CAP theorem

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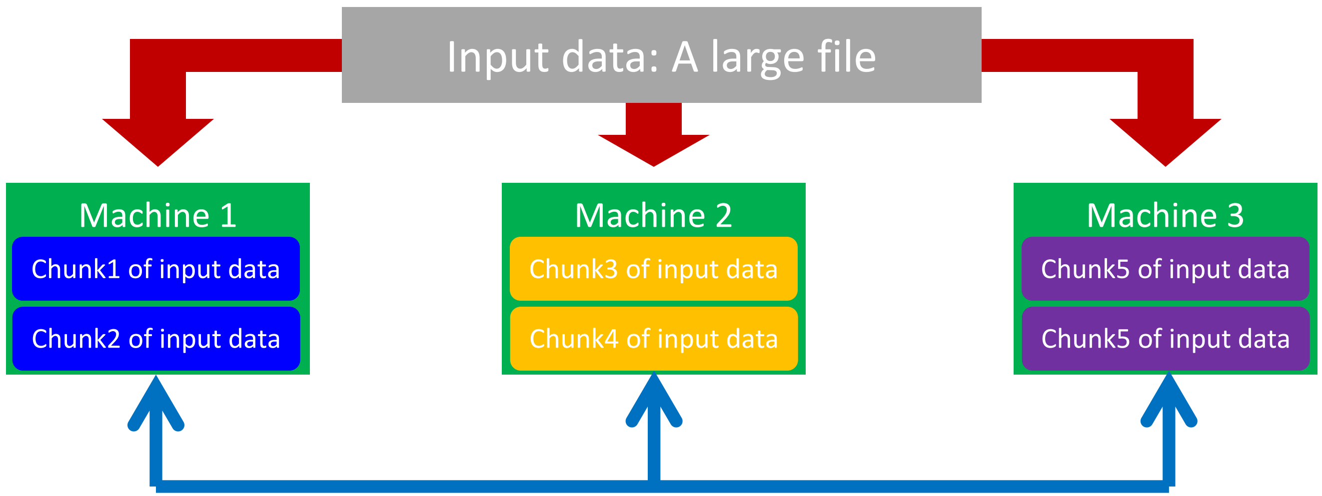
Scaling Traditional Databases

- 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

Data sharding

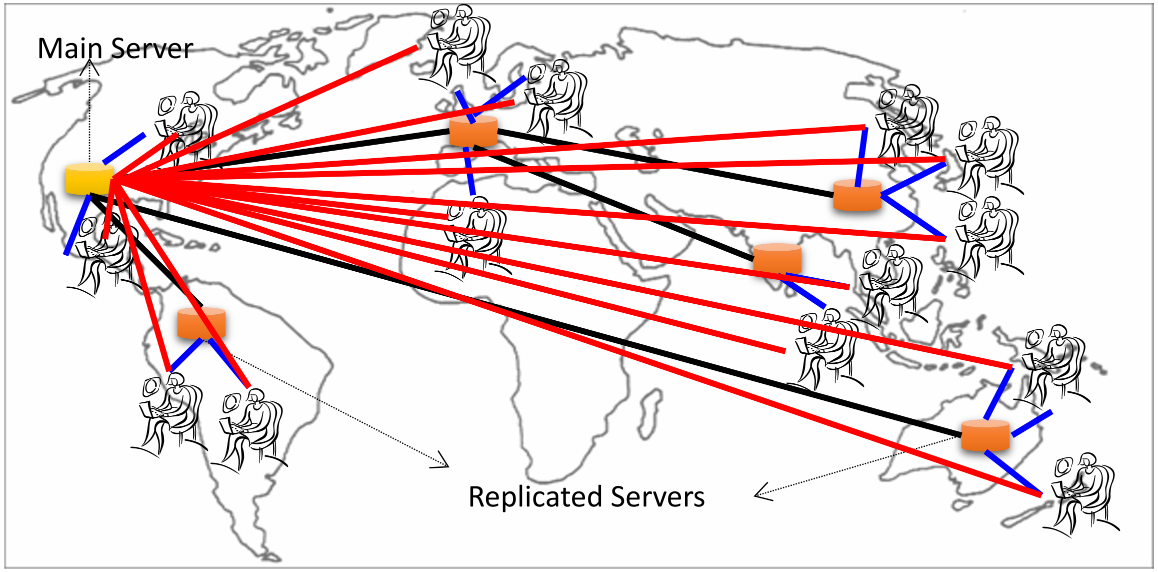
- Data is typically sharded (or striped) to allow for concurrent/parallel accesses
- Will it scale for complex query processing?



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

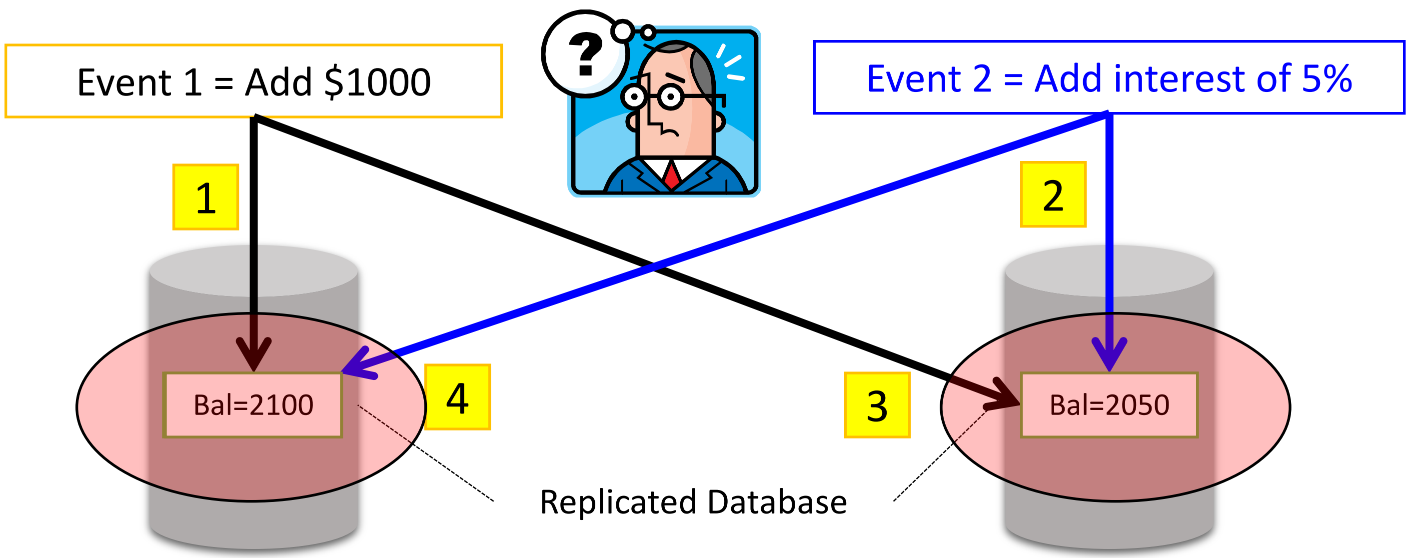
Data replicating

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



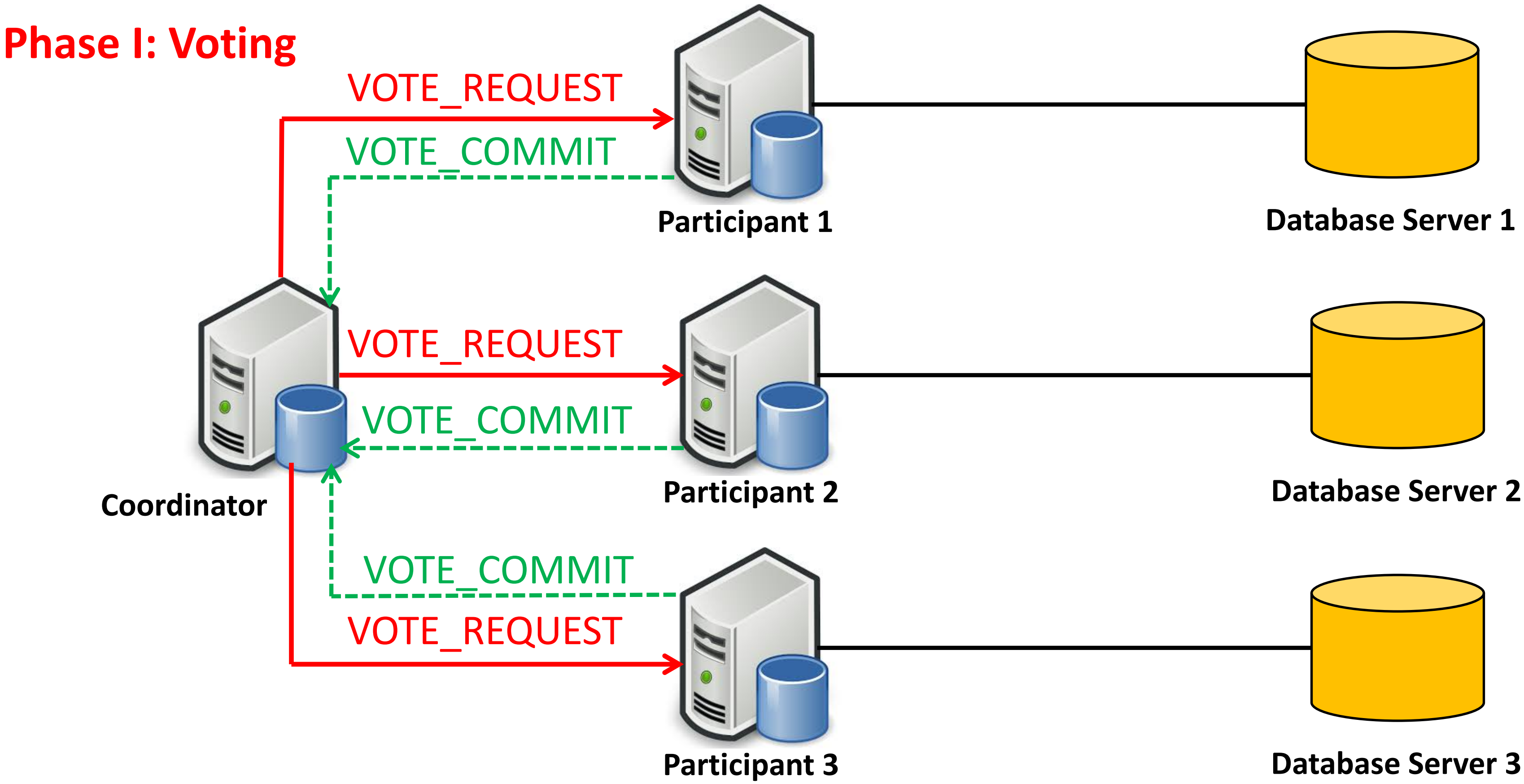
But, Consistency Becomes a Challenge

- 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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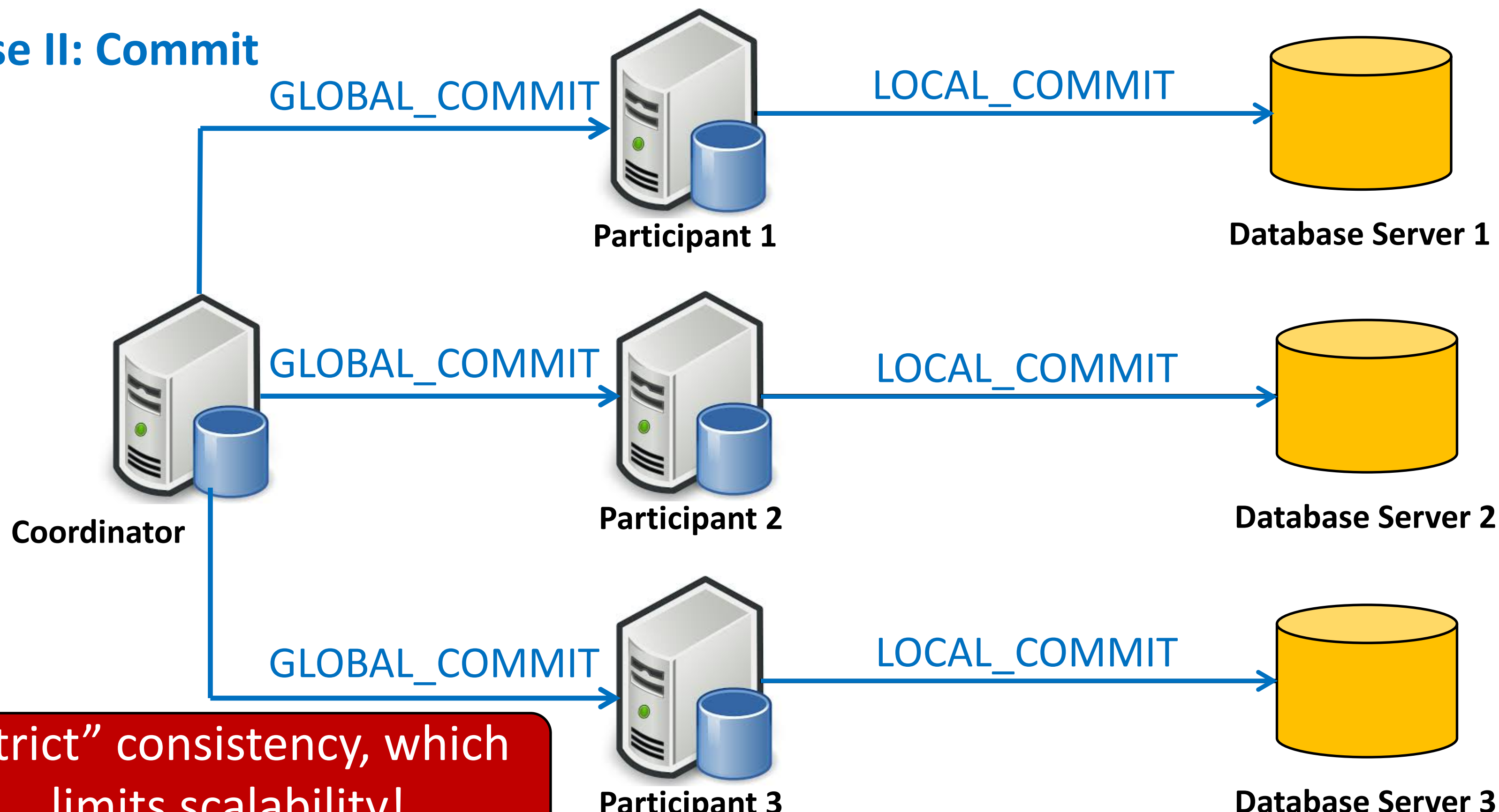
Phase II: Commit



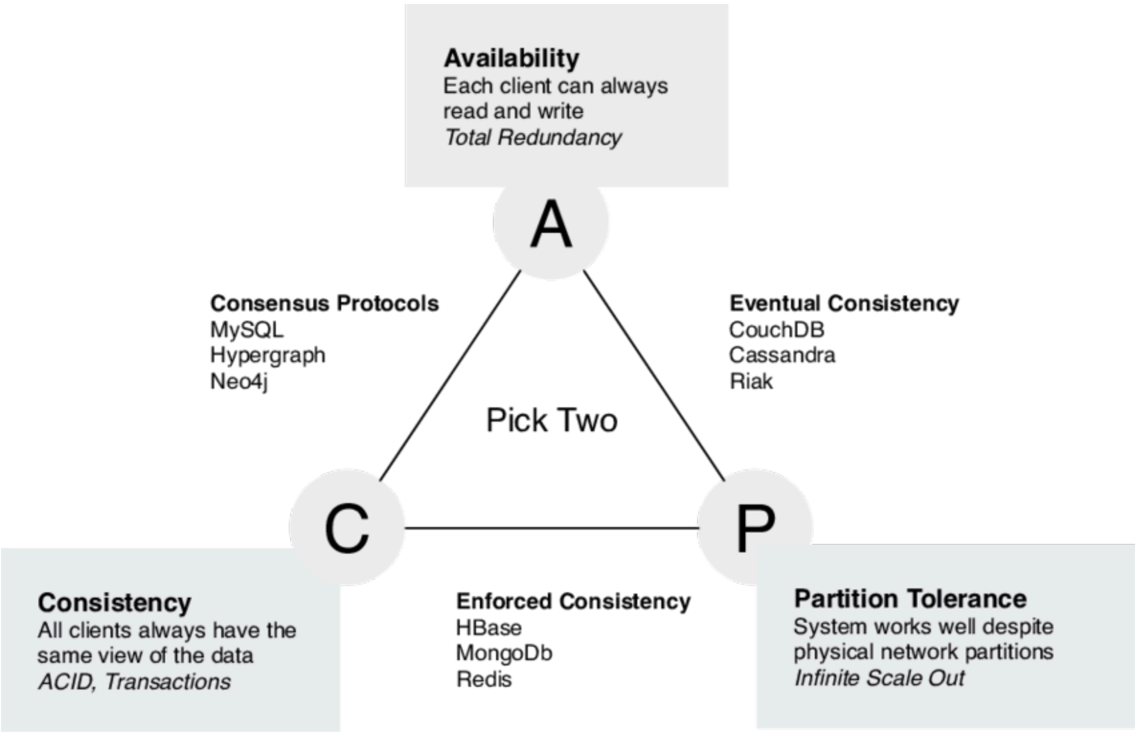
"Strict" consistency, which limits scalability!

The CAP Theorem

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

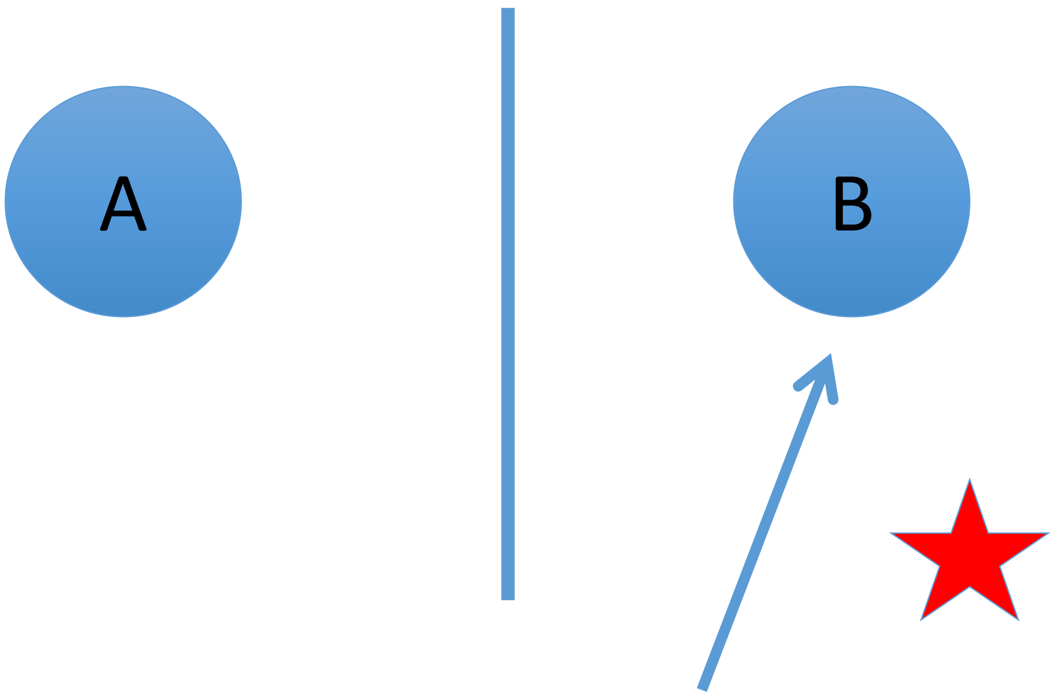
CAP theorem: any distributed database with shared data, can have ***at most two*** of the three desirable properties, C, A or P. These are trade-offs involved in distributed system by Eric Brewer in PODC 2000.

CAP Theorem


Availability
Each client can always read and write
Total Redundancy
A
Consensus Protocols
MySQL
Hypergraph
Neo4j
Eventual Consistency
CouchDB
Cassandra
Riak
Pick Two
C
P
Consistency
All clients always have the same view of the data
ACID, Transactions
Enforced Consistency
HBase
MongoDb
Redis
Partition Tolerance
System works well despite physical network partitions
Infinite Scale Out

CAP Theorem: Proof

- A simple proof using two nodes:



CAP Theorem: Proof

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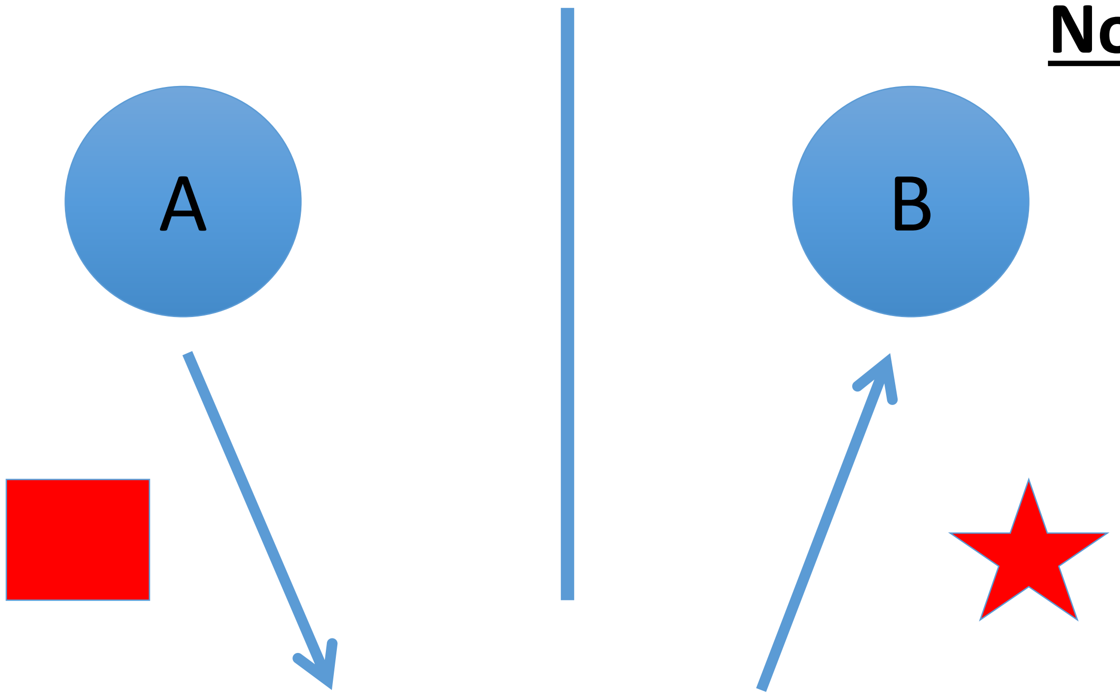
Not Consistent!



Respond to client

CAP Theorem: Proof

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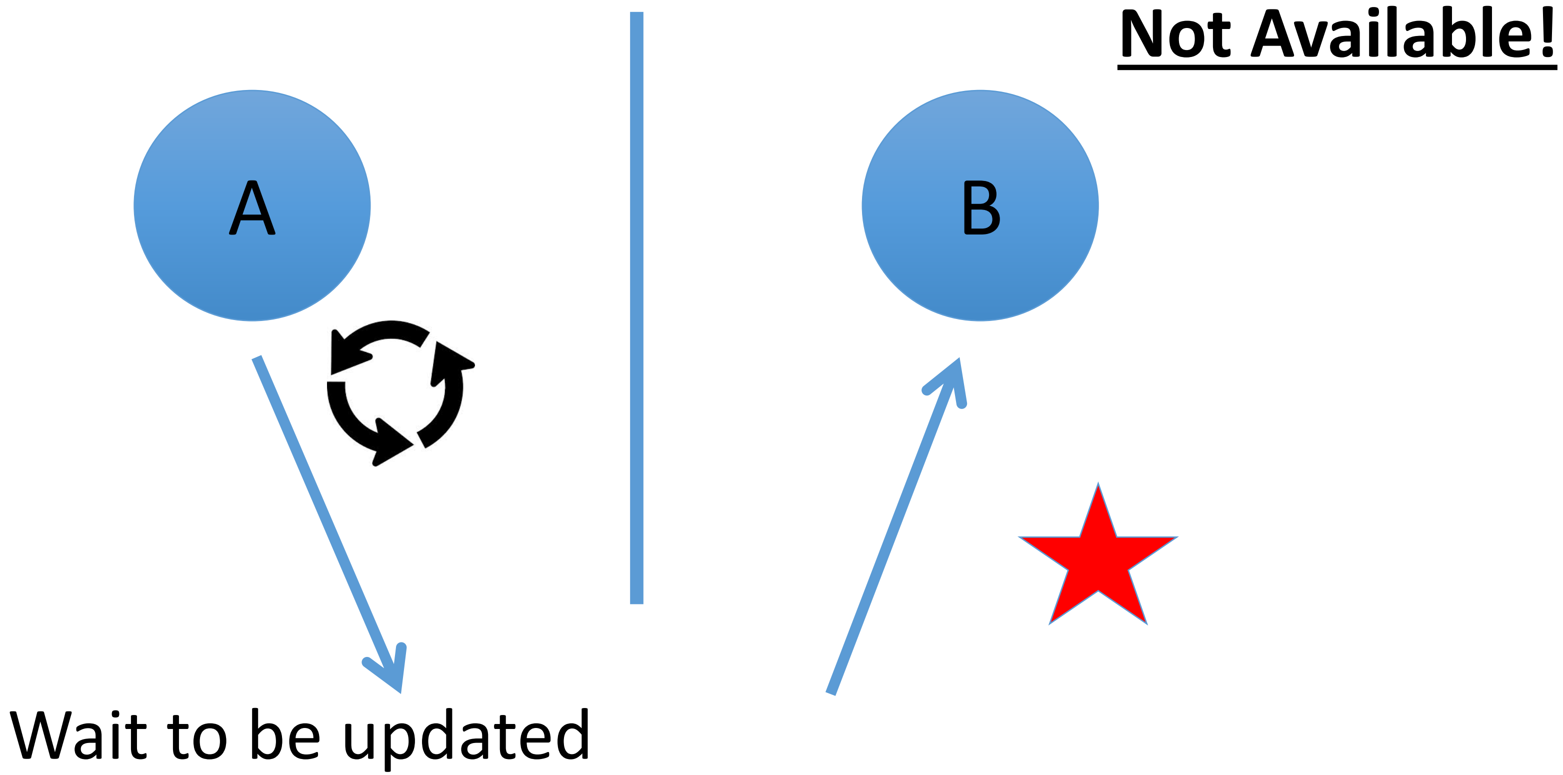

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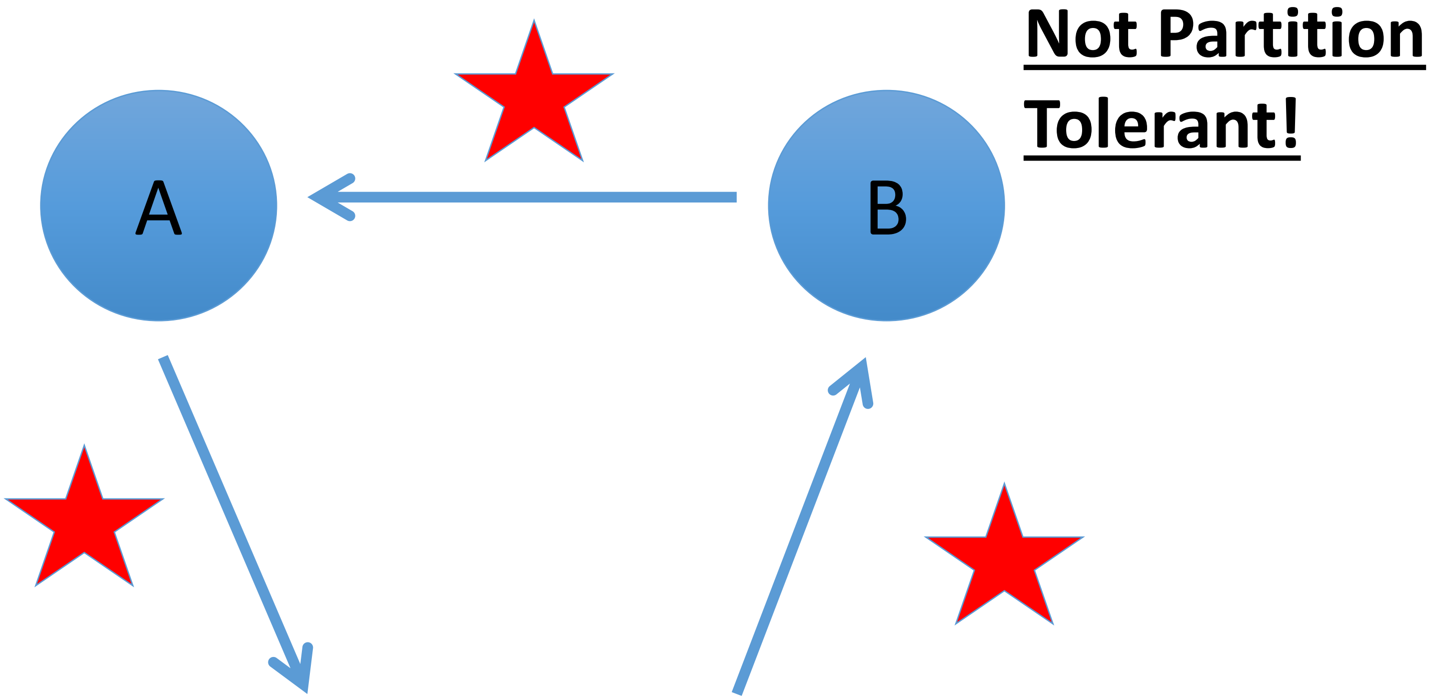

A gets updated from B

Scalability of relational databases

- The Relational Database is built on the principle of **ACID** (Atomicity, Consistency, Isolation, Durability)
- It implies that a truly distributed relational database should have **availability, consistency and partition tolerance**.
- Which unfortunately is **impossible** …

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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Loose Consistency ⟷ **Strict Consistency**

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

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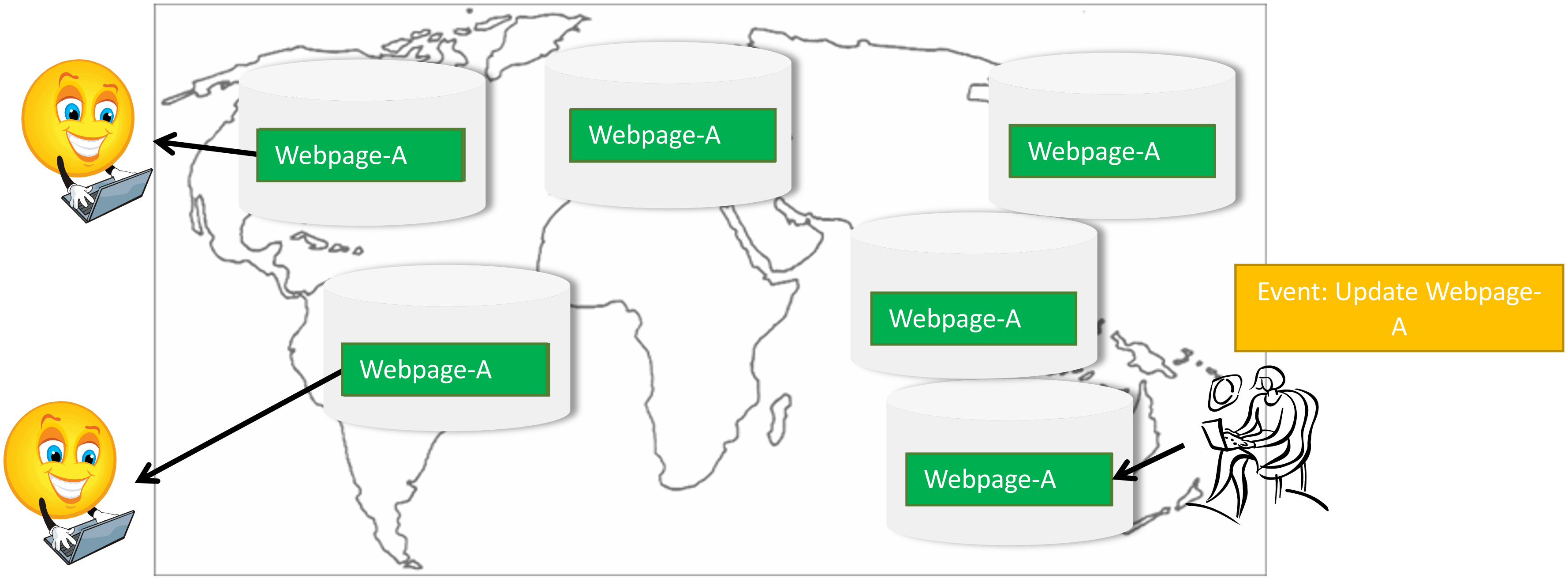
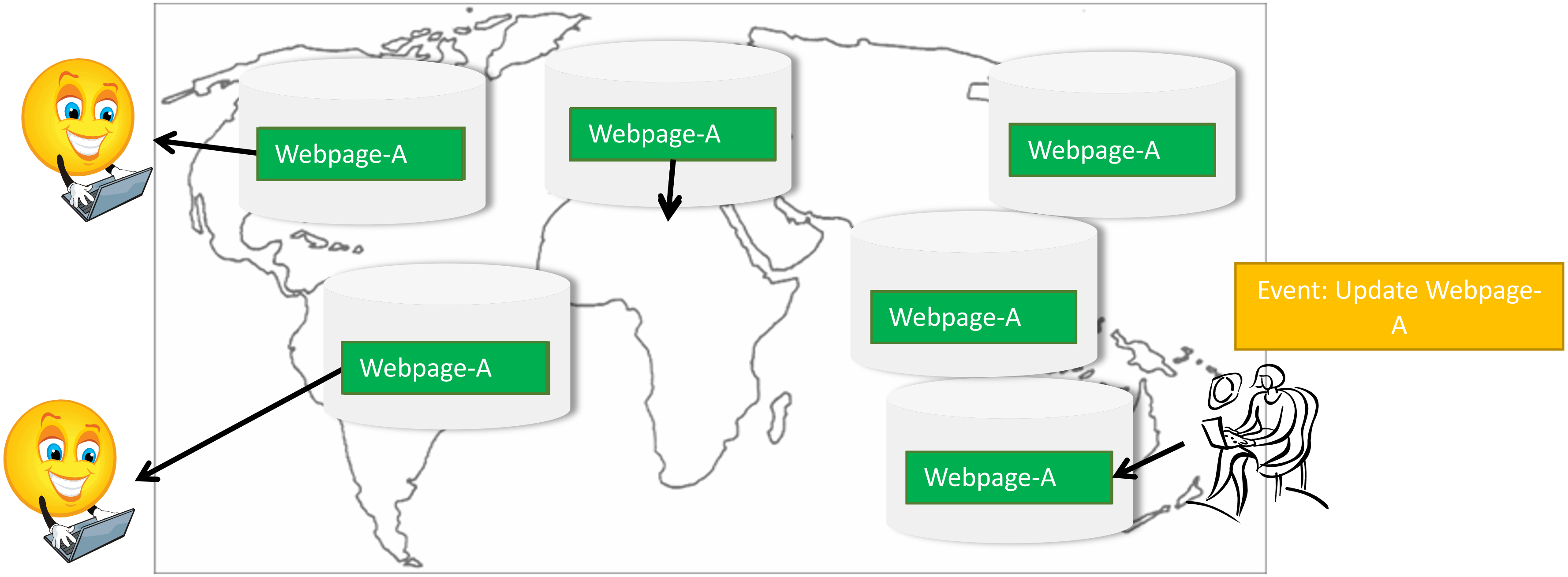


Read-after-write consistency (eg. Amazon S3)

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



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

Thank you for your attention!
Q&A