Implementation considerations in making No SQL systems

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Data Distribution and Replication

- Data Distribution
  - What is?
  - Why do we do it? “Scaling”
  - How do we do it?
- Replication
  - What is?
  - Why do we do it? “Fault Tolerance”
  - How do we do it?
- What are the factors that affect and are considered while distribution and replication is done.
- Consistency Support

What is Data Distribution or Sharding?

- Sharding splits data on multiple nodes, each of **node does its own reads and writes**.

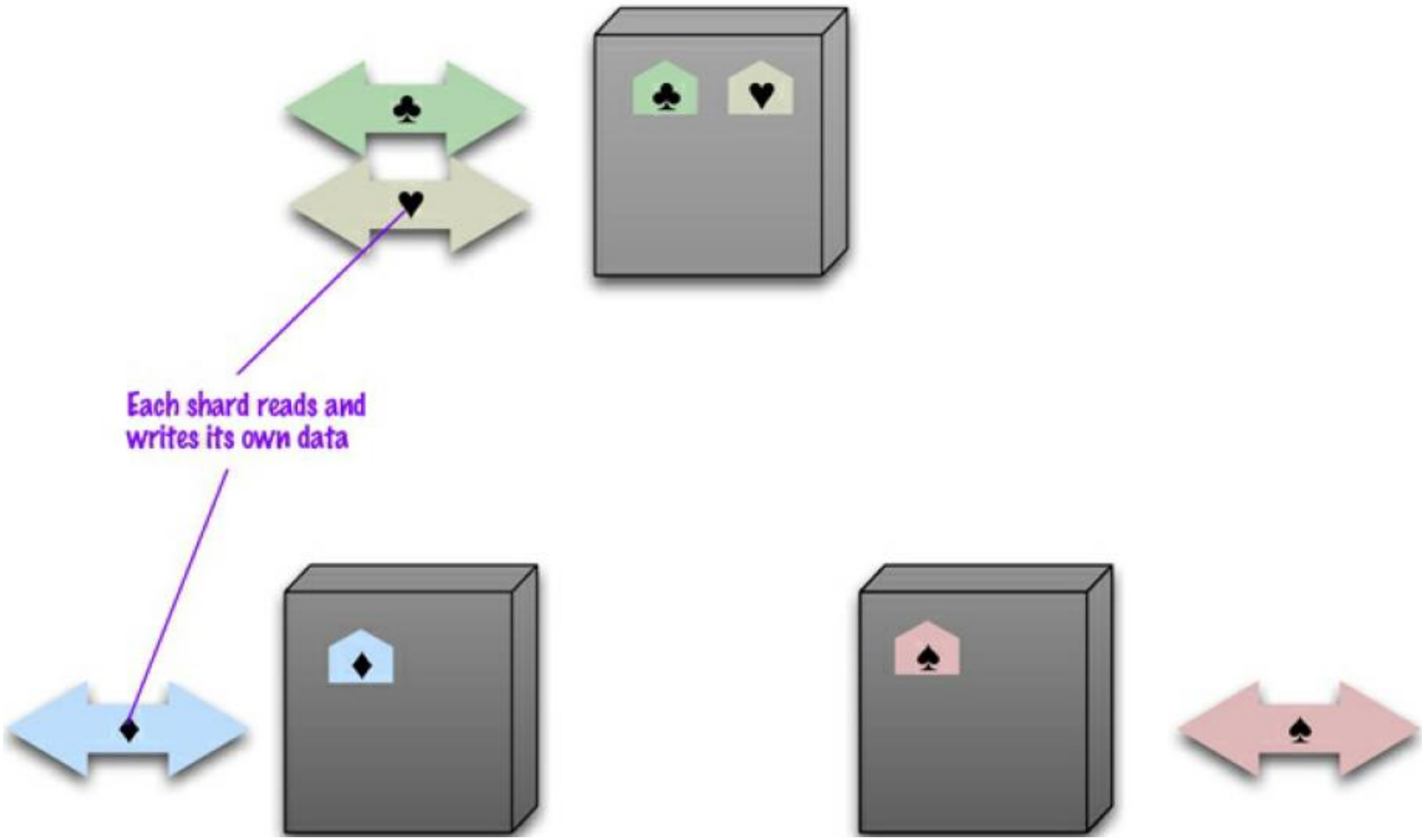

Figure source: No SQL Distilled

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Data Distribution / Sharding

- What is it?
  - Database is split on multiple nodes, each of **node does its own reads and writes**.
- Why do we do it?
  - To scale out horizontally, “use cluster” for computation
- How do we do it?
  - Use some strategy, primarily “<u>hashing based on Key</u>”, and considers certain factors (shown next)

How do we do Sharding?

- Partitioning is be done such that -

  (1) a query can be answered from a single server
    – efficient query answering

  (2) each server gets workload evenly distributed
    – load balancing

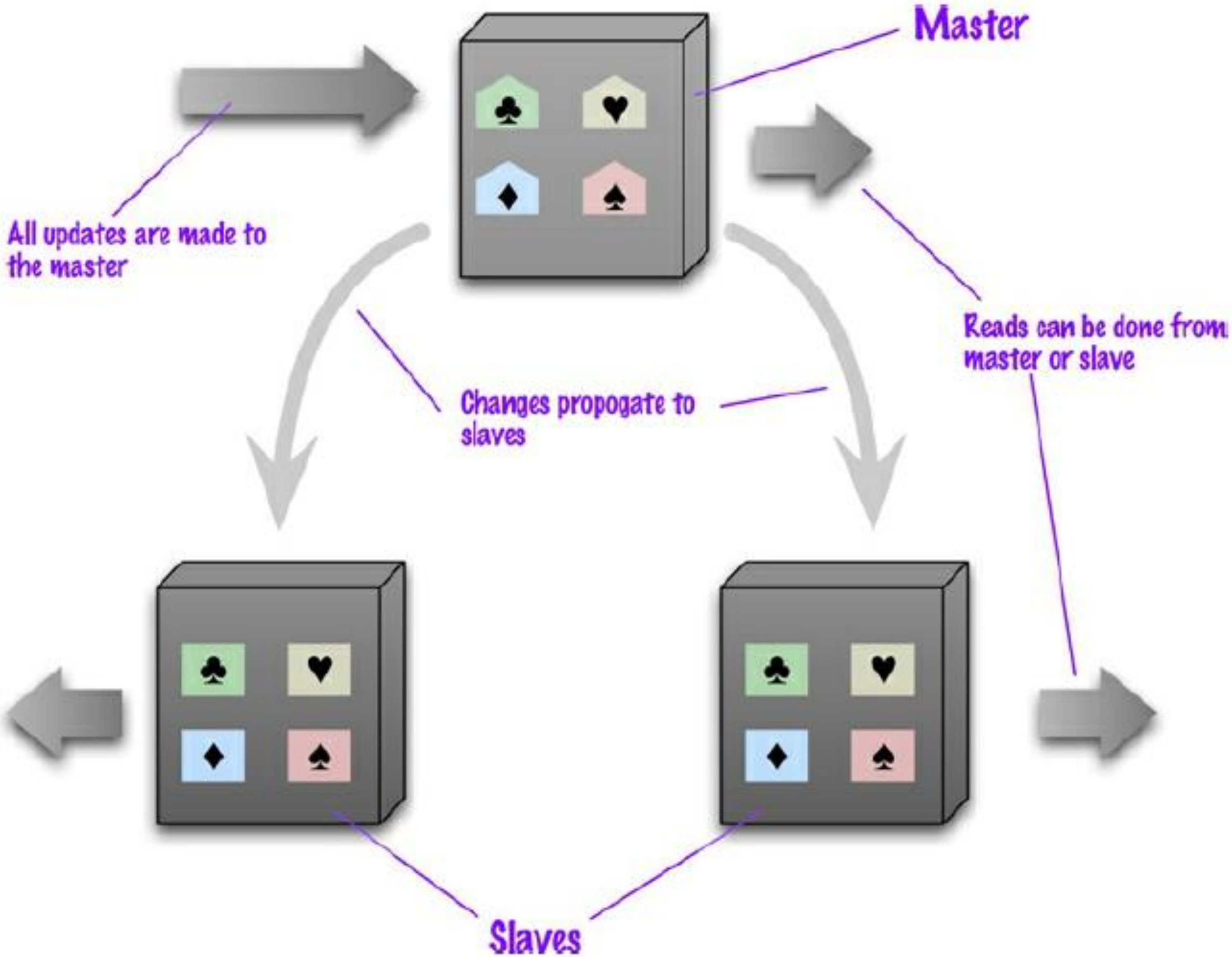
Replication

- What is?
  - Replicate data on multiple servers (nodes) with a replication factor, say 3.
- Why do we do it?
  - Fault tolerance – to deal with system and network failures.
  - If a server containing data fails, read/write can be done on other server.
- How do we deal with it?
  - Strategies like “Master-Slave”, and “Peer to Peer”
  - Requires going hand to hand with “Consistency Support”

Master-slave replication

- Let us understand in single server context
- We have few replicas - one of them act as Master node, and others as slaves
- Write are done only on Master node while read can be done from any other server
- A general strategy is reads are always routed to slave nodes
- <u>Mongo DB uses Master Slave Strategy</u>!

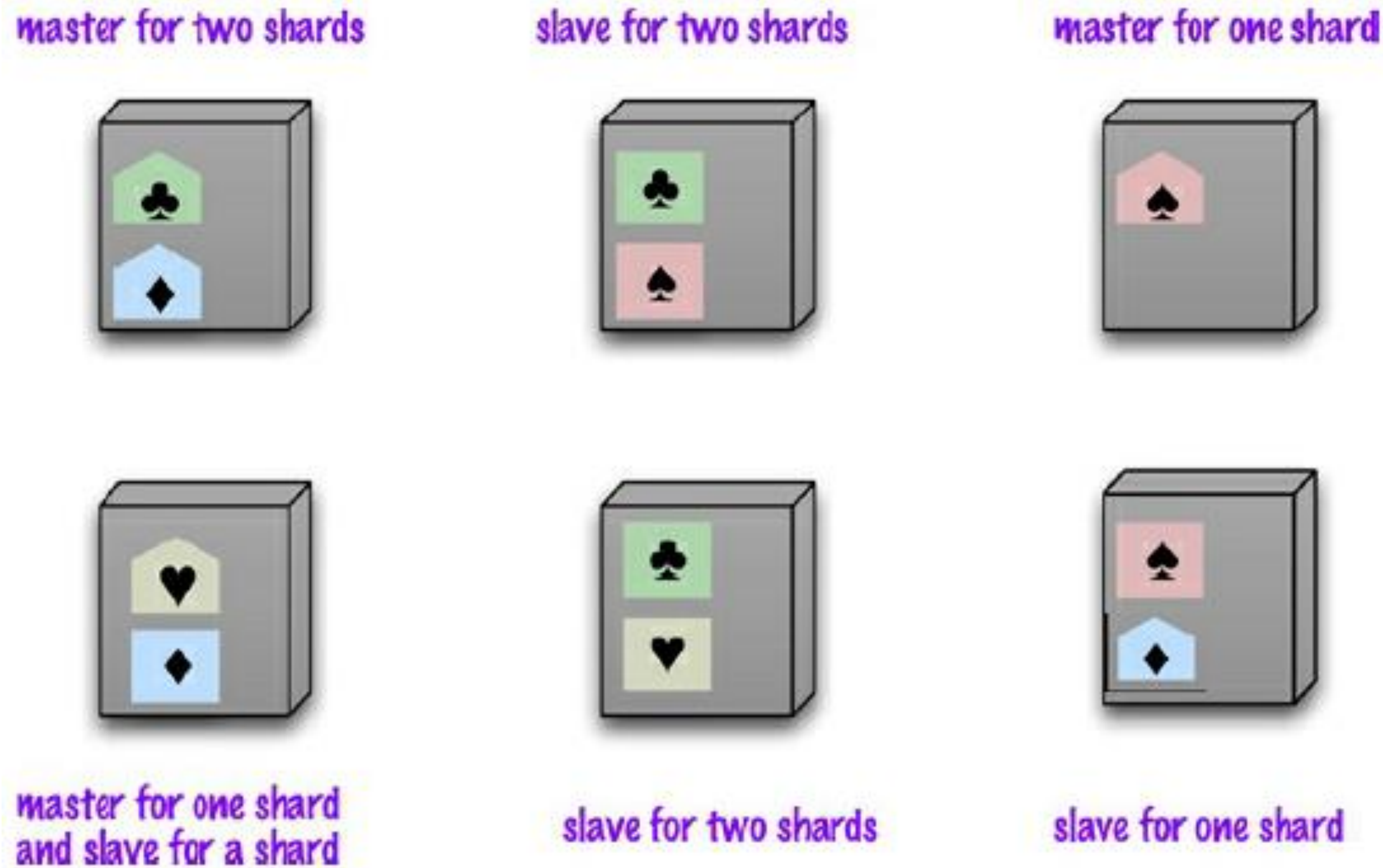
Master-slave replication



Master Slave with Sharding

- We have data partitions
- This means we have multiple masters, but each “data item” has only a single master.
- Depending on configuration, we may choose a node to be a master for some data and slaves for others, or we may dedicate nodes for master or slave duties only

Master-slave replication



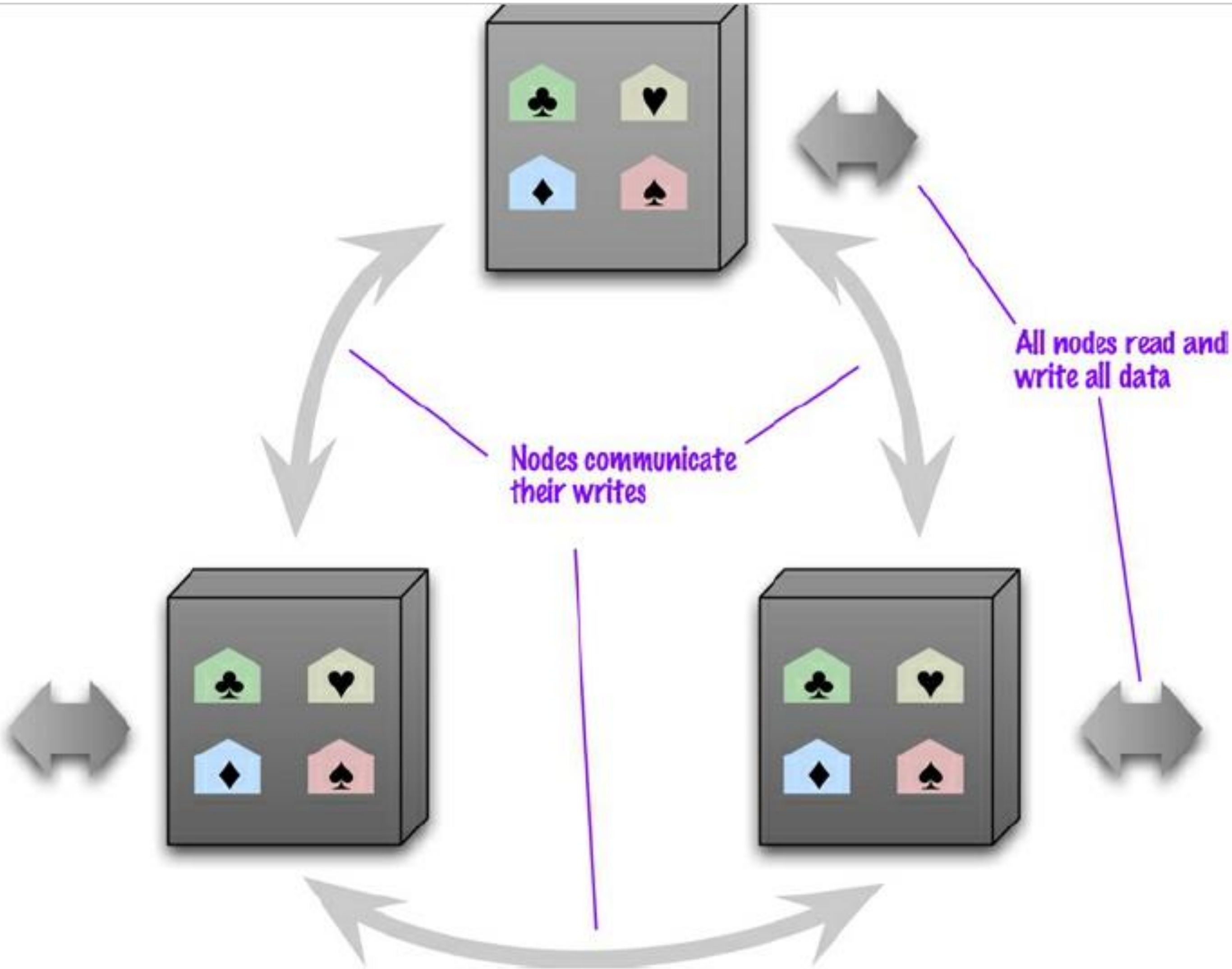
Master-slave replication

- "Writing ONLY ON master" brings in few concerns:
  - It can not scale out for writing, as writing is limited to master and master is only one.
  - If master node becomes unreachable, this adds to delays.
  - If master node fails, there is more serious problem. One of the slave can be made is master but, that adds significantly to the latency (delay), and
  - Still there is possibility of loosing data of master!
- However, strategy is good for reads. **Can scale well for reads**
  - reads can still be continued even when master node fails.

Peer to Peer Replication

- Master-slave replication helps with read scalability but doesn't help with scalability of writes.
- It provides resilience against failure of a slave, but not of a master.
- This essentially makes master as single point of failure.
- Peer-to-peer replication attacks this problem by not having a master.
- All the replicas have equal weight, they can all accept writes, and the loss of any of them doesn't prevent access to the data store.

Peer to Peer Replication



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Peer to Peer Replication

- The peer-to-peer arrangement looks very fine
  - We can perform read and write on any node
  - This take care of any node failing
  - We can improve the performance by simply adding more nodes, all nodes are equal
- Dynamo DB uses Peer to Peer Strategy.

Problems with Replication

- Replication brings in a primary problem of "**inconsistency**".
- Different clients reading different slaves, and hence may be reading different values (there is always possibility of replicas being inconsistent; eventually though they will not)
- In the worst case, a client cannot read a write that it just made. **GOT IT**?
  – Your program write a data item X, and immediately attempts reading it, and
  – on READ, since it may read from different replica that has not got update so far, will not get what itself wrote?

Problems with Replication - Problems

- Consistency problems becomes higher in Peer-to-Peer replication
- While “stale read” is one. It might also bring in WRITE-WRITE CONFLICT and that leads to things like “LOST UPDATE” or so.

A question?

- Do we still would use No SQL systems, where we have
  - No Sharding
  - No Replication
- Yes!
- For
  - Ease of programming - Impedance mismatch
  - For special purpose data like graph databases!
  - These systems may turn out to be more efficient than Relational systems for simple “key value” based database access patterns.

Consistency … what is it?

- Here is what we learnt in context classical databases
- Does not have “dirty read” and “lost update”
- Consistent read (repeatable read) in a transaction
- Read should be reading latest update of data
- Relational databases support ACID properties.
  - Atomic execution of transaction
  - Ensure Serializability (for isolation), and
  - So forth

Consistency and No SQL databases

- The “traditional” database systems that are based on monolithic architecture implements consistencies very well
  - ACID compliant systems provide “strict consistency”.
- On the other hand, modern web scale systems that have “partitioned” and “replicated” data struggle to provide such a consistency.
- CAP theorem proposed by Eric Brewer [2] show that “high-availability” and “consistency” conflict when data are “partitioned” and “replicated” on the network.
- Therefore, sacrifice on consistency is acceptable in No-SQL systems in favor of scaling and availability.

CAP Theorem[2]

- **Consistency**: degree of consistency after the execution of an update operation.
- A distributed system is typically considered to be consistent if after an update operation of some writer, all readers see updated value. [shall see more in a moment]
- **Availability** is System's ability to deal with node failure; i.e. system is till available with all of its data even if some nodes, or any other hardware failure (or down due to some maintenance work)

CAP Theorem[2]

- **Partition Tolerance ("Network Tolerant")**
  - It is system's ability to recognize additional part of data becoming available temporarily or permanently
  - It is system's ability to deal with dynamic addition or deletion of nodes

- CAP Theorem says that: A distributed database systems can have at most two of these properties!

CAP Theorem[2]

Choice	Traits	Examples
Consistence + Availability (Forfeit Partitions)	2-phase-commit cache-validation protocols	Single Server databases Cluster databases LDAP xFS file system
Consistency + Partition tolerance (Forfeit Availability)	Pessimistic locking Make minority partitions unavailable	Classical Distributed Databases Distributed locking Majority protocols
Availability + Partition tolerance (Forfeit Consistency)	expirations/leases conflict resolution optimistic	Cluster friendly databases Web caching[sic!] DNS

BASE as new consistency descriptor for No SQL systems

- Eric Brewer [2] also presents BASE, acronym for **B**asically **A**vailable, **S**oft-state, **E**ventual consistency.
- Presents a comparison with ACID (next slide)

ACID vs. BASE

Inktomi

ACID	BASE
◆ Strong consistency	◆ Weak consistency – stale data OK
◆ Isolation	◆ Availability first
◆ Focus on "commit"	◆ Best effort
◆ Nested transactions	◆ Approximate answers OK
◆ Availability?	◆ Aggressive (optimistic)
◆ Conservative (pessimistic)	◆ Simpler!
◆ Difficult evolution (e.g. schema)	◆ Faster
	◆ Easier evolution

← But I *think* it's a *spectrum* →

PODC Keynote, July 19, 2000

Consistency in “Distributed” and “Replicated” context

- Understanding of Consistent requires revisit in the context of “Distributed” and “Replicated” databases.
- The article “Eventual Consistency”[3] describes following of consistency models in this context.
  - Strict Consistency
  - Weak Consistency
  - Eventual Consistency
  - Casual Consistency, Read Your Write Consistency, …
- <u>These are in client’s view of “Consistency”.</u>

Consistency Models [3]

- Before looking into lets establish the context
  - Database is replicated with a factor of K
  - There are processes A, B, and C, such that
    - A write a data item X
    - B and C read that data item
- **Strict|Strong consistency** requires that after update of X is confirmed, any subsequent read (by A, B, or C) will get the updated value.

Consistency Models [3]

- **Weak consistency**: in this case, system does not guarantee subsequent reads getting the updated value.
- It takes a while before every replica gets updated by a write.
- Time interval of update and every replica getting updates is called "*inconsistency window*"
- **Eventual consistency:** it is a specific form of weak consistency; the storage system guarantees that if new updates are made to the object, eventually all reads will get the correct (updated) version; that is when "inconsistency windows" gets over!
- The duration of "inconsistency window" depends on factors like communication delays, the load on the system, and the replication factor (number of replicas are involved).

Consistency Models [3]

- The eventual consistency model has a number of variations that are important to consider:
- **Causal consistency:** If process A has communicated to process B that it has updated a data item, a subsequent access by process B will get the updated value.
- However, read by process C that has no information about A's write, may not get the updated value of (Eventually, of course!)
- **Read-your-writes consistency** is an important model where process A, after having updated a data item, always accesses the updated value and never sees an older value.
- This is a special case of the causal consistency model

Consistency Models [3]

- **Session consistency**: this is a practical version of the previous model, where a process accesses the storage system in the context of a session.
- As long as the session exists, the system guarantees “read-your-writes consistency”
- However, if the session terminates because of a certain failure, guarantee is not carried forward to newer session.
- **Monotonic read consistency**. If a process has seen a particular value for the object, any subsequent accesses will never return any previous values.

Consistency Models [3]

- **Monotonic write consistency**. In this case, the system guarantees to serialize the writes by the same process.
- Systems that do not guarantee this level of consistency are notoriously difficult to program.
- Real systems may be implementing multiple models of these consistencies!

References/Further Readings

[1] Chapter 4 and 5 of book *NoSQL distilled*.

[2] Brewer, Eric A.: *Towards Robust Distributed Systems*. Portland, Oregon, July 2000. –Keynote at the ACM Symposium on Principles of Distributed Computing (PODC) on 2000-07-19.

[3] Vogels, Werner. "Eventually consistent." *Communications of the ACM* 52.1 (2009): 40-44.
http://www.cs.berkeley.edu/~brewer/cs262b-2004/PODC-keynote.pdf

[4] Lloyd, Wyatt, et al. "A short primer on causal consistency." *USENIX; login magazine* 38.4 (2013): 41-43.