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Chapter 4

NoSQL - part 1

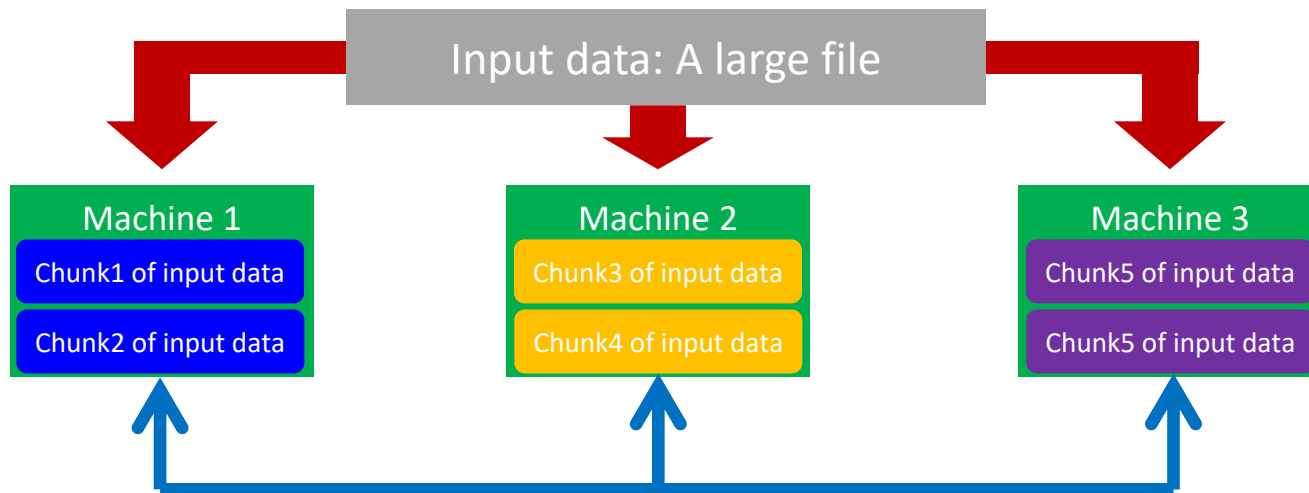
CAP theorem

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

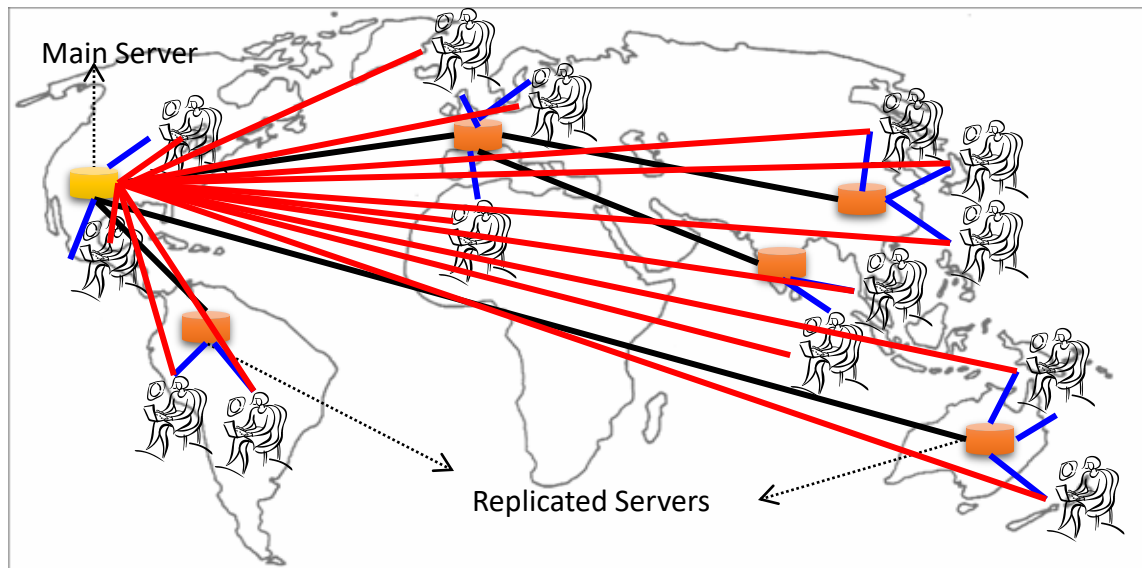
- Data is typically sharded (or striped) to allow for concurrent/parallel accesses
- Will it scale for complex query processing?



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

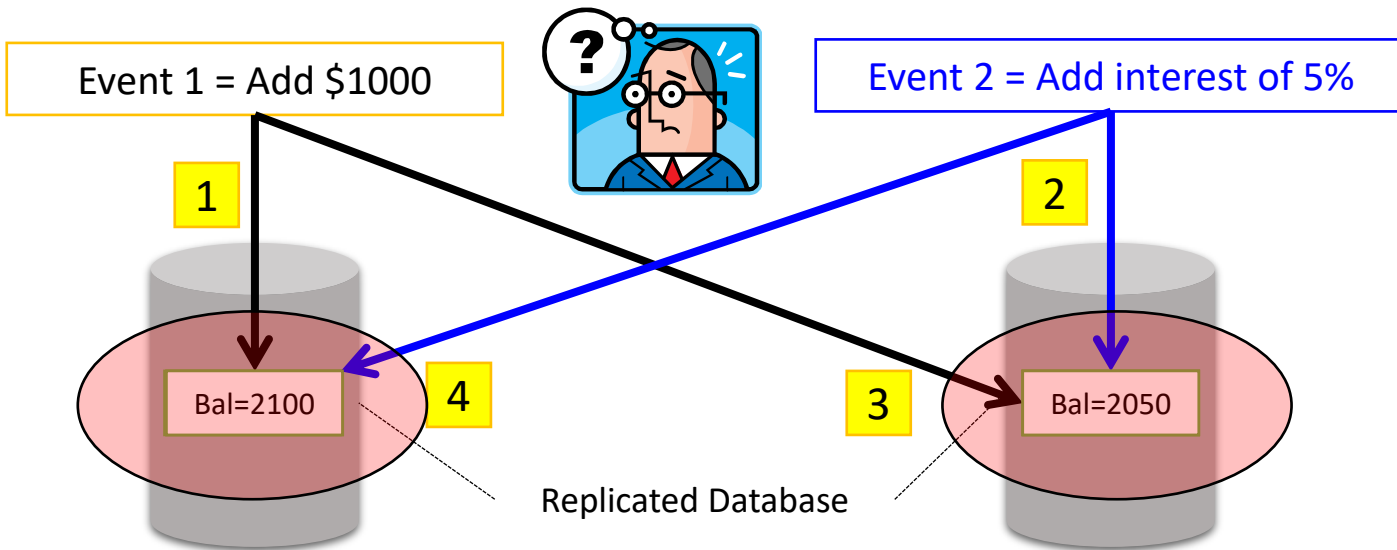
Data replication

- 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

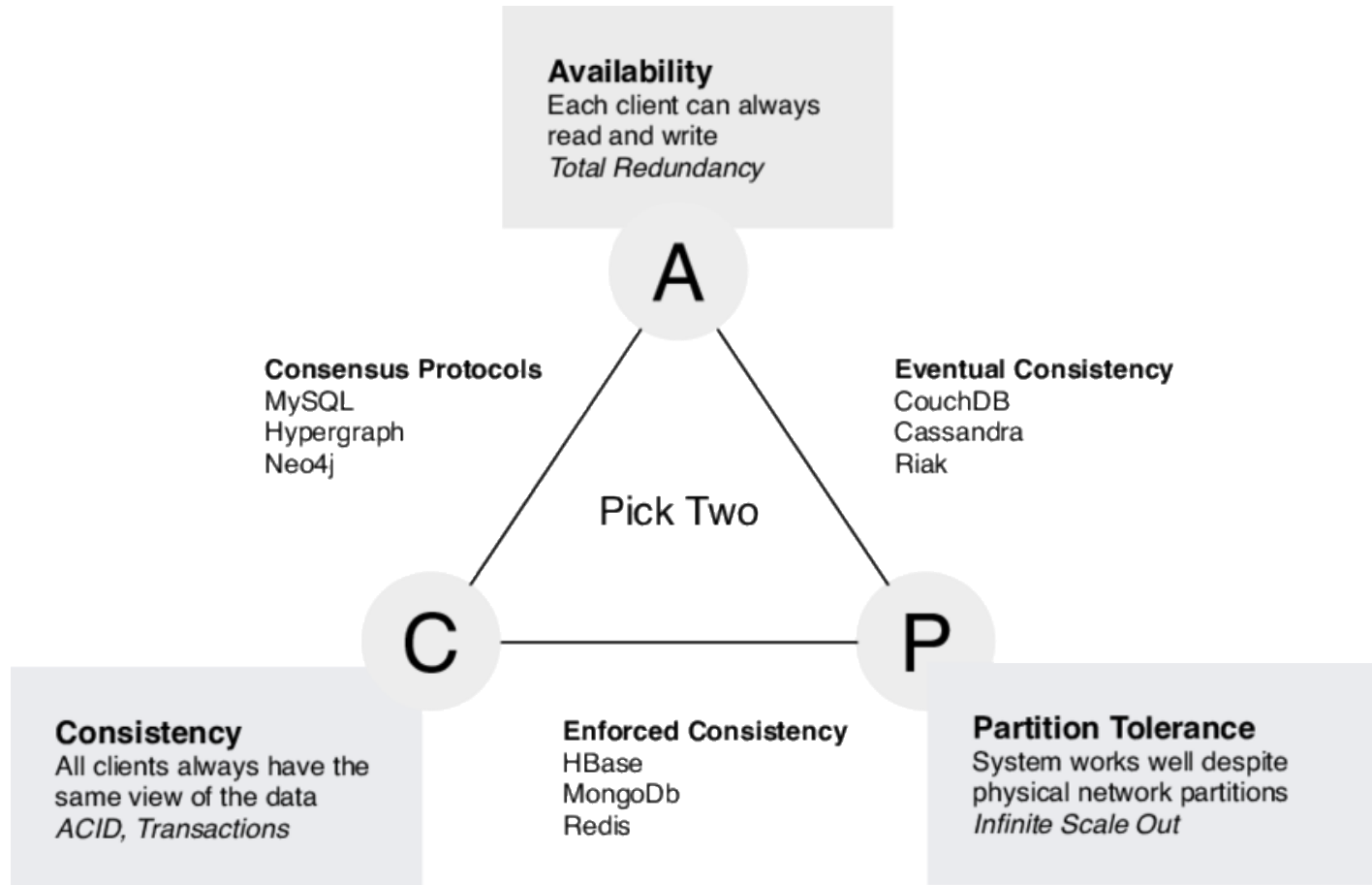


The CAP Theorem

- 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

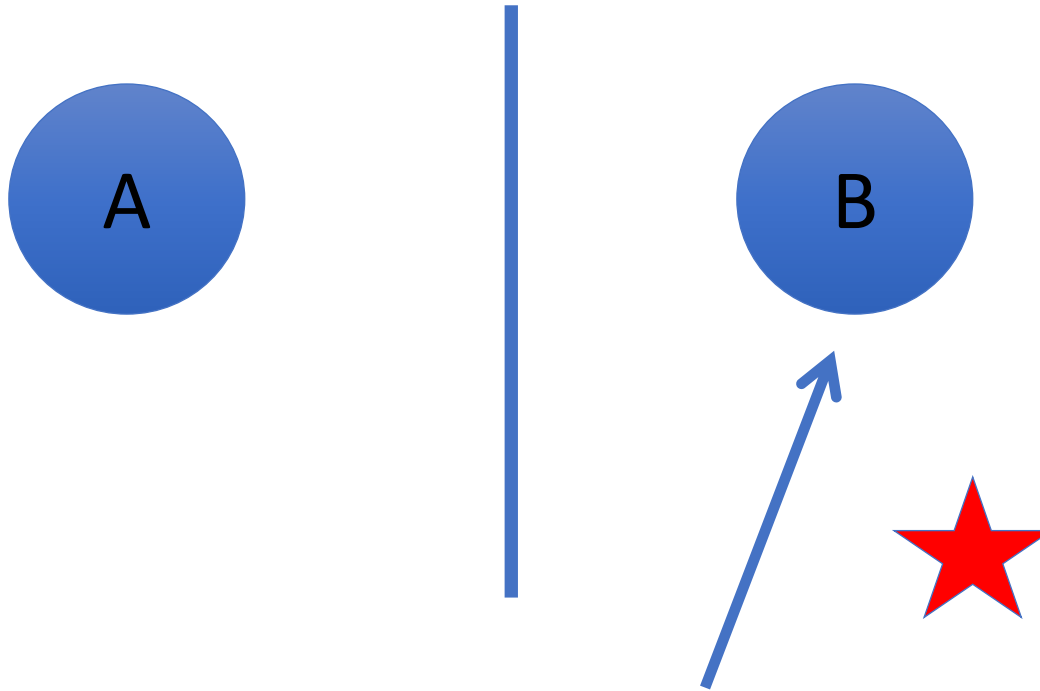
CAP theorem: any distributed database with shared data, can have at most two of the three desirable properties, C, A or P. **These are trade-offs involved in distributed system by Eric Brewer in PODC 2000.**

CAP Theorem



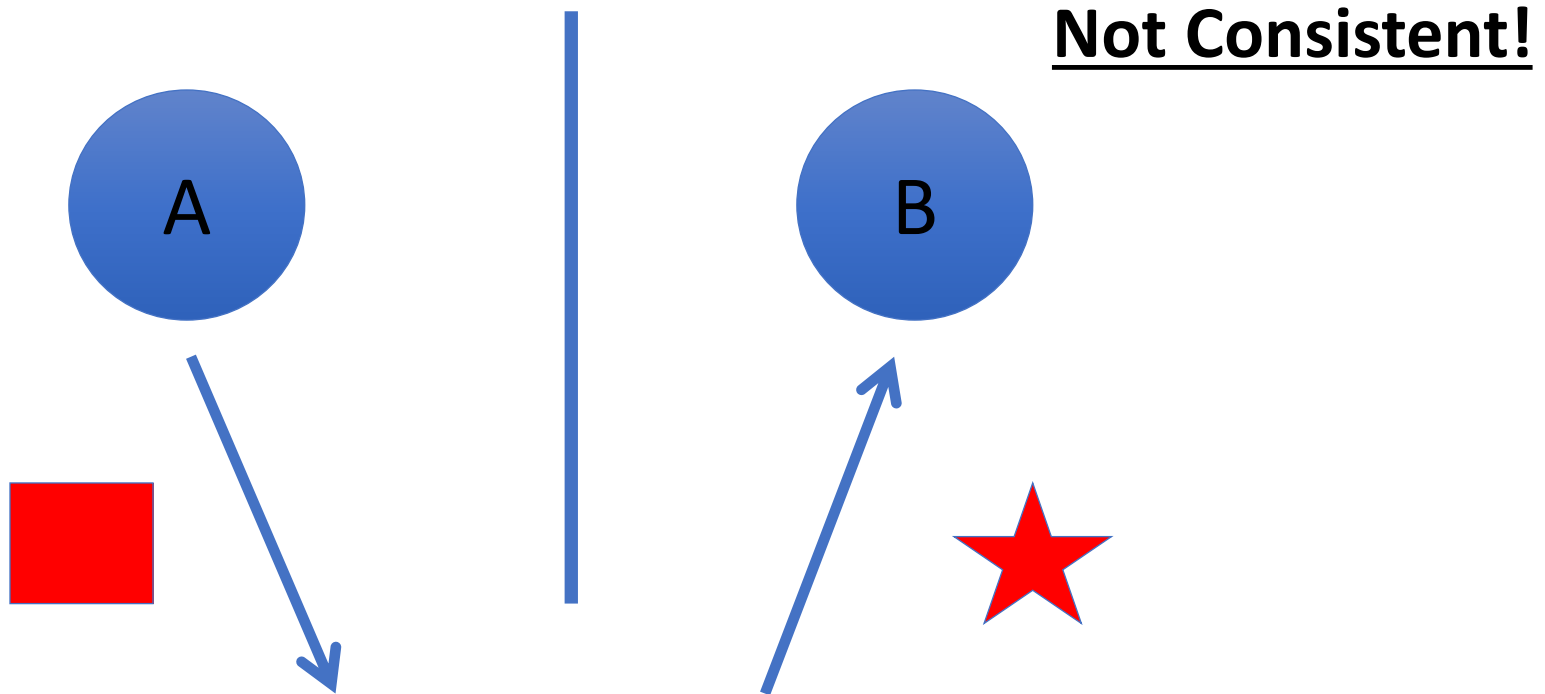
CAP Theorem: Proof

- A simple proof using two nodes:



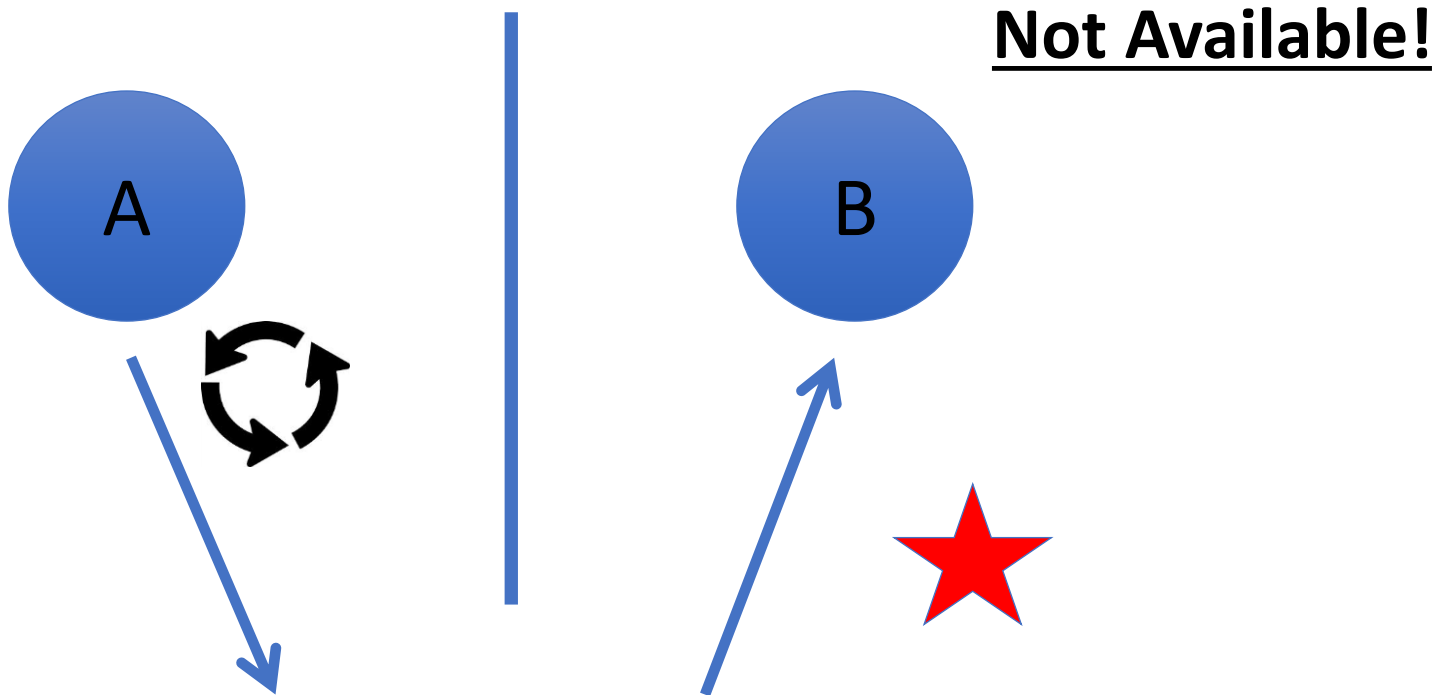
CAP Theorem: Proof

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CAP Theorem: Proof

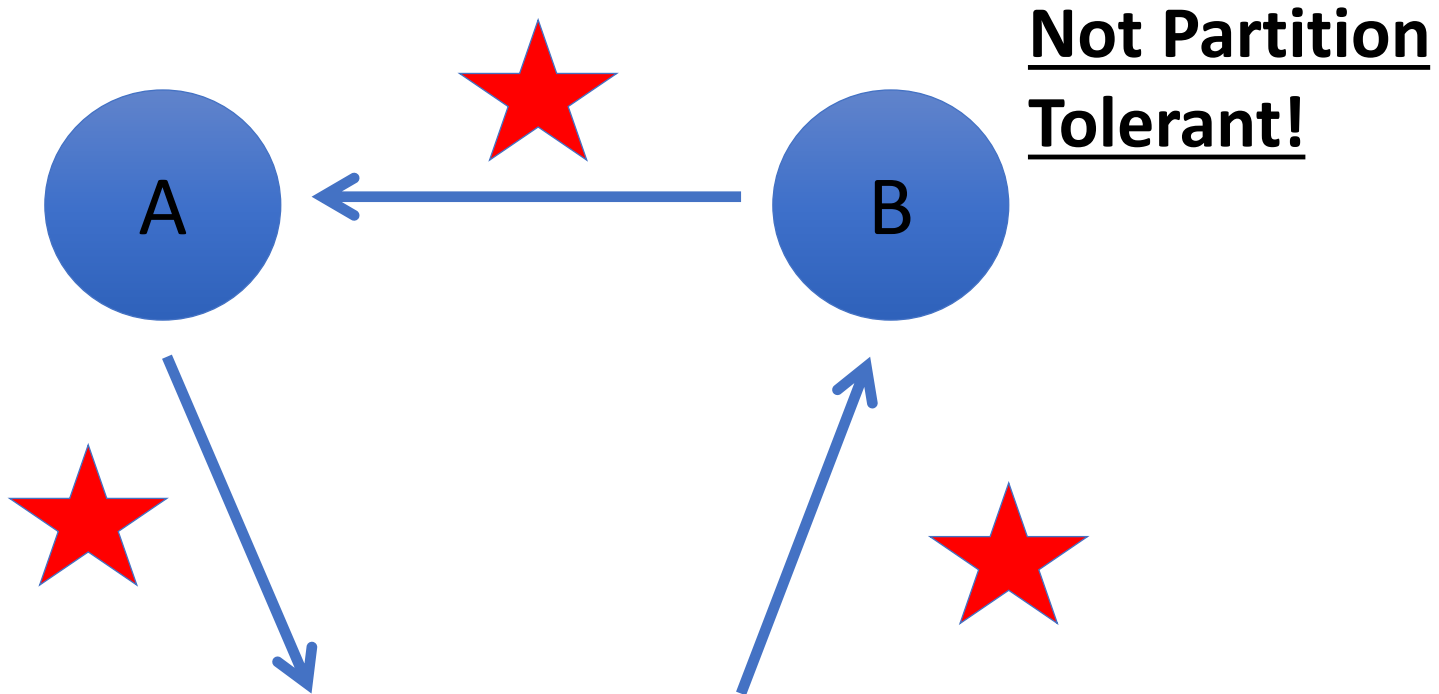
- A simple proof using two nodes:



Wait to be updated

CAP Theorem: Proof

- A simple proof using two nodes:



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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The BASE Properties

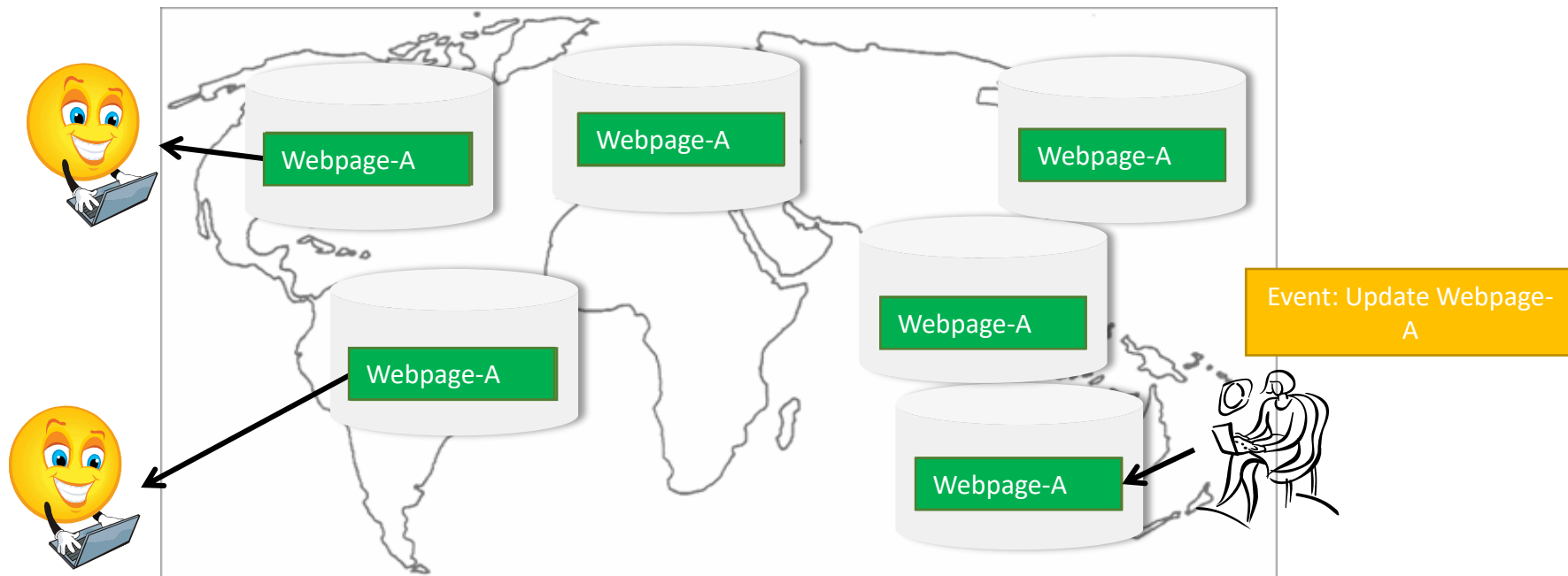
- The CAP theorem proves that it is impossible to guarantee strict Consistency and Availability while being able to tolerate network partitions
- This resulted in databases with relaxed ACID guarantees
- In particular, such databases apply the BASE properties:
 - Basically Available: the system guarantees 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 new updates

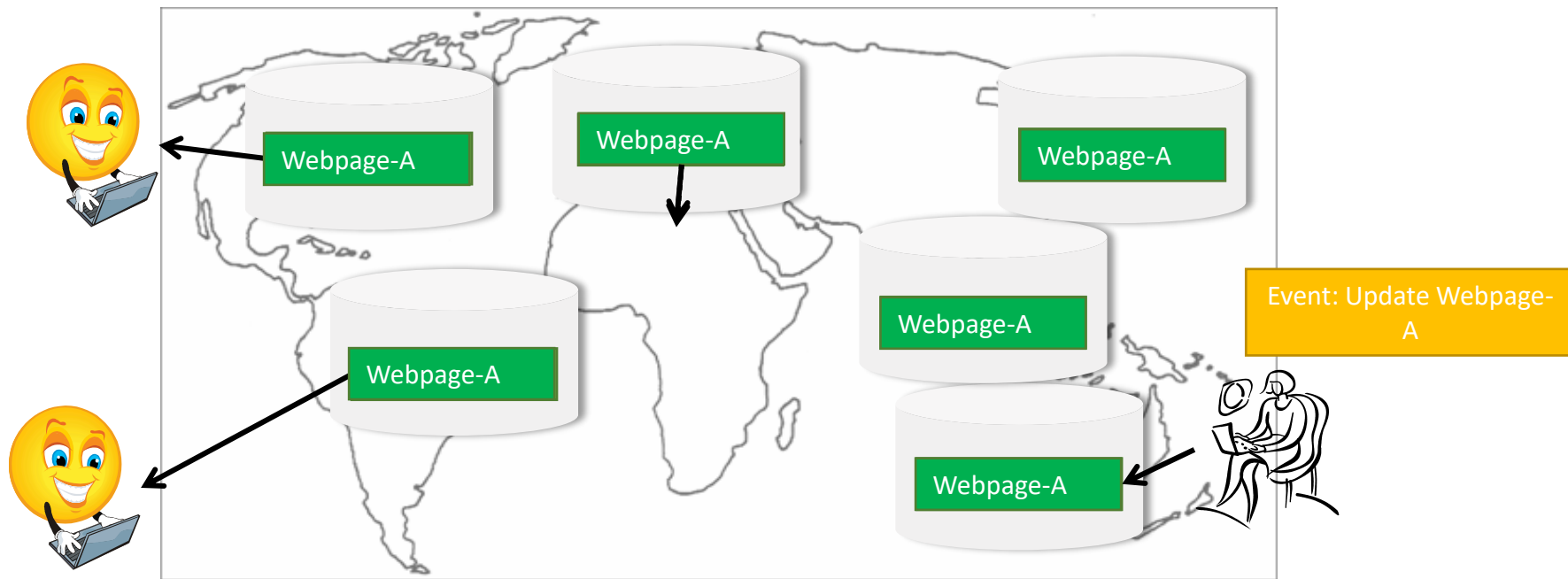
Eventual Consistency

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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!

References

- Gilbert, Seth, and Nancy Lynch. "Perspectives on the CAP Theorem." *Computer* 45.2 (2012): 30-36.
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- Brewer, Eric. "CAP twelve years later: How the " rules" have changed." *Computer* 45.2 (2012): 23-29.
- Chandra, Deka Ganesh. "BASE analysis of NoSQL database." *Future Generation Computer Systems* 52 (2015): 13-21.



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