column oriented storage in some relational systems.
  - This is an internal concept for improving the performance of an RDBMS for OLAP workloads and stores the data of a table not record after record but column by column.
- E.g., Apache Hbase and Apache Cassandra

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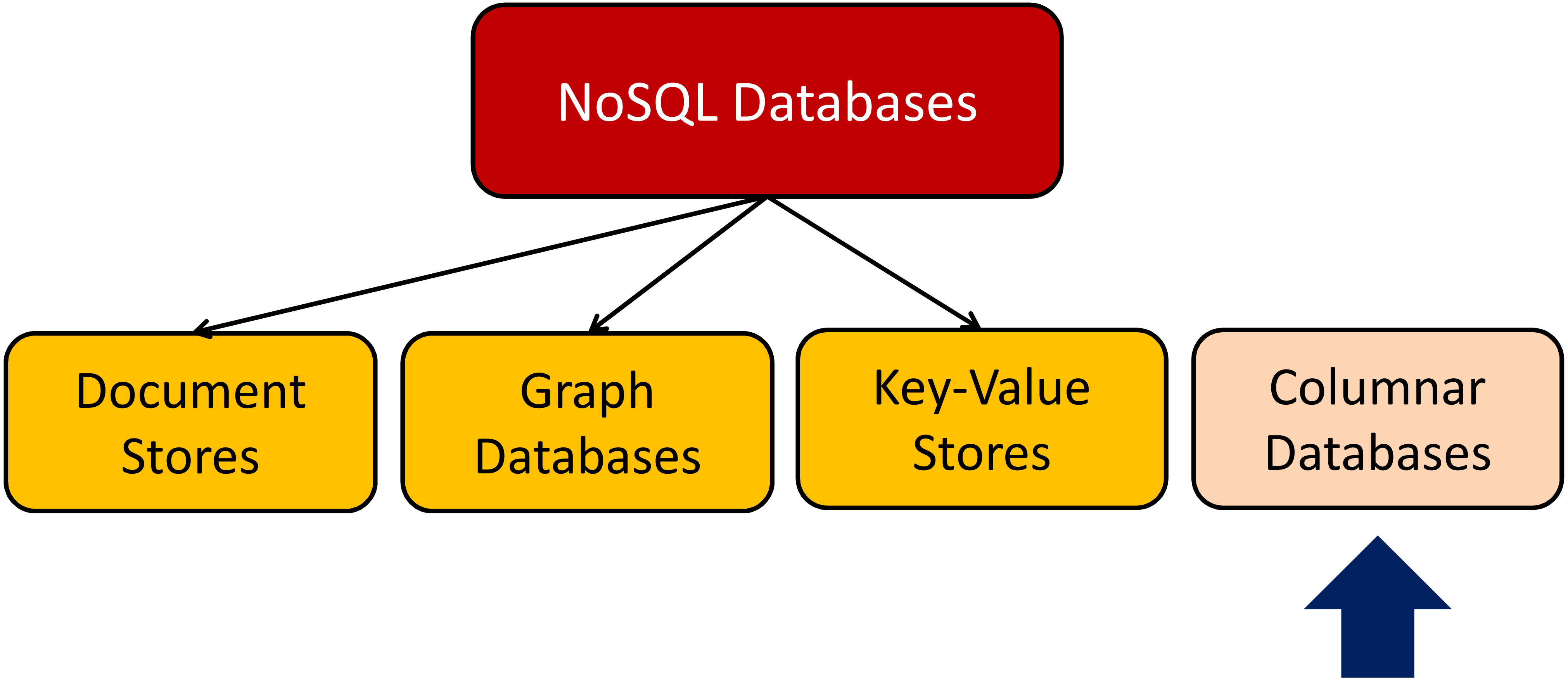
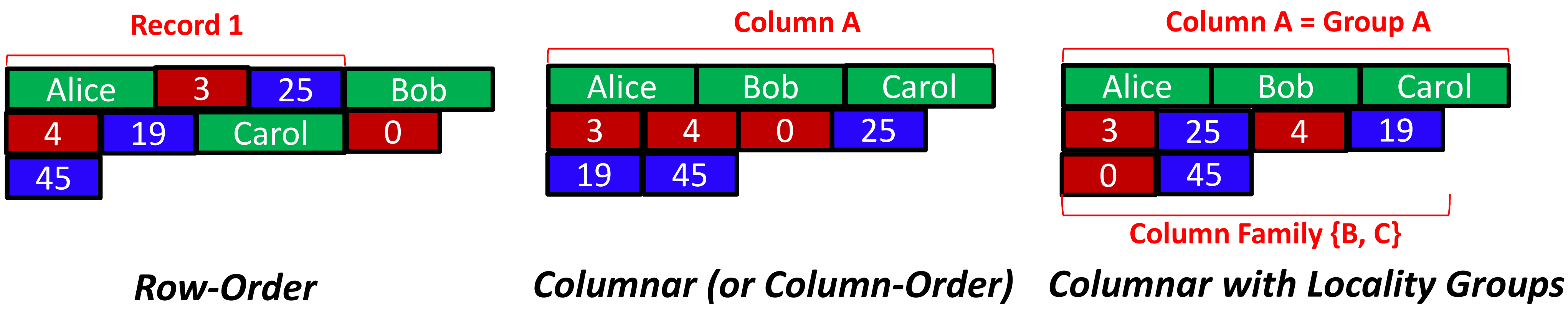


Columnar Databases

- Columnar databases are a hybrid of RDBMSs and Key-Value stores
  - Values are stored in groups of zero or more columns, but in Column-Order (as opposed to Row-Order)



  - Values are queried by matching keys

- E.g., Apache Druid and Vertica

Summary

- Data can be classified into 4 types, *structured*, *unstructured*, *dynamic* and *static*
- Different data types usually entail different database designs
- Databases can be scaled *up* or *out*
- The *2PC protocol* can be used to ensure strict consistency
- Strict consistency limits scalability

Summary (*Cont'd*)

- The *CAP theorem* states that any distributed database with shared data can have at most two of the three desirable properties:
  - **C**onsistency
  - **A**vailability
  - **P**artition Tolerance

- The CAP theorem lead to various designs of databases with *relaxed* ACID guarantees

Summary (*Cont'd*)

- *NoSQL* (or *Not-Only-SQL*) databases follow the *BASE properties*:
  - **B**asically **A**vailable
  - **S**oft-State
  - **E**ventual Consistency

- NoSQL databases have different types:
  - Document Stores
  - Graph Databases
  - Key-Value Stores
  - Columnar Databases