Database Applications
NoSQL Databases

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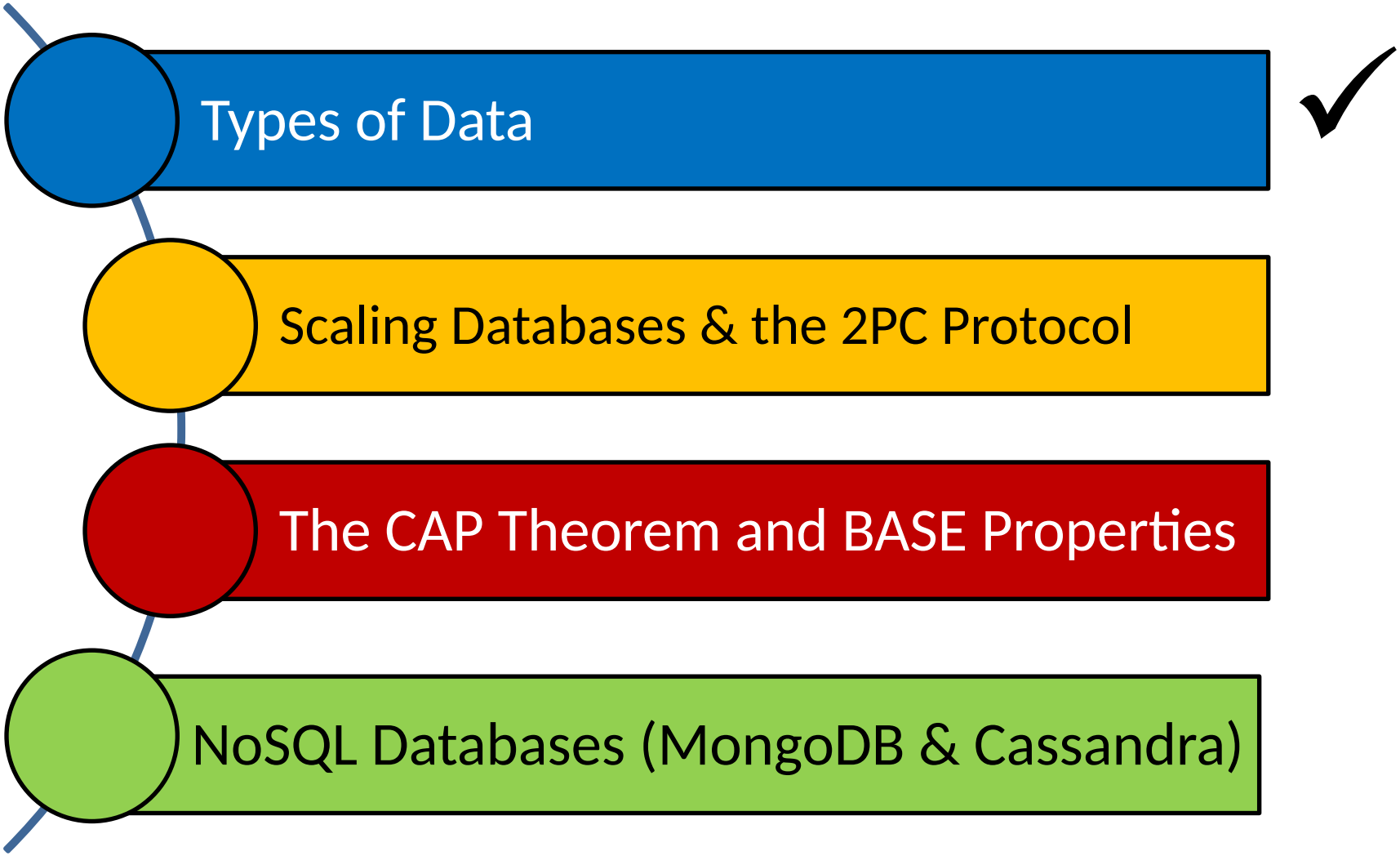
Today…

- Last Session:
  - Recovery Management followed by OO-DBs
- Today's Session:
  - NoSQL databases

Outline


Types of Data
Scaling Databases & the 2PC Protocol
The CAP Theorem and BASE Properties
NoSQL Databases (MongoDB & Cassandra)

Types of Data

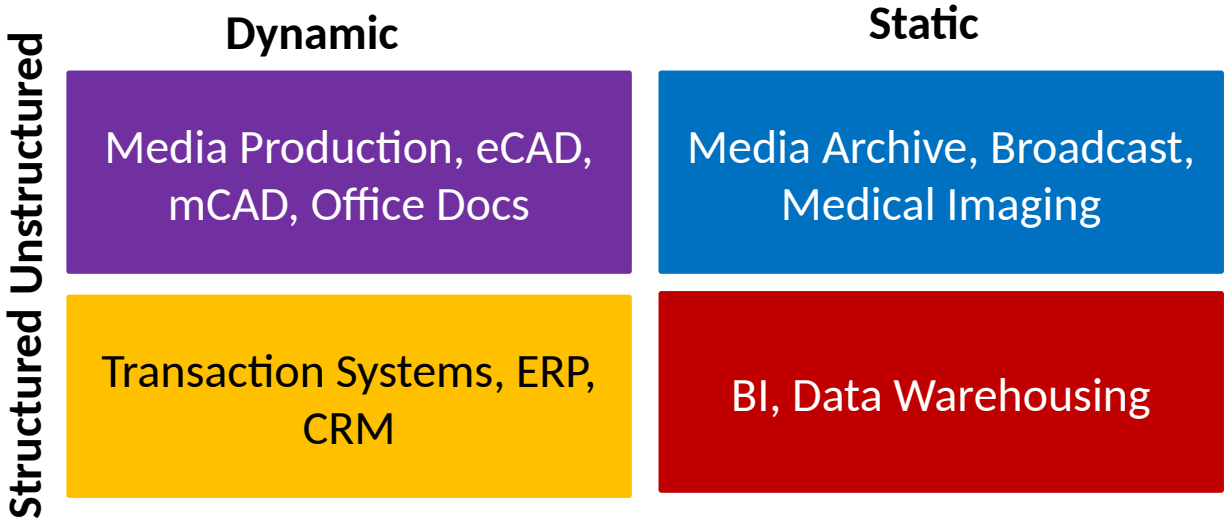
- Data can be broadly classified into four types:
  1. Structured Data:
     - Have a predefined model, which organizes data into a form that is relatively easy to store, process, retrieve and manage
     - E.g., relational data
  2. Unstructured Data:
     - Opposite of structured data
     - E.g., 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?

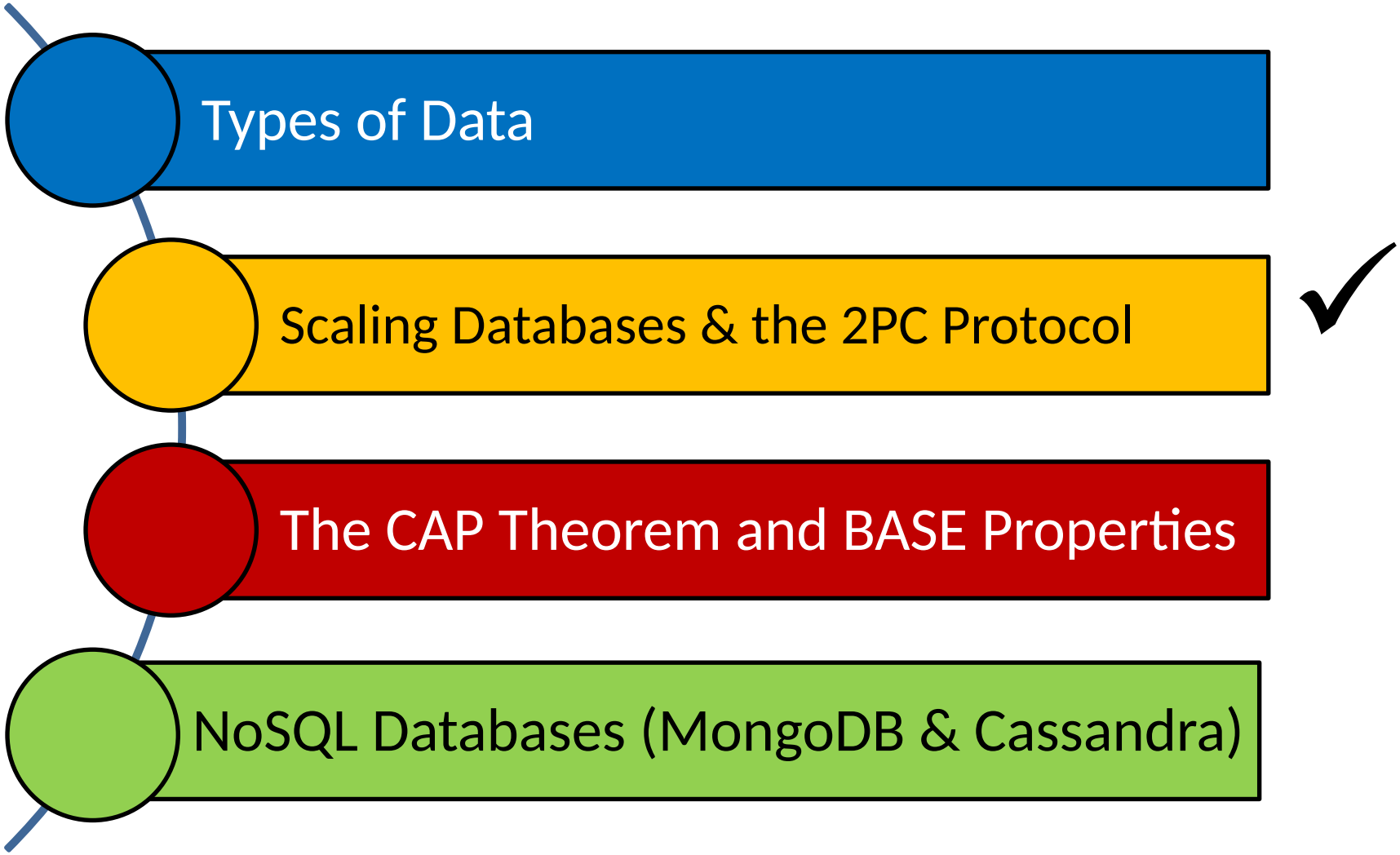
- Segmenting data into one of the following 4 quadrants can help in designing and developing a pertaining storage solution



- Relational databases are usually used for structured data

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

Outline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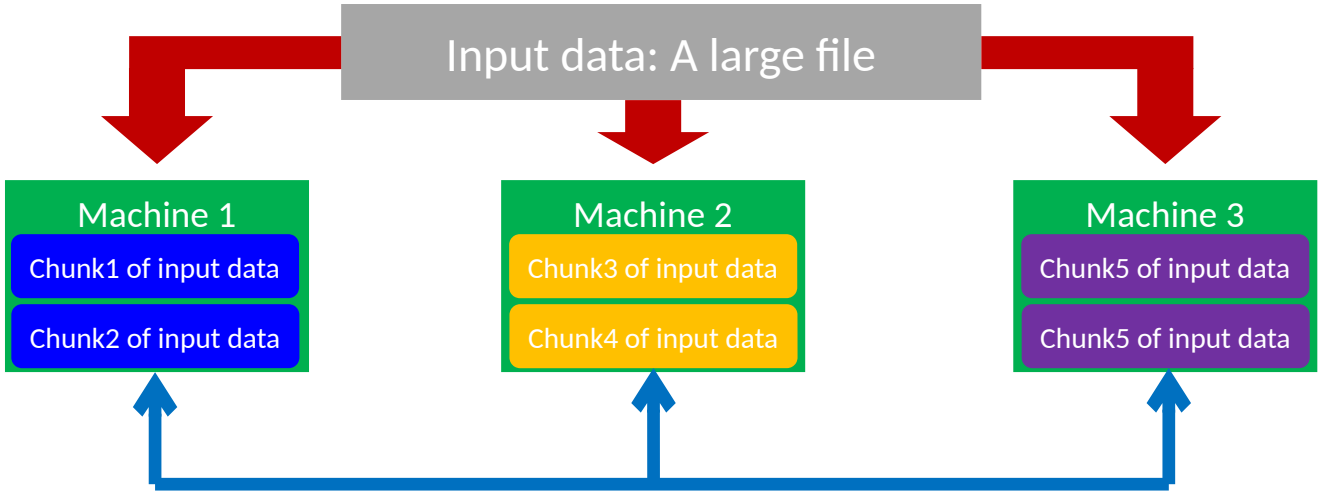
Scaling Traditional Databases

- 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 $1-s$ 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:

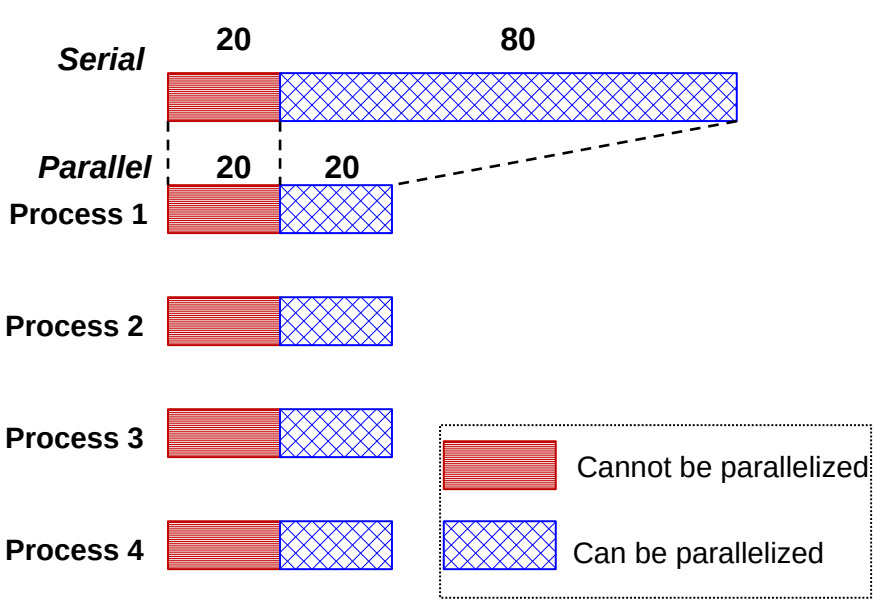
$$\frac{1}{s+\frac{1-s}{p}} = \frac{1}{0.2+\frac{0.8}{4}} = 2.5 \text{ times}$$

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

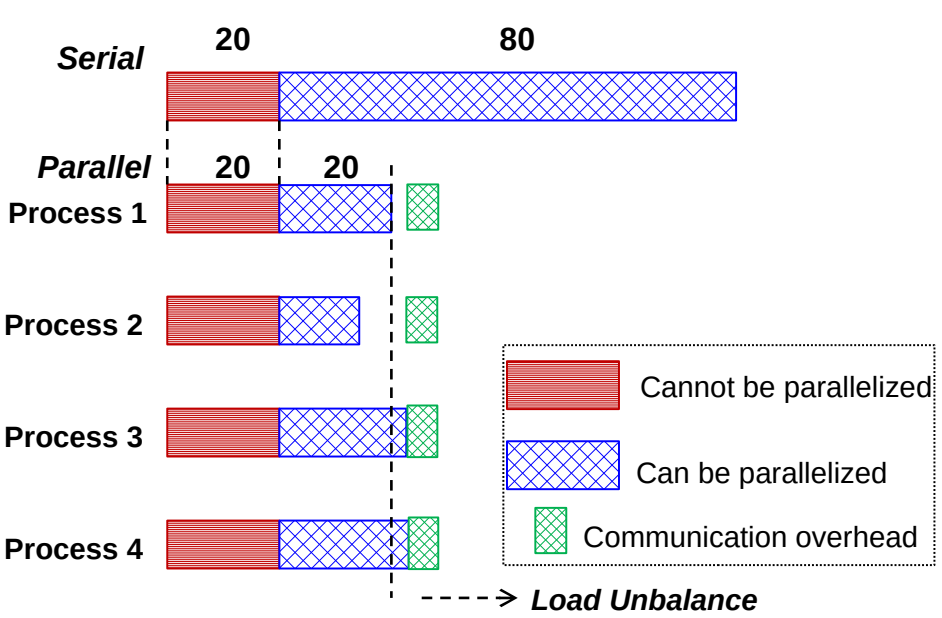
Real Vs. Actual Cases

- Amdahl's argument is too simplified

- In reality, communication overhead and potential workload imbalance exist upon running parallel programs



1. Parallel Speed-up: An Ideal Case



2. Parallel Speed-up: An Actual Case

Why Replicating Data?

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

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?

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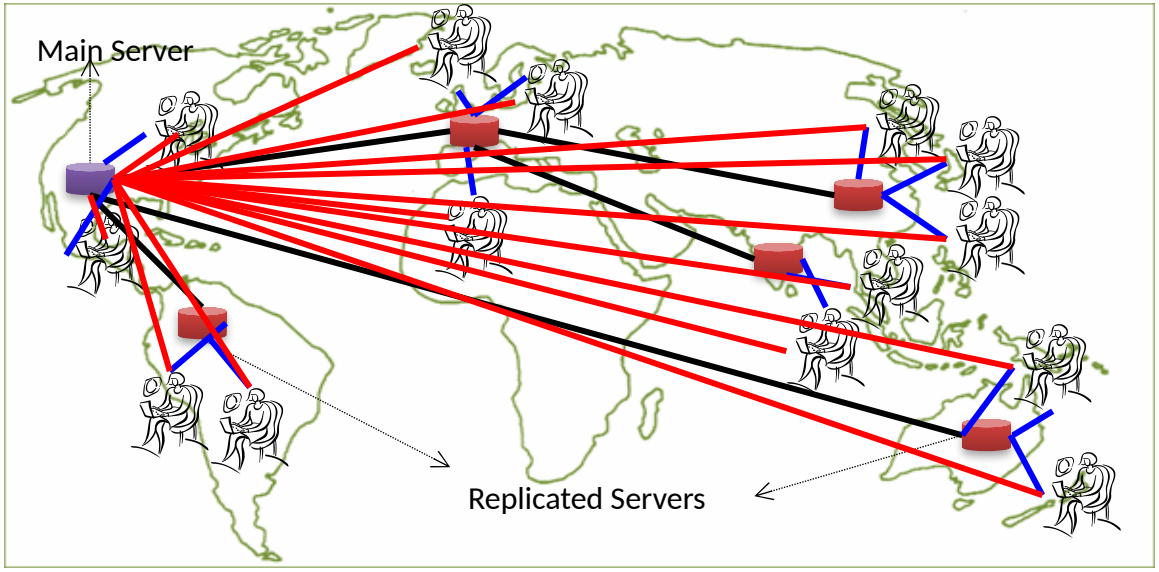
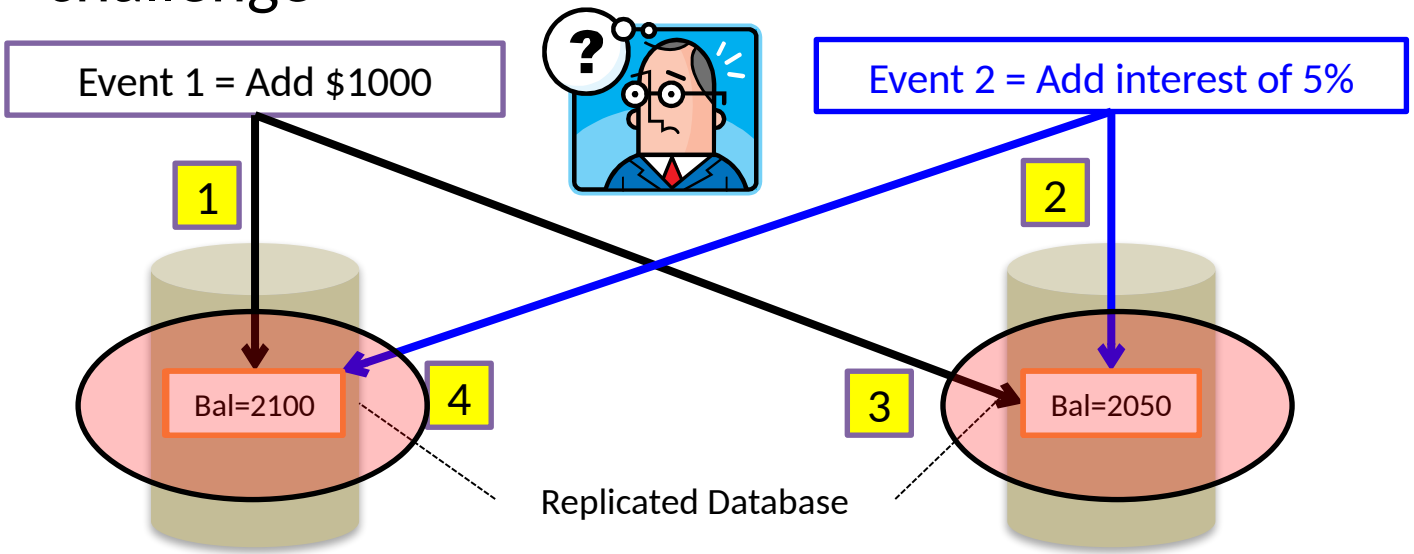


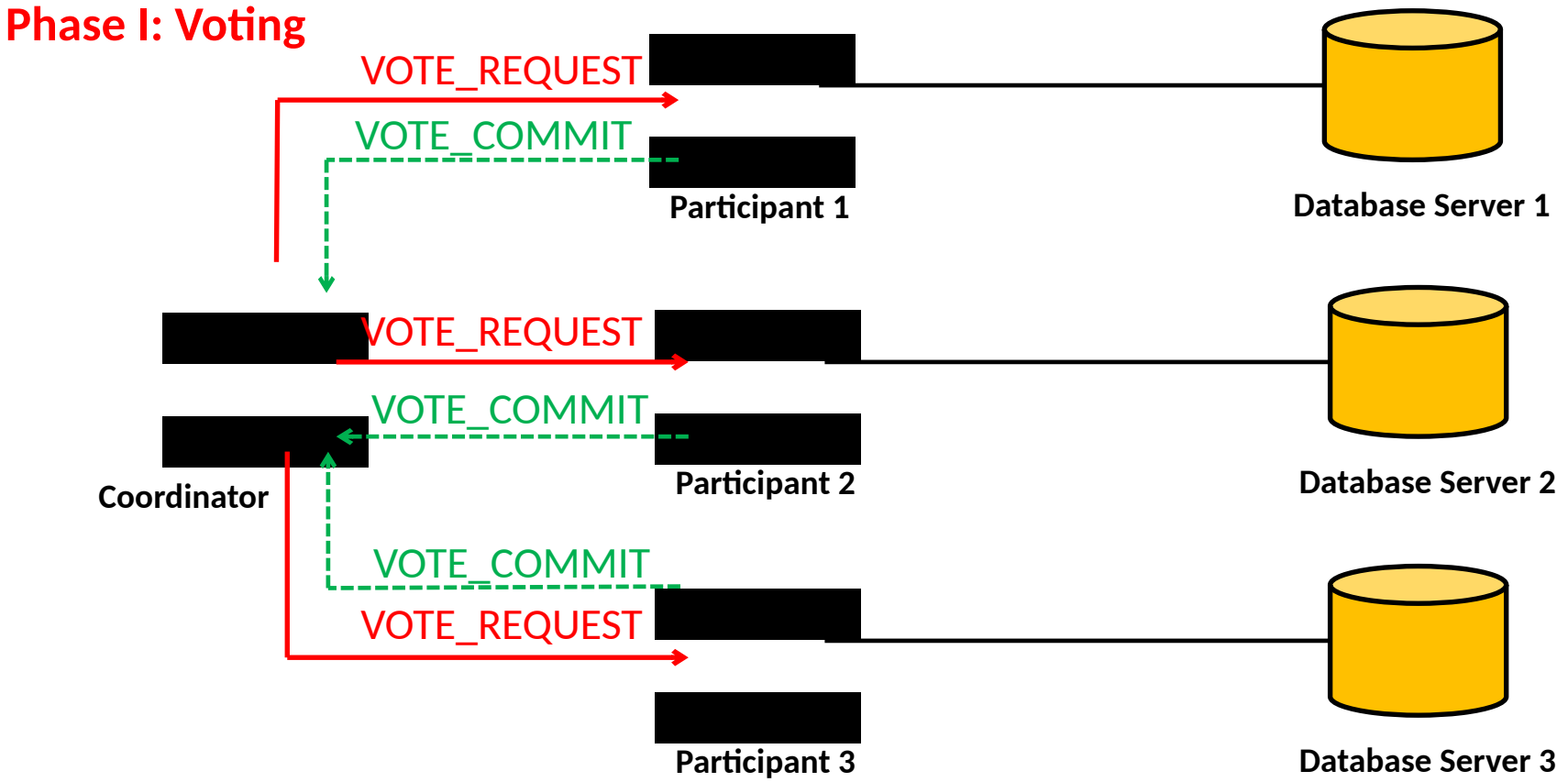
But Consistency Becomes a Challenge??

- 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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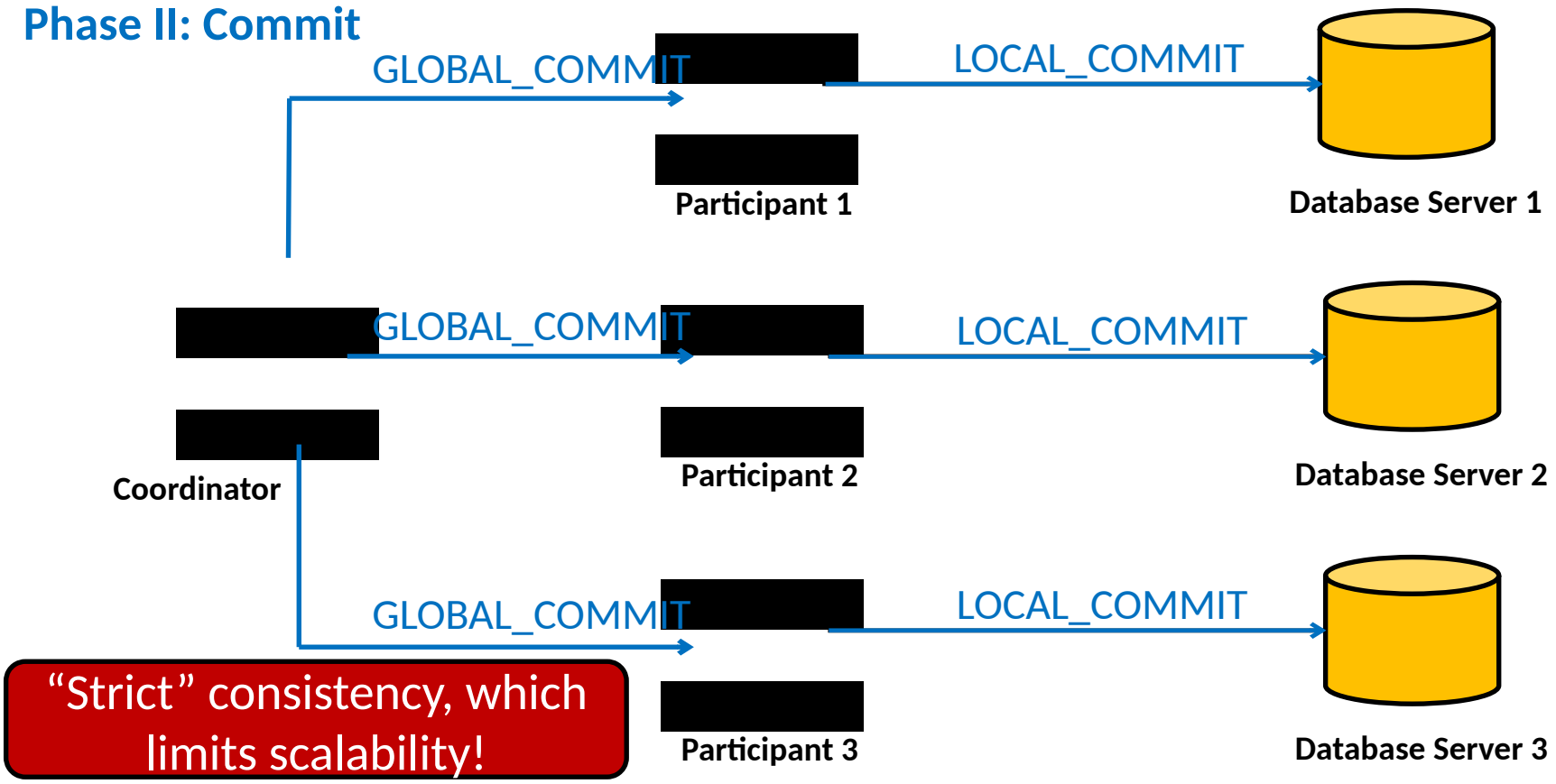

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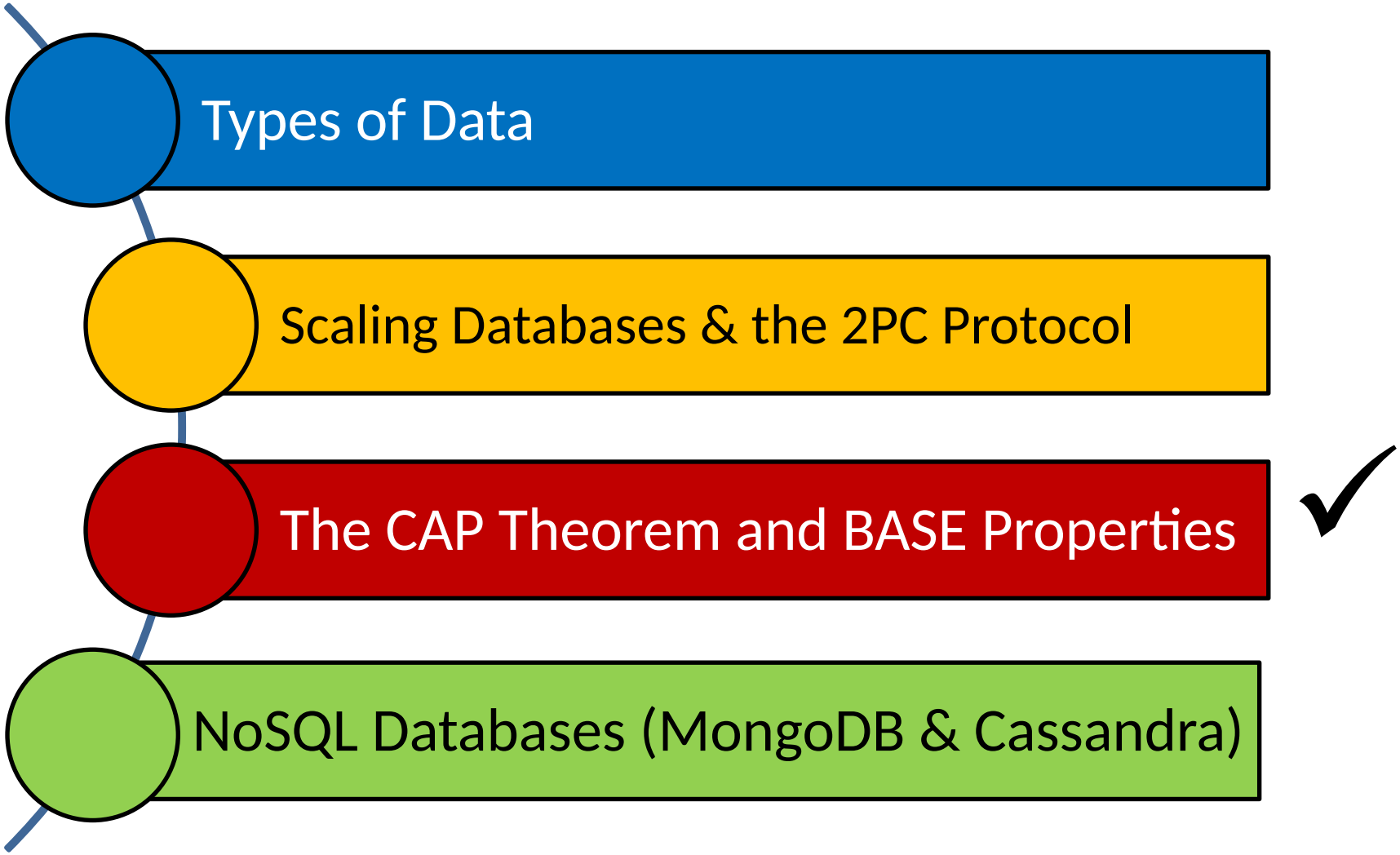
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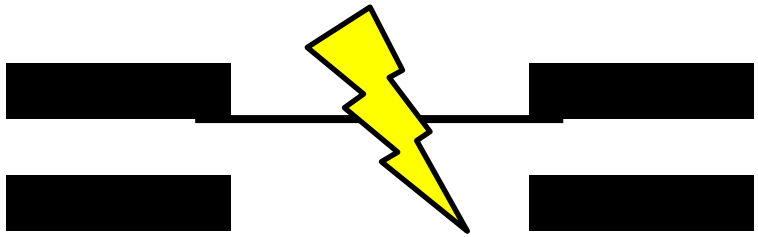
The CAP Theorem

- 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.

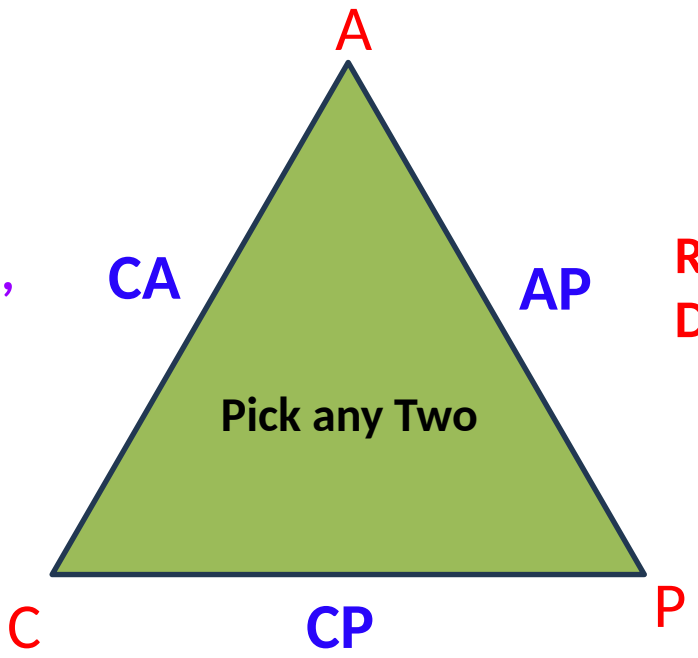
- Consistency + Availability is only possible if there is no network partition, thereby forfeiting Partition Tolerance.

When to choose consistency over availability and vice-versa..

- Choose availability over consistency when your business requirements allow some flexibility around when the data in the system synchronizes.
- Choose consistency over availability when your business requirements demand atomic reads and writes.

Glimpse of databases that adhere to two of the three characteristics

Traditional RDBMS, PostgreSQL, MySQL, etc.,



Riak, Cassandra, CouchDB,, Dynamo like systems

Hbase, MongoDB, Redis, BigTable like systems

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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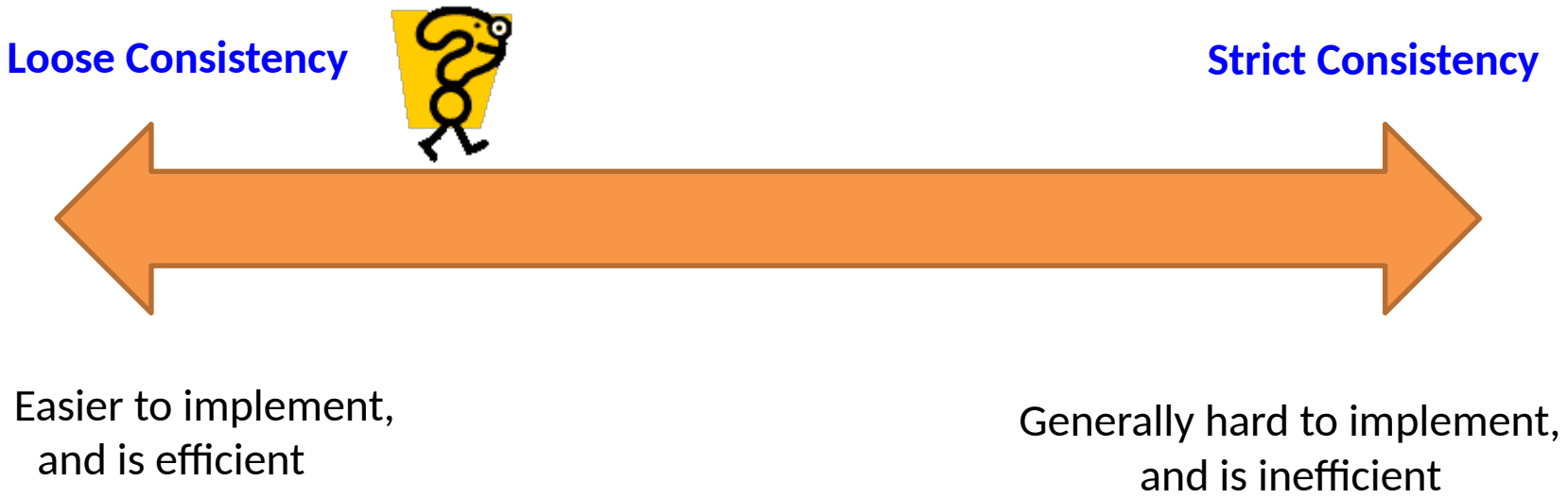

Easier to implement,
and is efficient

Generally hard to implement,
and is inefficient

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:
  - **Basically Available**: the system guarantees Availability
  - **Soft-State**: the state of the system may change over time
  - **Eventual 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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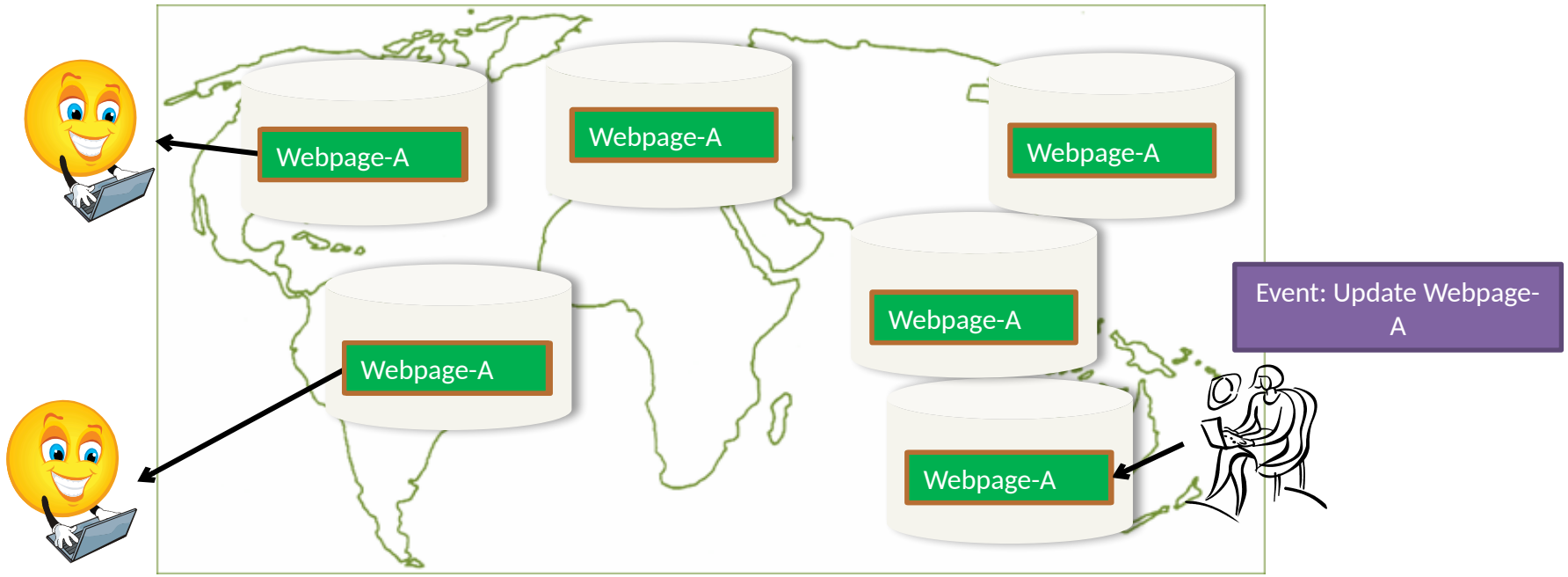
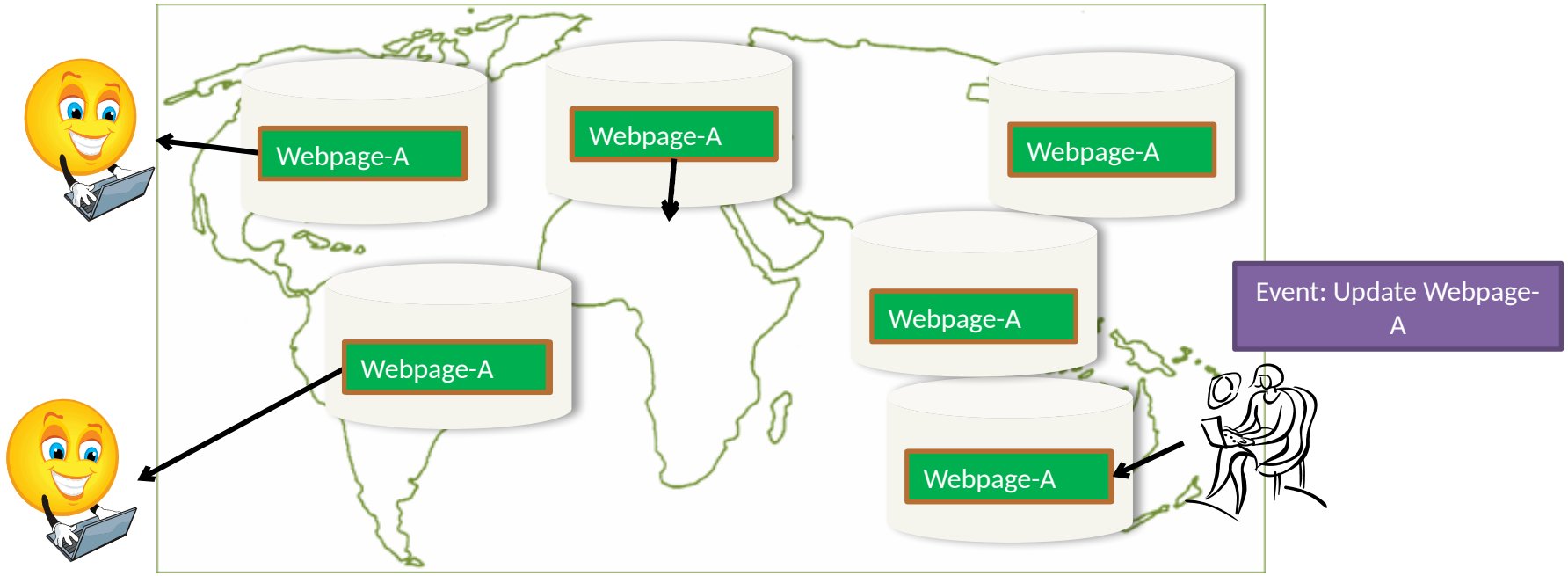


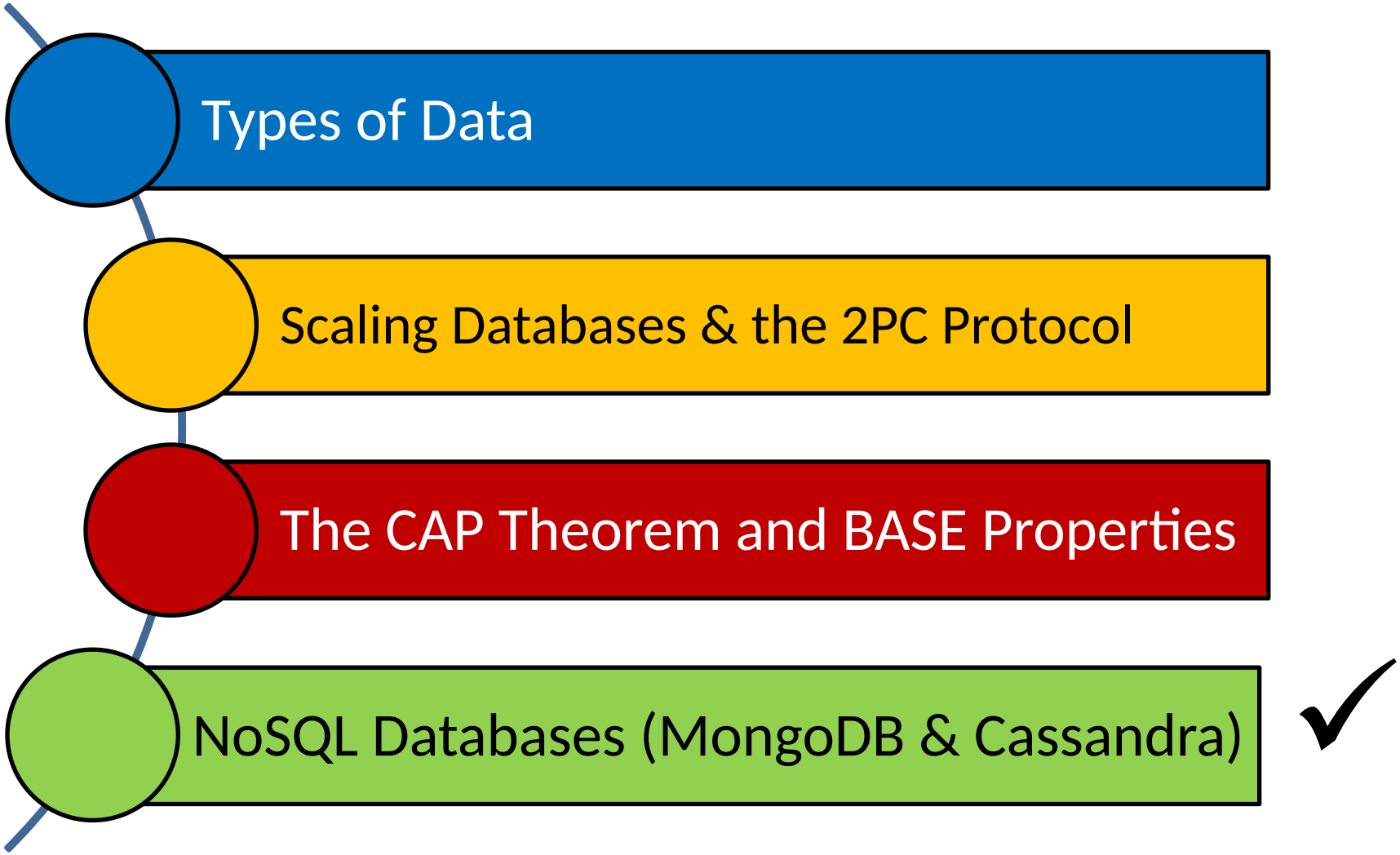
Eventual Consistency: A Main Challenge

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



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

Outline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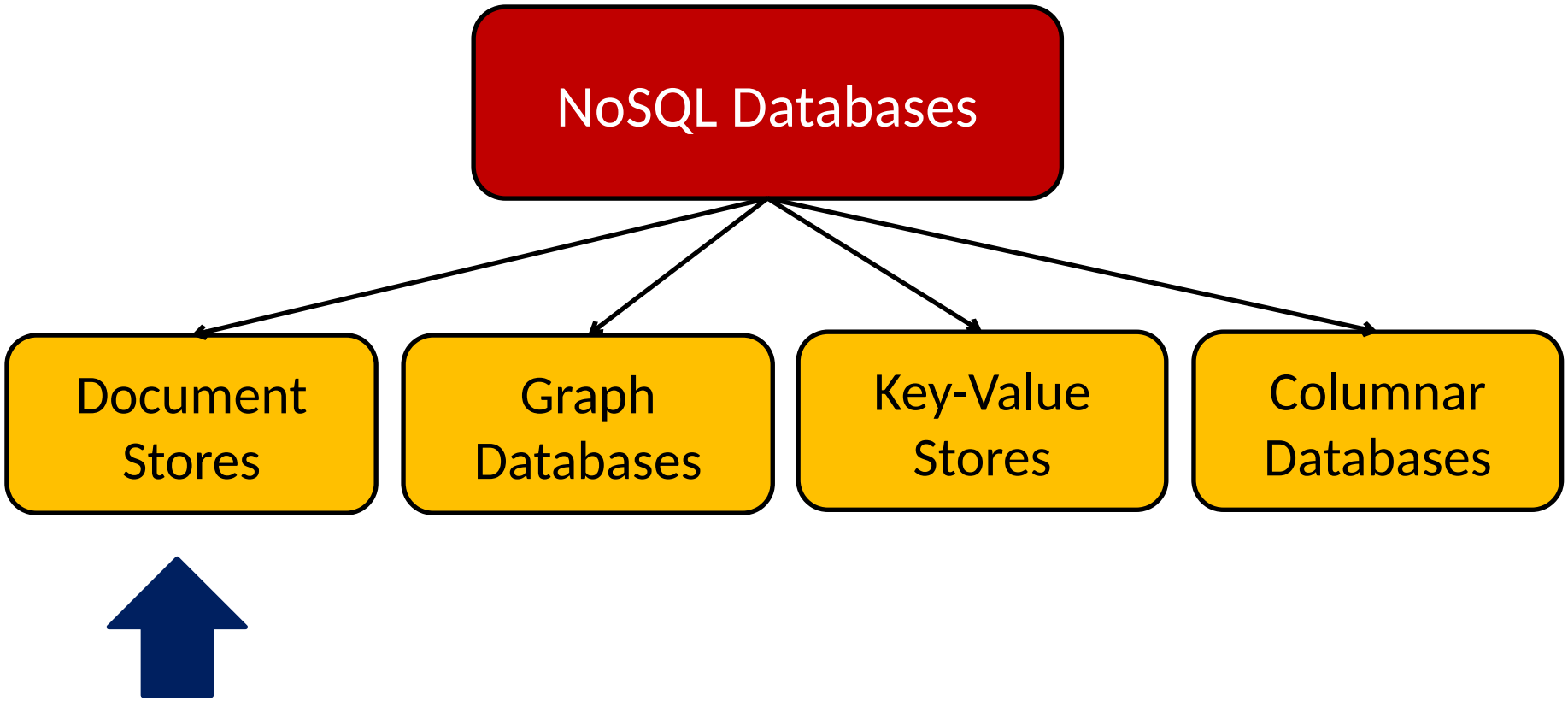
NoSQL Databases

- 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)

What MongoDB

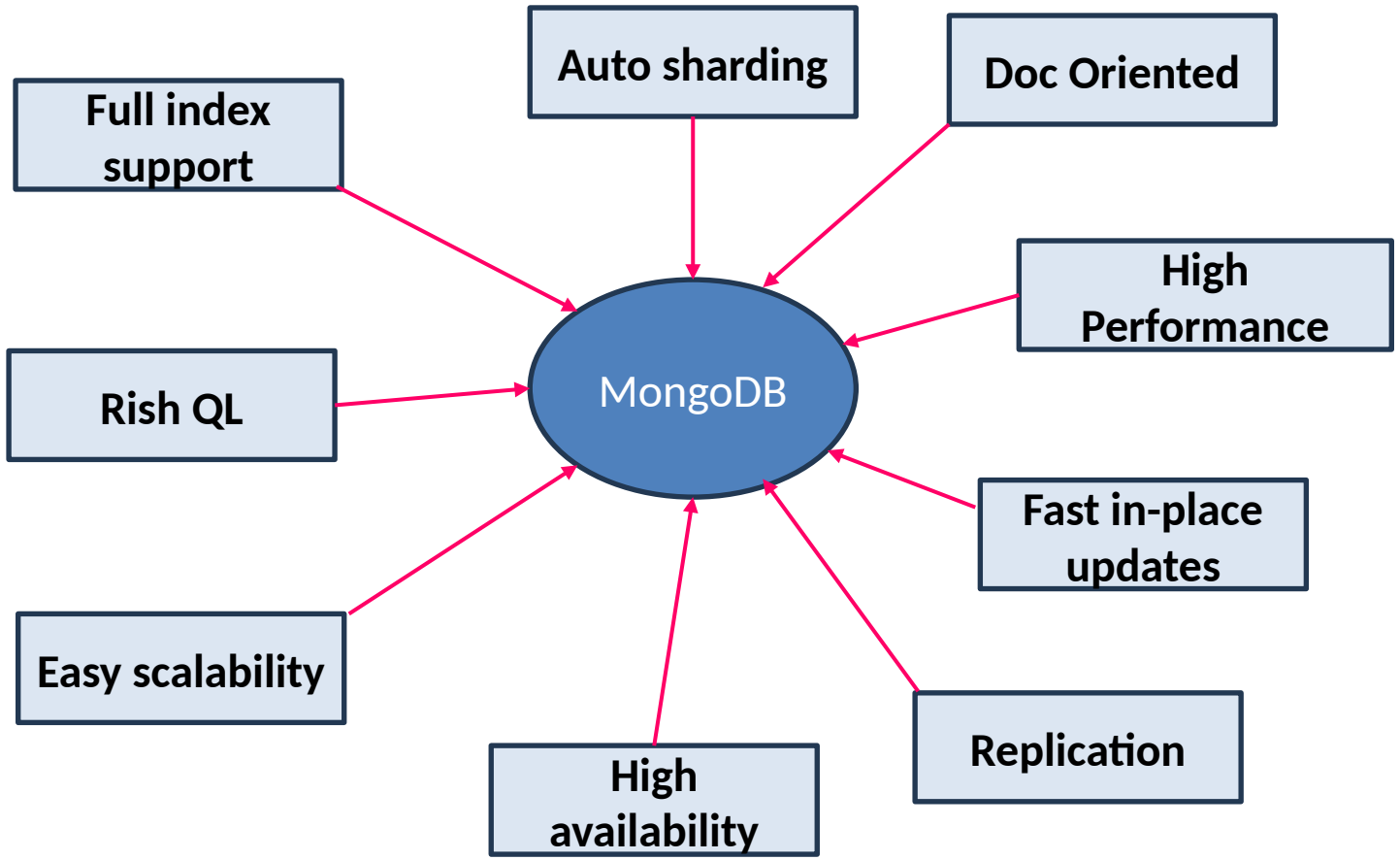
Mongo DB is:

(i) Cross-Platform
(ii) Open Source
(iii) Non-relational
(iv) Distributed
(v) NoSQL
(vi) Document Oriented data store

Why MongoDB

- ✓ Few of the major challenges with traditional RDBMS are dealing with large volume of data, rich variety of data – particularly unstructured data, and meeting up to the scale needs of enterprise data.
- ✓ The need of a DB that scale out or scale horizontally to mee the scale requirements, has flexibility w.r.t schema, is fault tolerant, is consistent and partition tolerant, and can be easily distributed over multiple of nodes in a cluster.

Why MongoDB


Auto sharding
Doc Oriented
Full index support
High Performance
MongoDB
Rish QL
Fast in-place updates
Easy scalability
Replication
High availability

Creating or Generating A Unique Key: MongoDB uses JSON mechanism, where it provides the much-needed ease to store and retrieved documents.

- The binary form of JSON is BSON, where in most of the cases it consumes less space as compared to the text-based JSON.
- Each JSON document should have a unique identifier such as _id key, similar to the primary key in relational DB. This facilitates search for documents based on the unique identifier.

Database: A Single MongoDB server can hold/house several databases

Collection: It holds several MongoDB documents

Document: It has a dynamic schema.

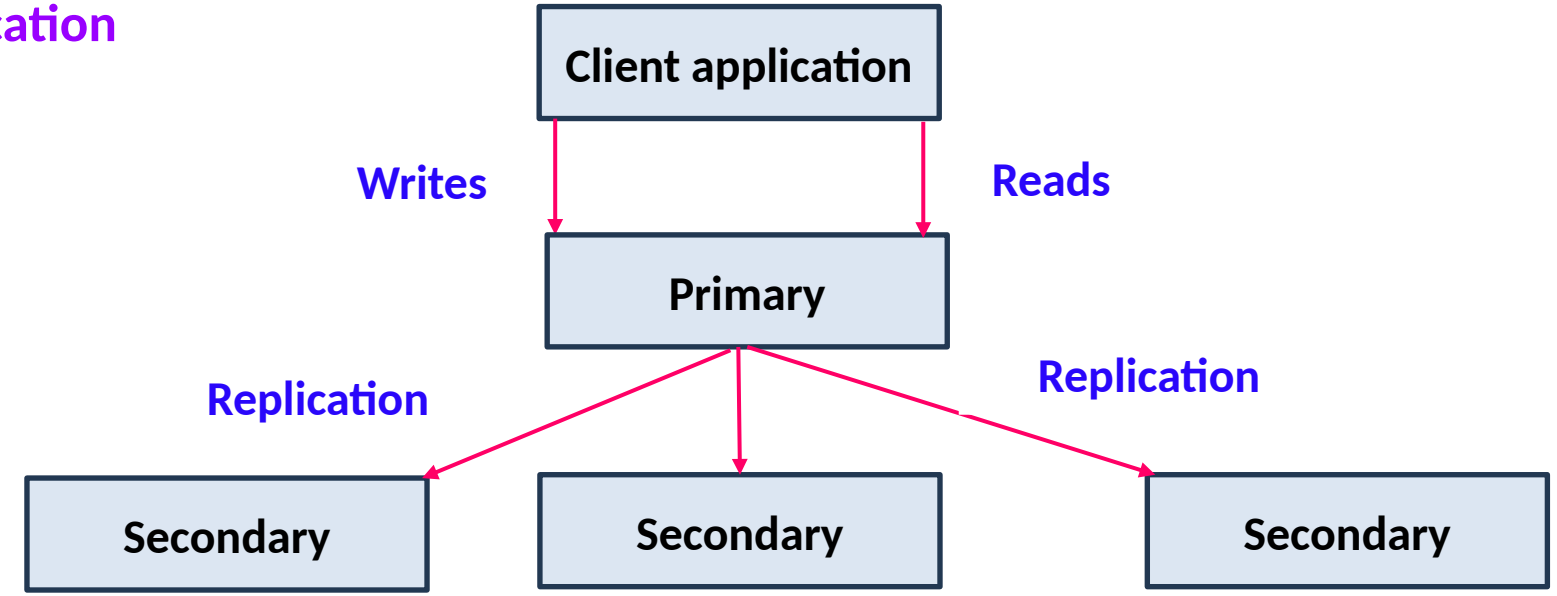
Support for Dynamic Queries: Dynamic data and static queries.

Storing Binary Data:

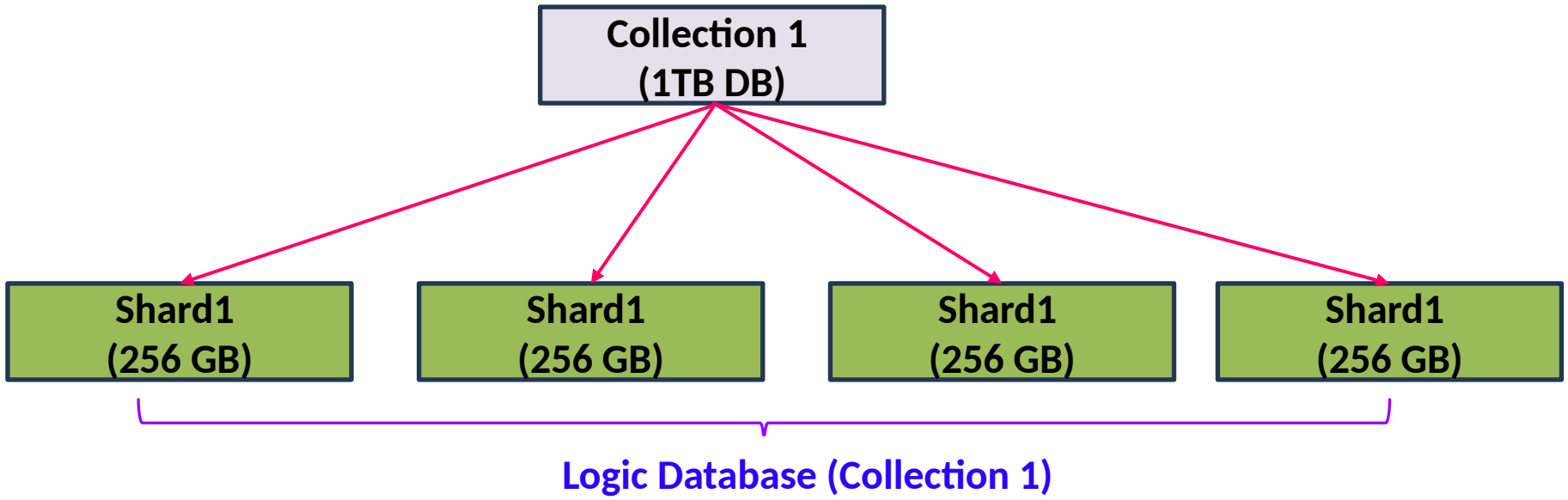
(i) MongoDb provides GridFS to support the storage of Binary data.

(ii) It stores metadata in a collection called “file”. This breaks into smaller pieces called chunks.

Replication



Sharding



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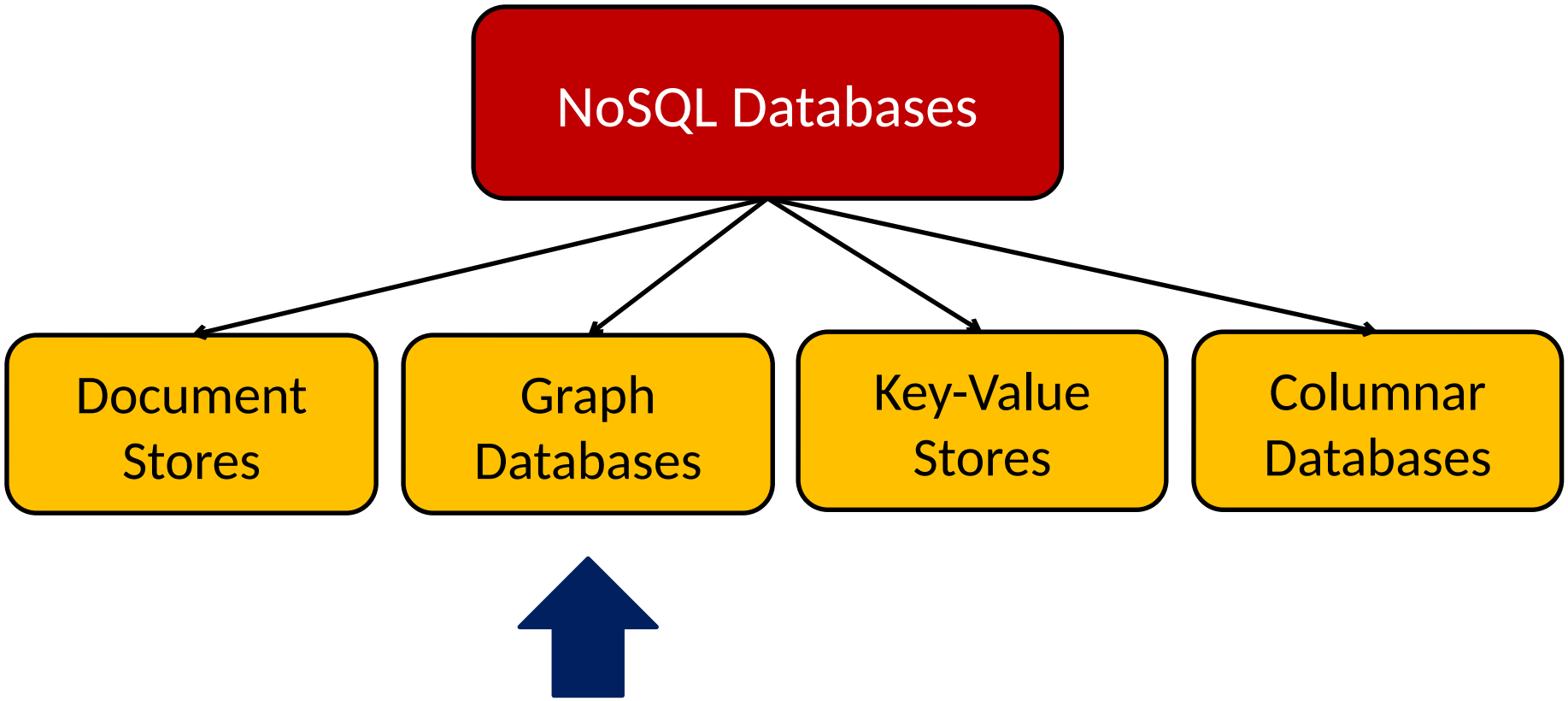

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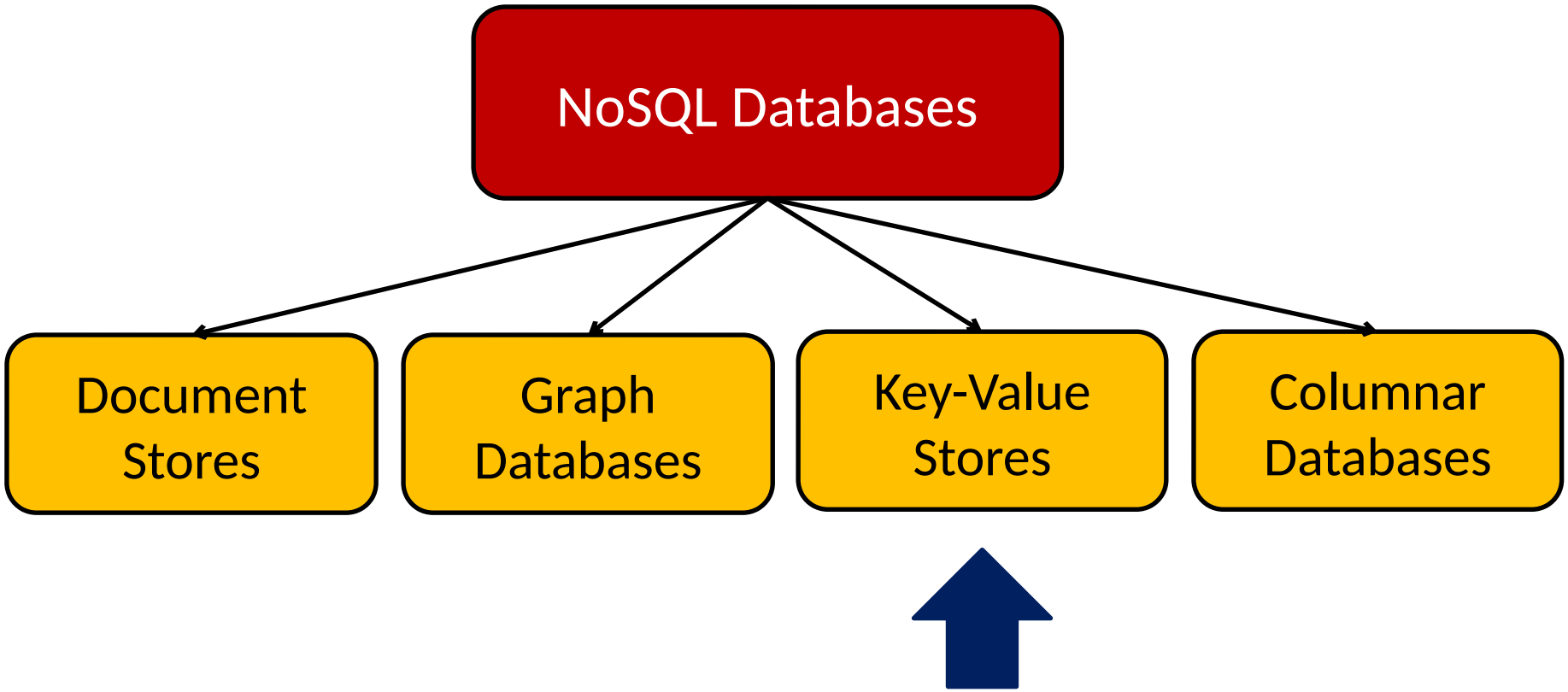

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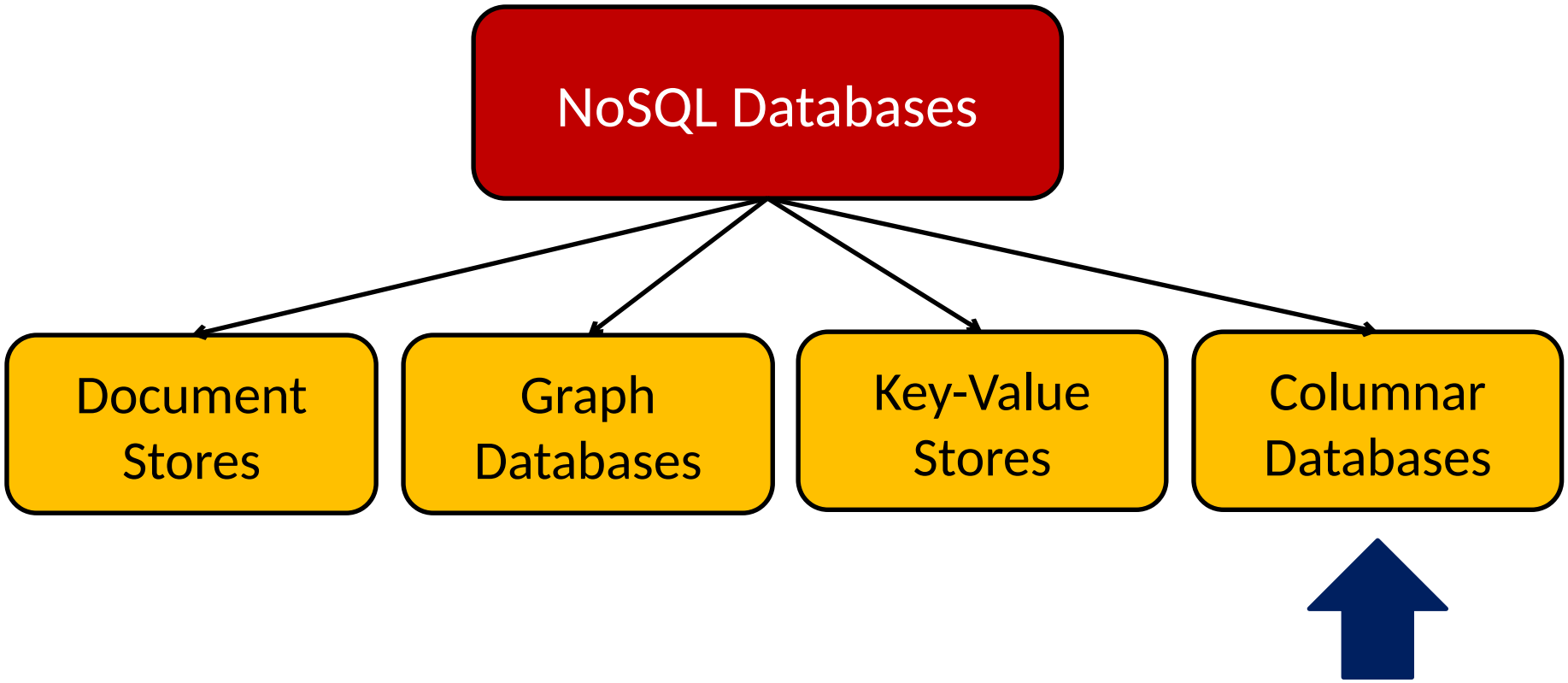
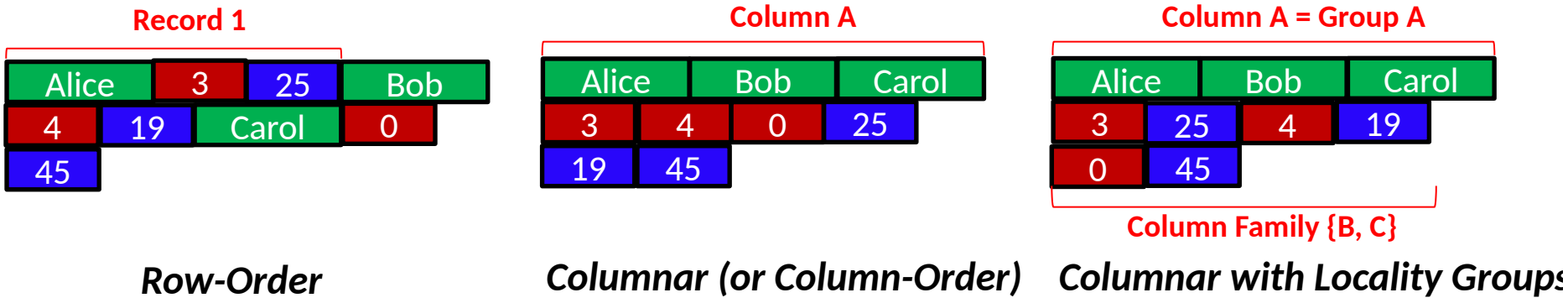


Columnar Databases

- 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)



Row-Order ***Columnar (or Column-Order)*** ***Columnar with Locality Groups***

  - Values are queried by matching keys

- E.g., HBase and Vertica

Cassandra

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