NoSQL

Enterprise Architectures for Big Data

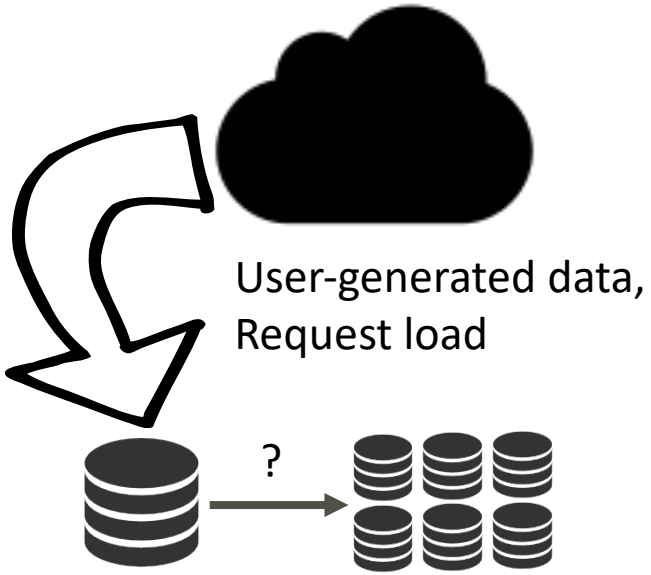
NoSQL

- „NoSQL“ term coined in 2009
- Interpretation: „Not Only SQL“

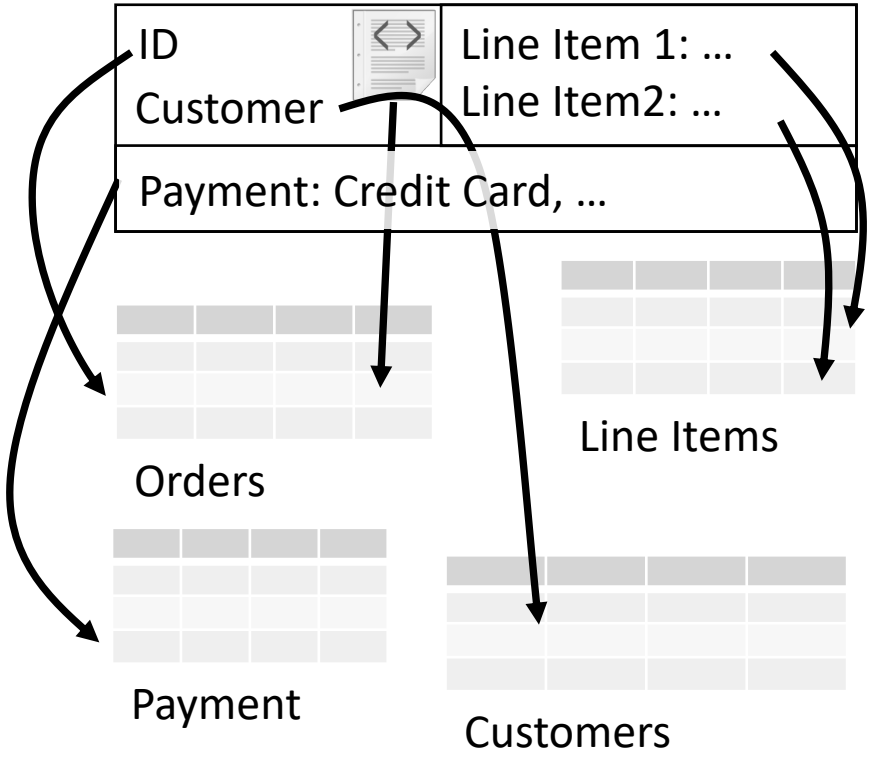
- Typical properties:
  - Non-relational
  - Often Open-Source
  - Schema-less (schema-free)
  - Optimized for distribution (clusters)
  - Tunable consistency

Two main motivations

Scalability



Impedance Mismatch



NoSQL Paradigm Shift
Open Source & Commodity Hardware

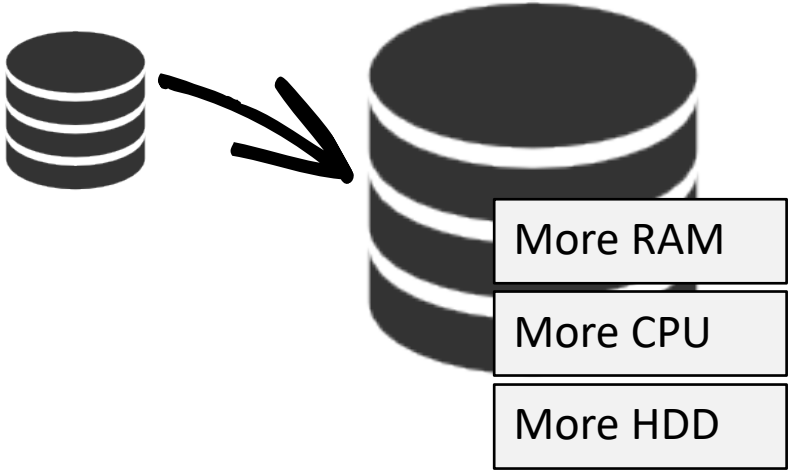
Commercial DBMS	Open-Source DBMS
Specialized DB hardware (Oracle Exadata, etc.)	Commodity hardware
Highly available network (Infiniband, Fabric Path, etc.)	Commodity network (Ethernet, etc.)
Highly Available Storage (SAN, RAID, etc.)	Commodity drives (standard HDDs, JBOD)

Source: Gessert (2016)

Scaling Strategies

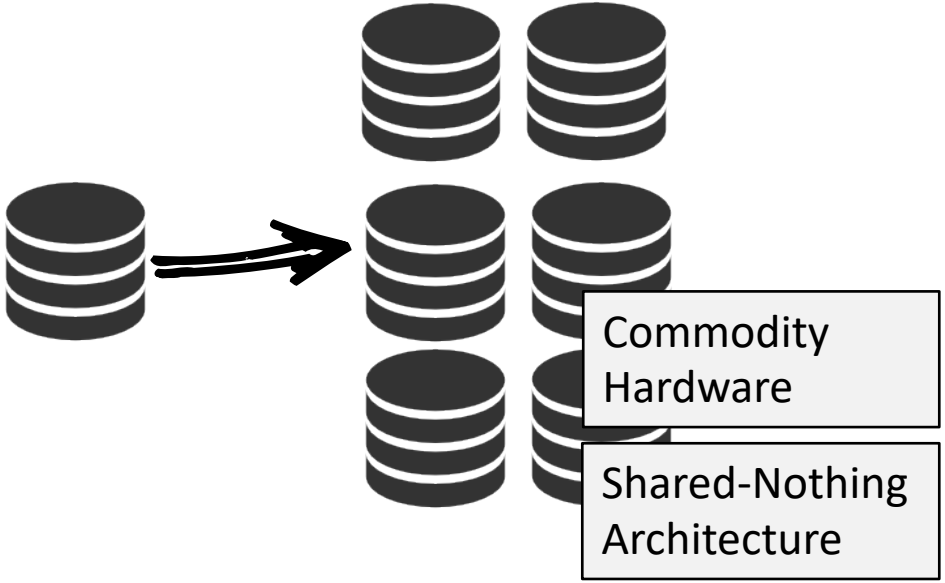
Scale-up

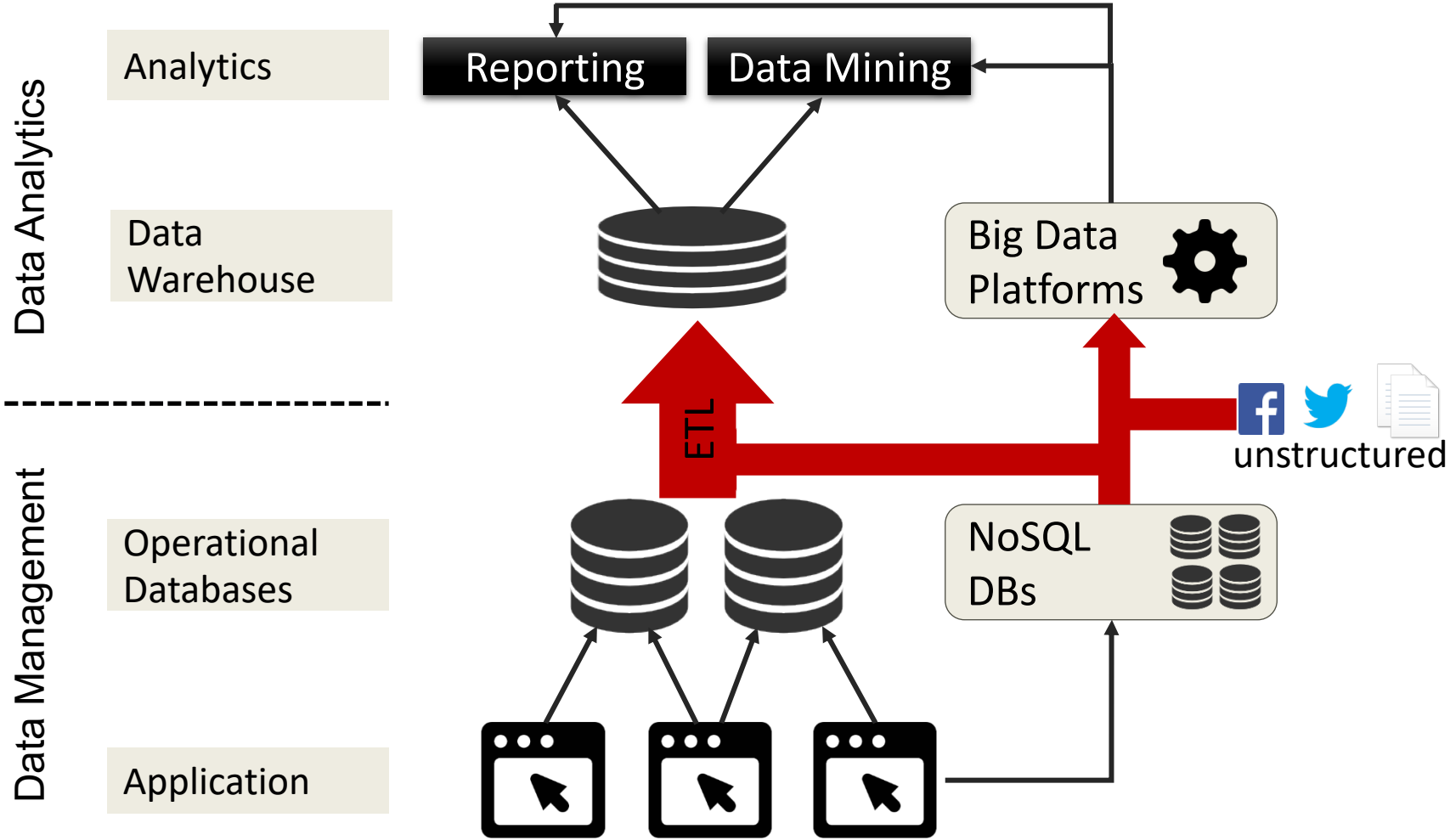
- Vertical Scaling



Scale-out

- Horizontal scaling

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Data Mining
Data Warehouse
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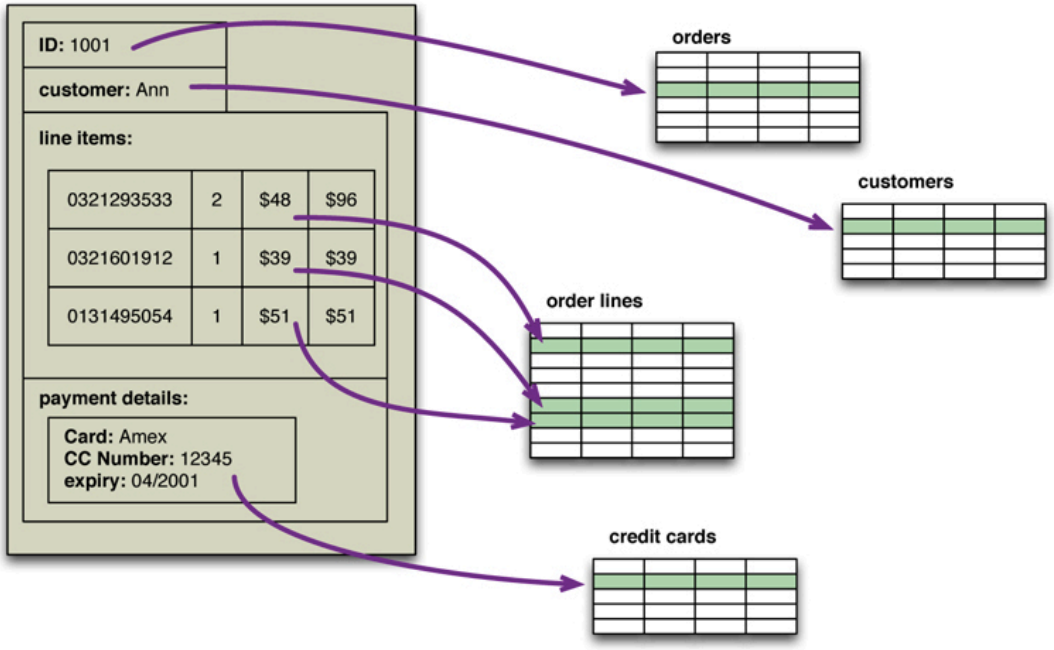
ETL
unstructured
Data Management
Operational Databases
NoSQL DBs
Application

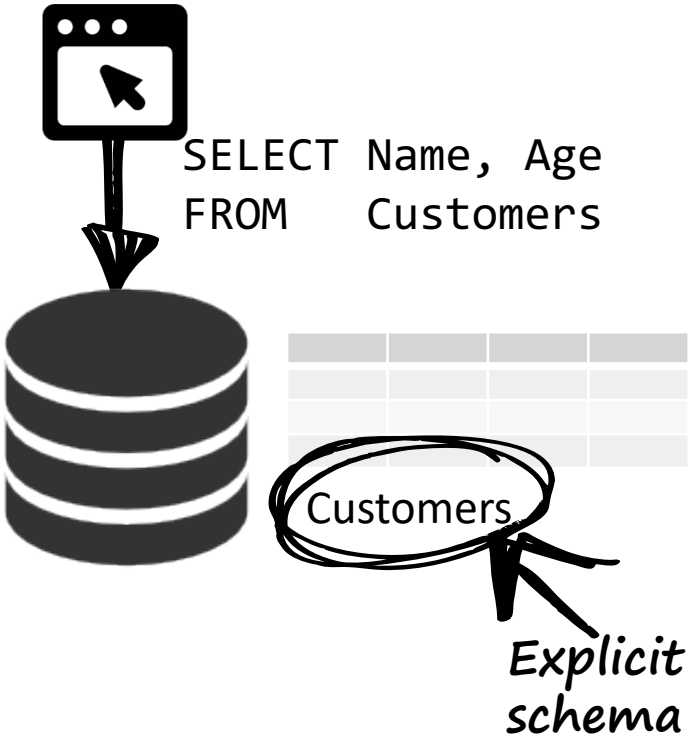
Impedance Mismatch

- An order are many tables in a relational database

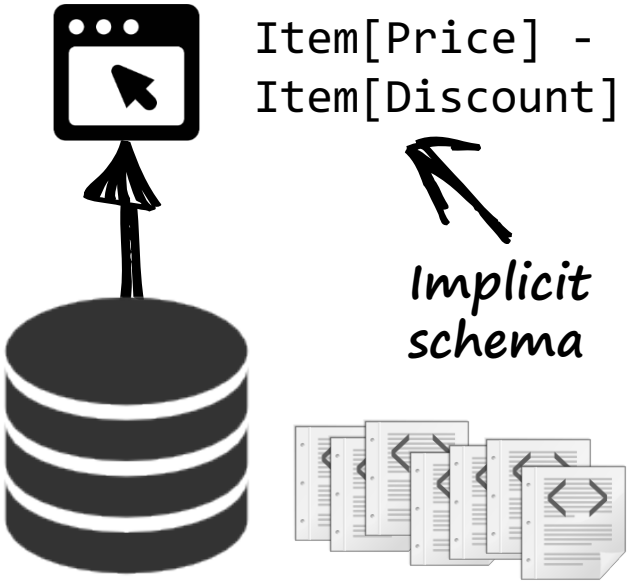


Schema Free Data Modeling

RDBMS



NoSQL DB



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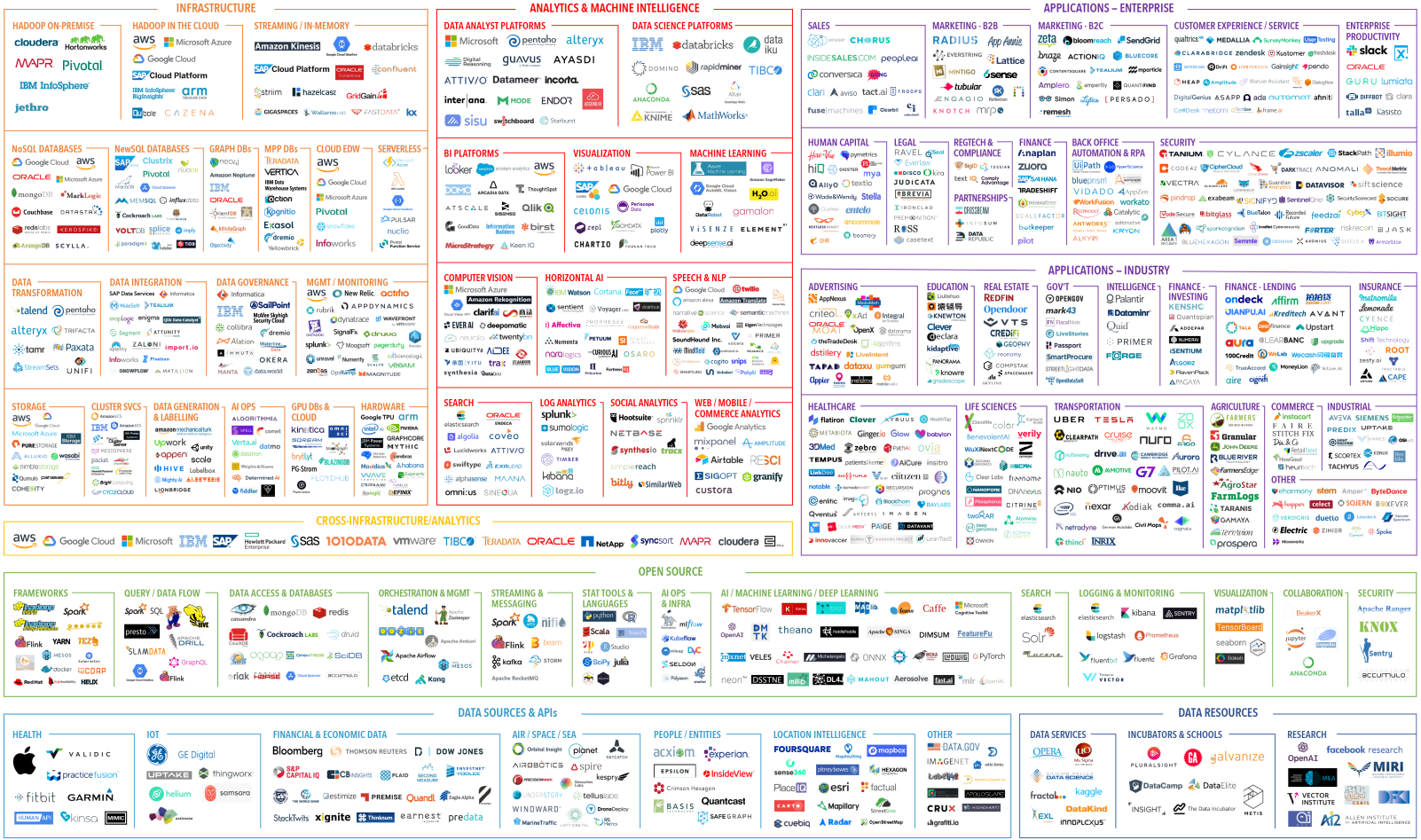

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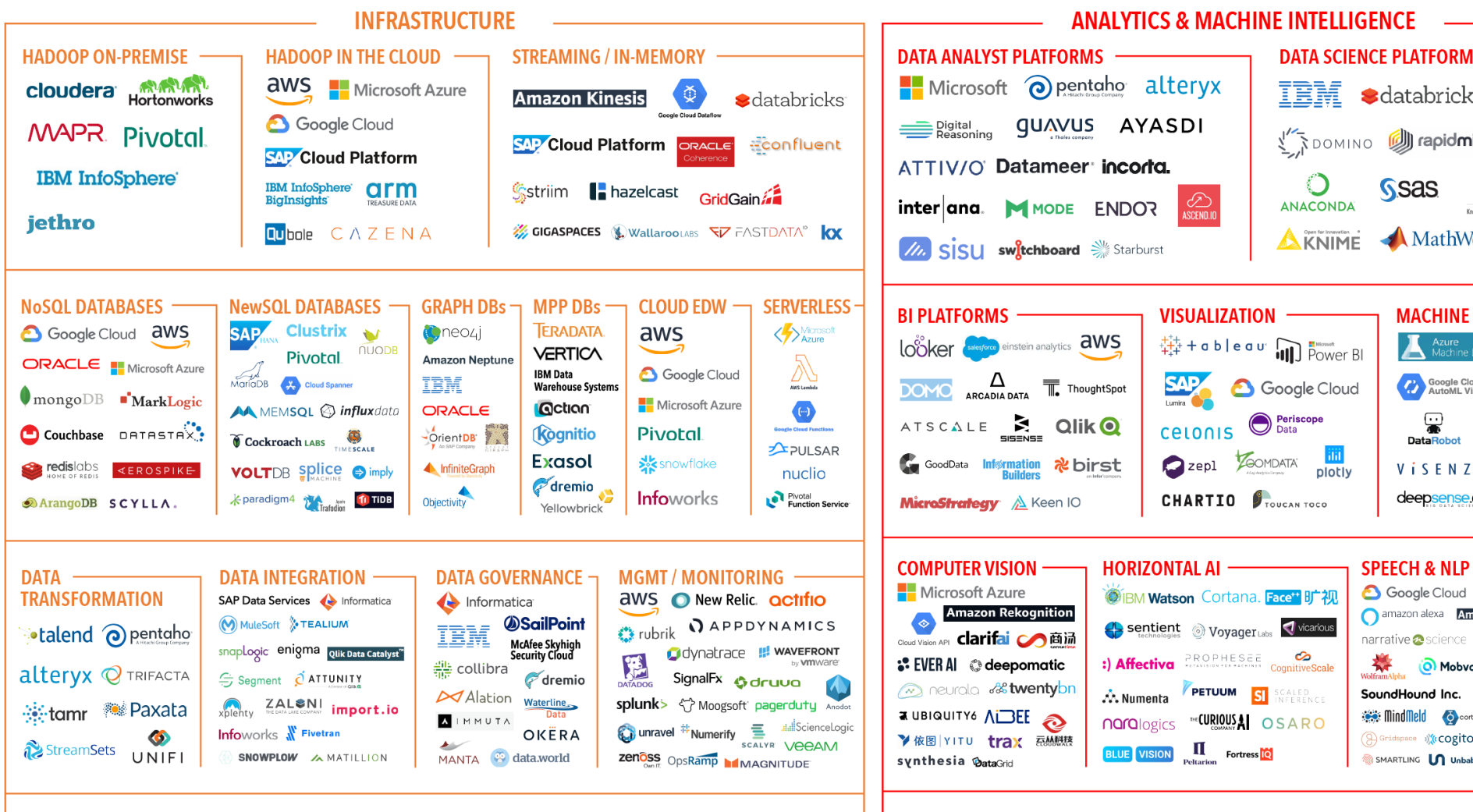
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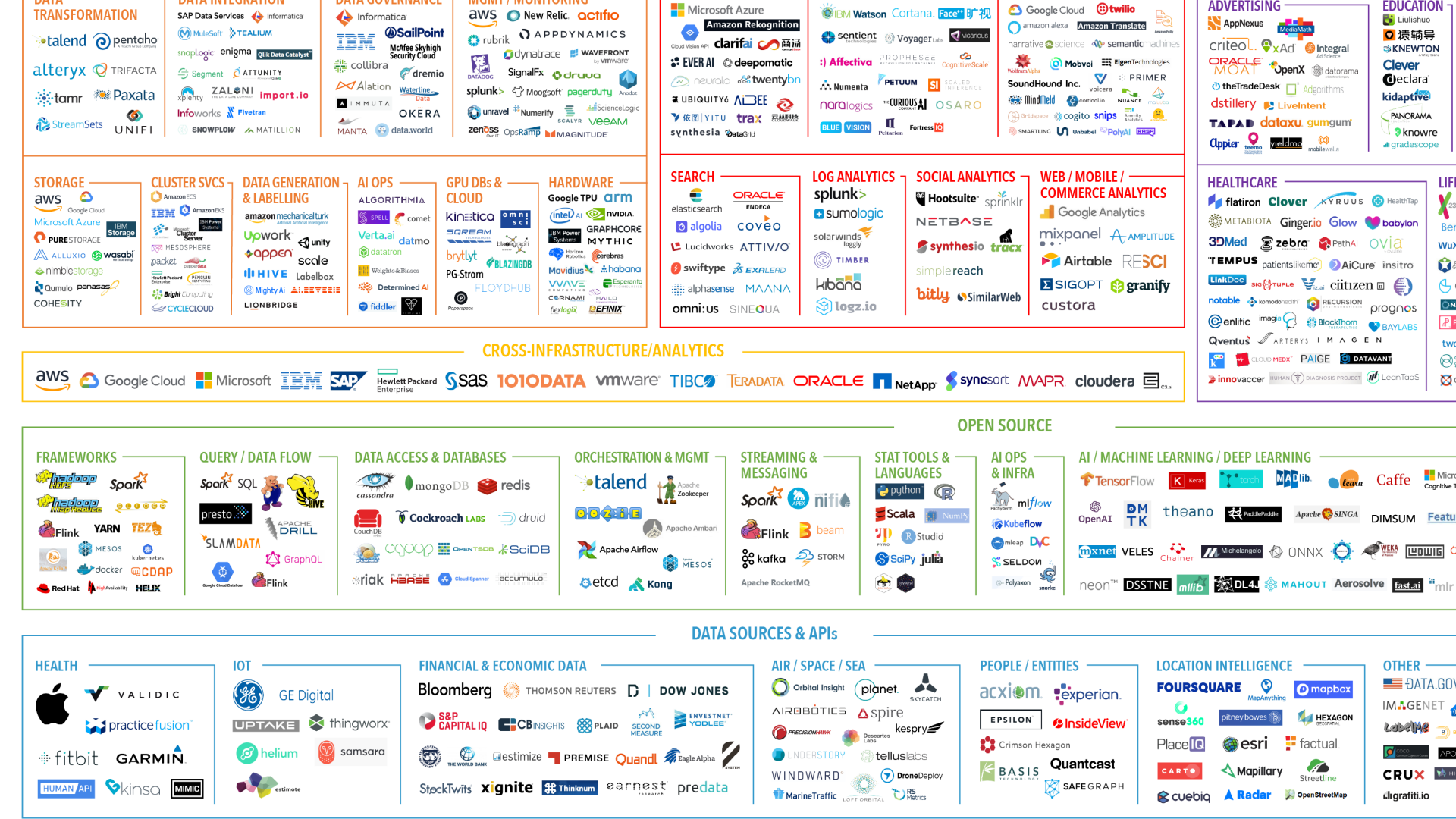
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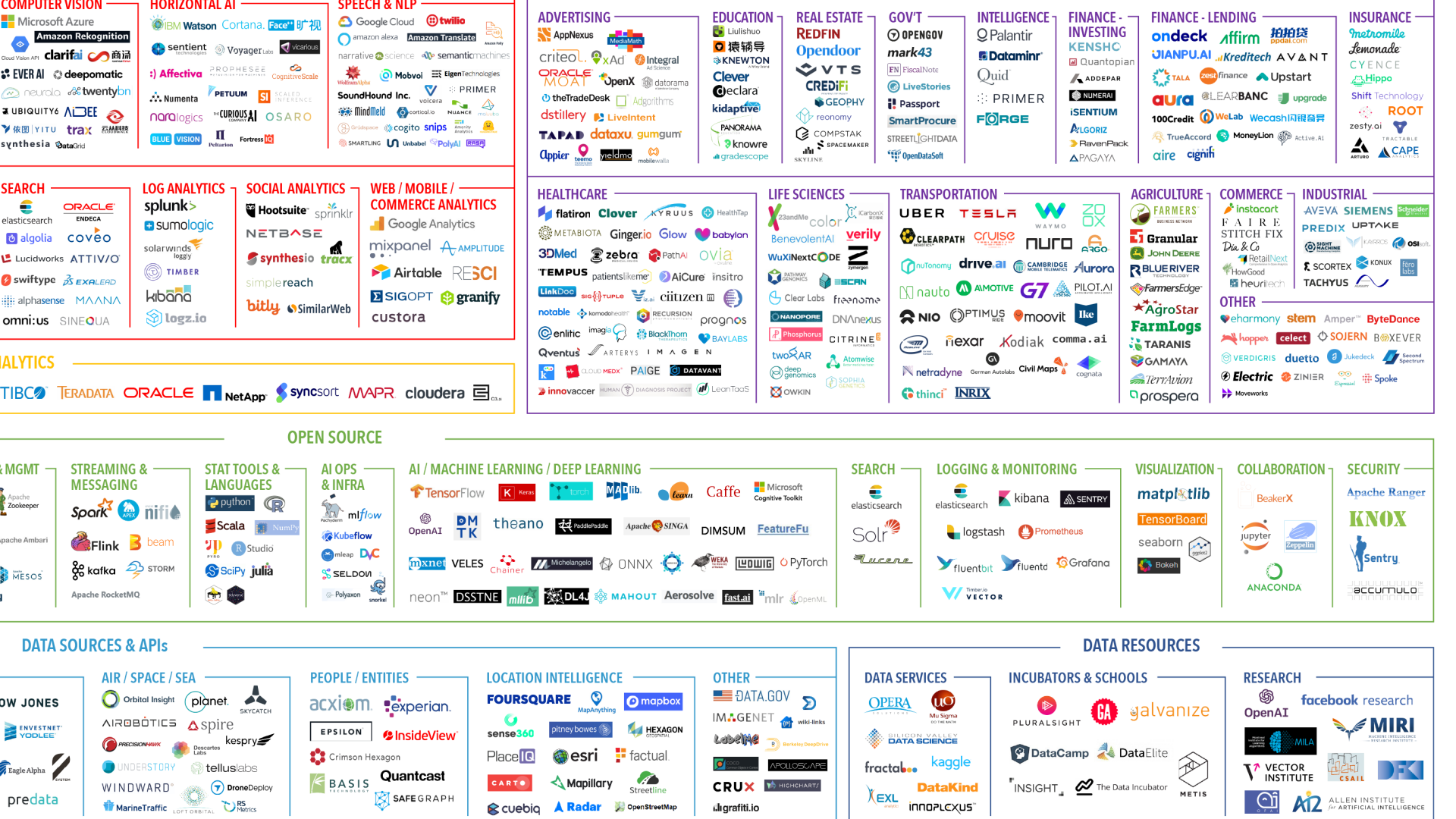
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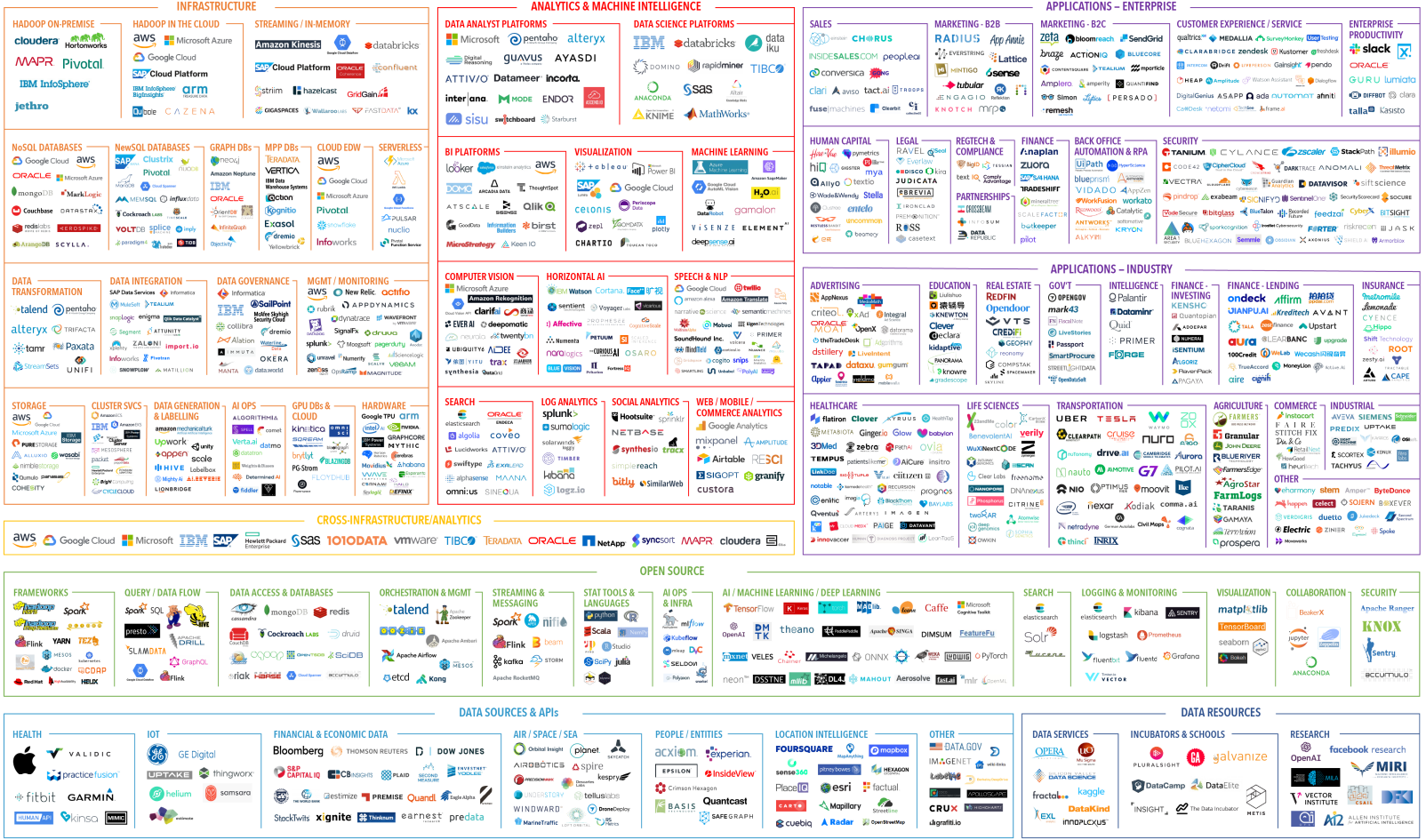

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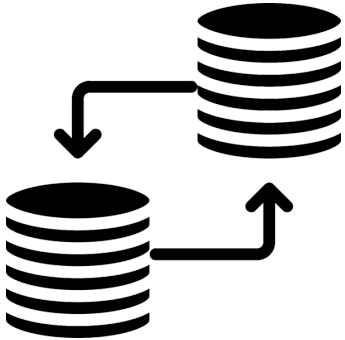
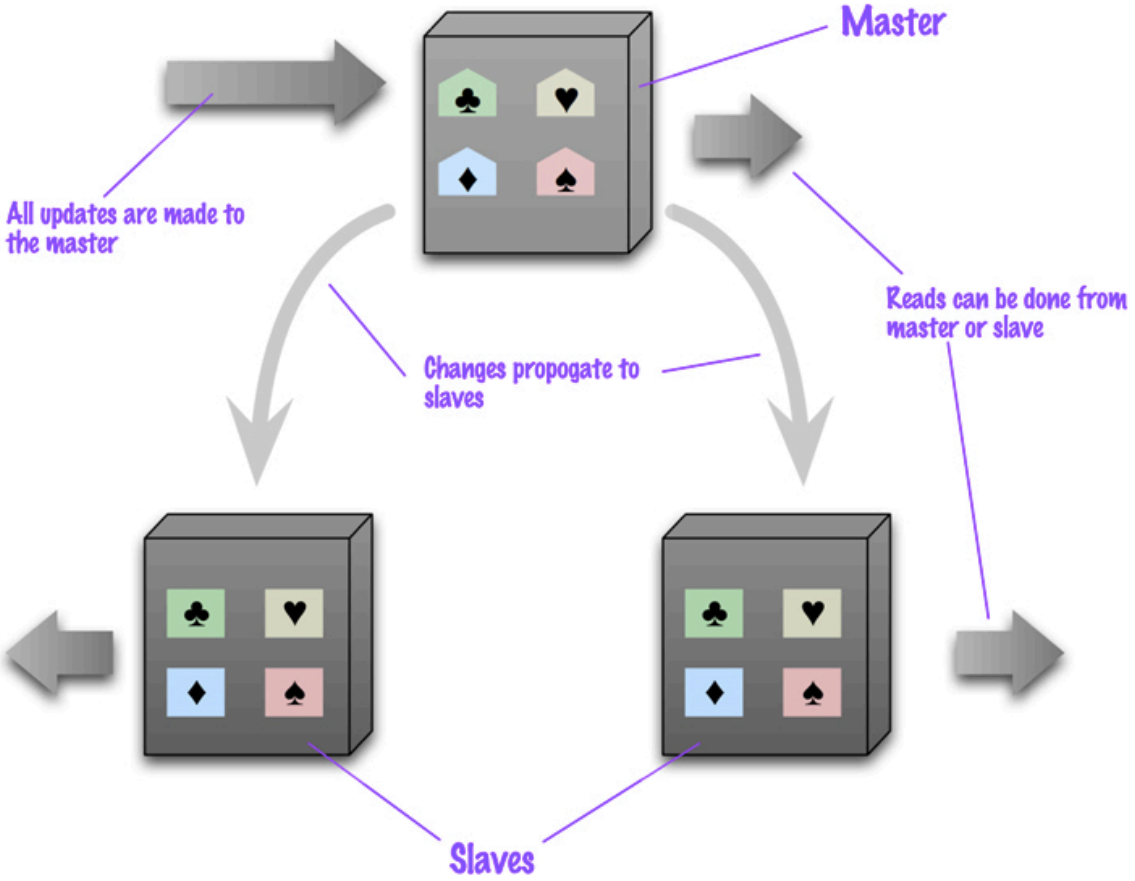


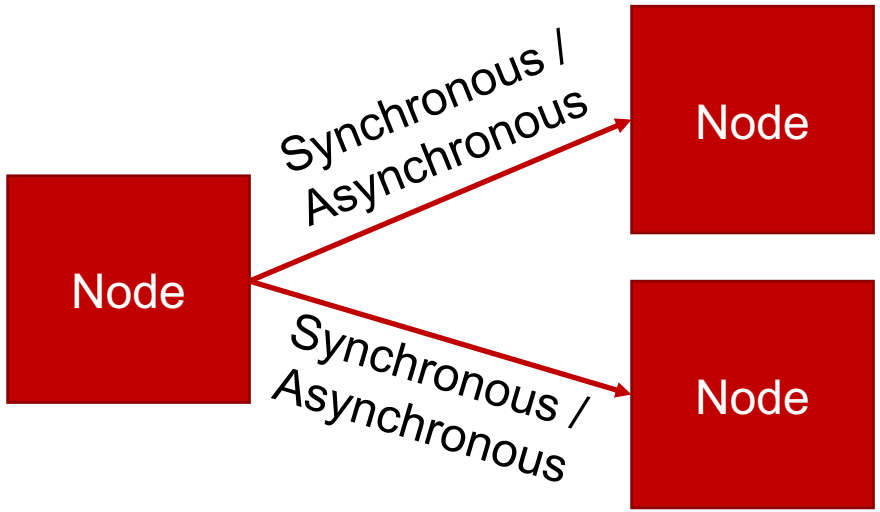
Replication

Replication

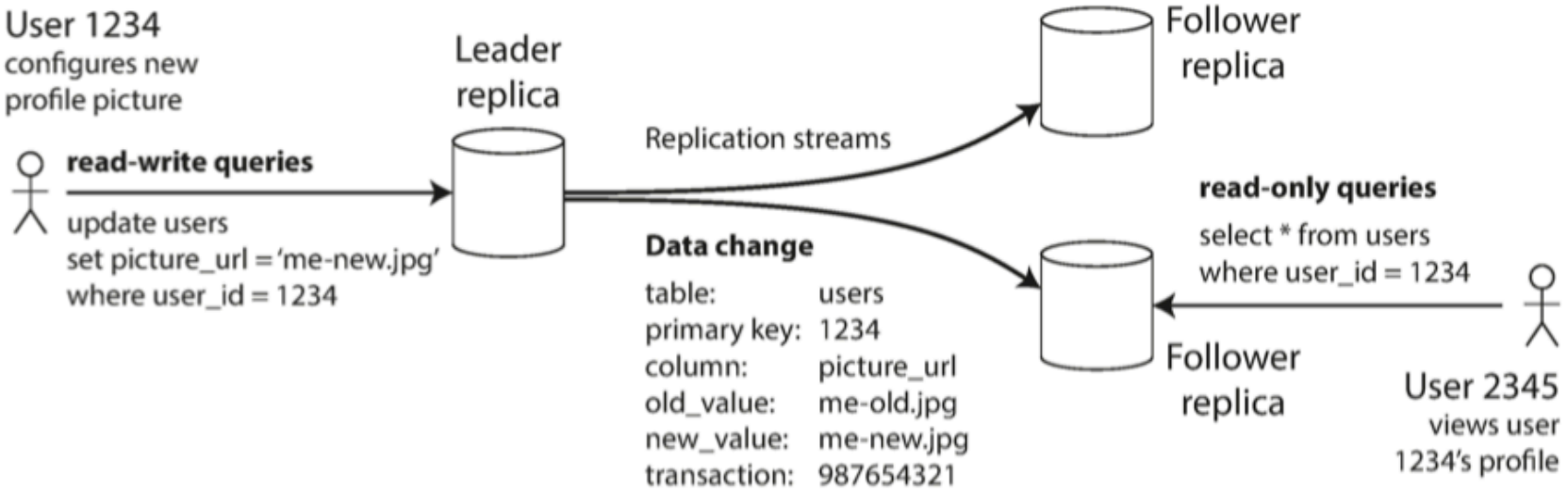


Replication

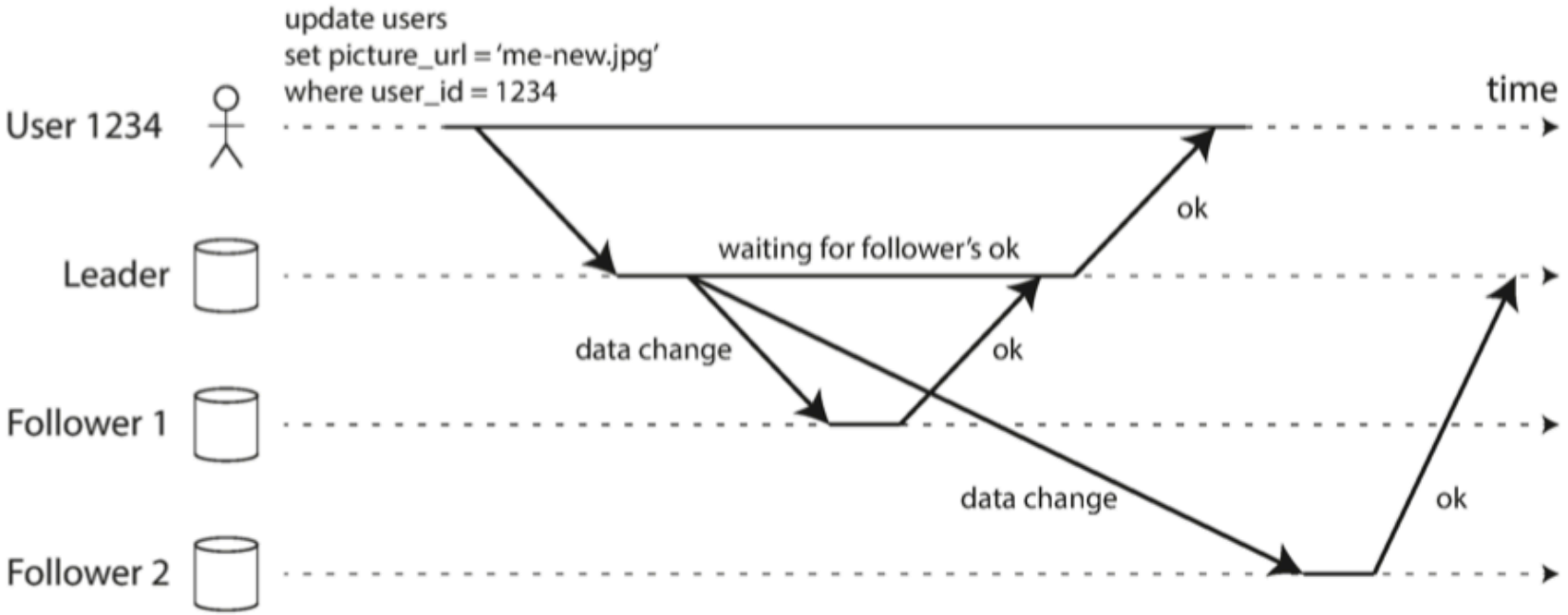
- Stores N copies of each data item
- Consistency model: synchronous vs. asynchronous
- Coordination: Single-leader, Multi-Leader, Leaderless



Leader-based (Master–Slave) Replication



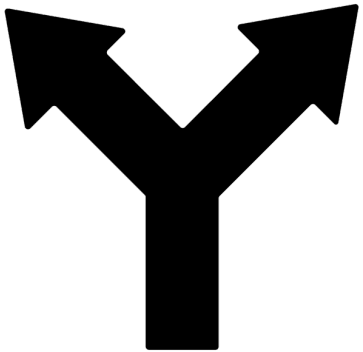
Leader-based replication with one synchronous and one asynchronous follower



Three main approaches to replication

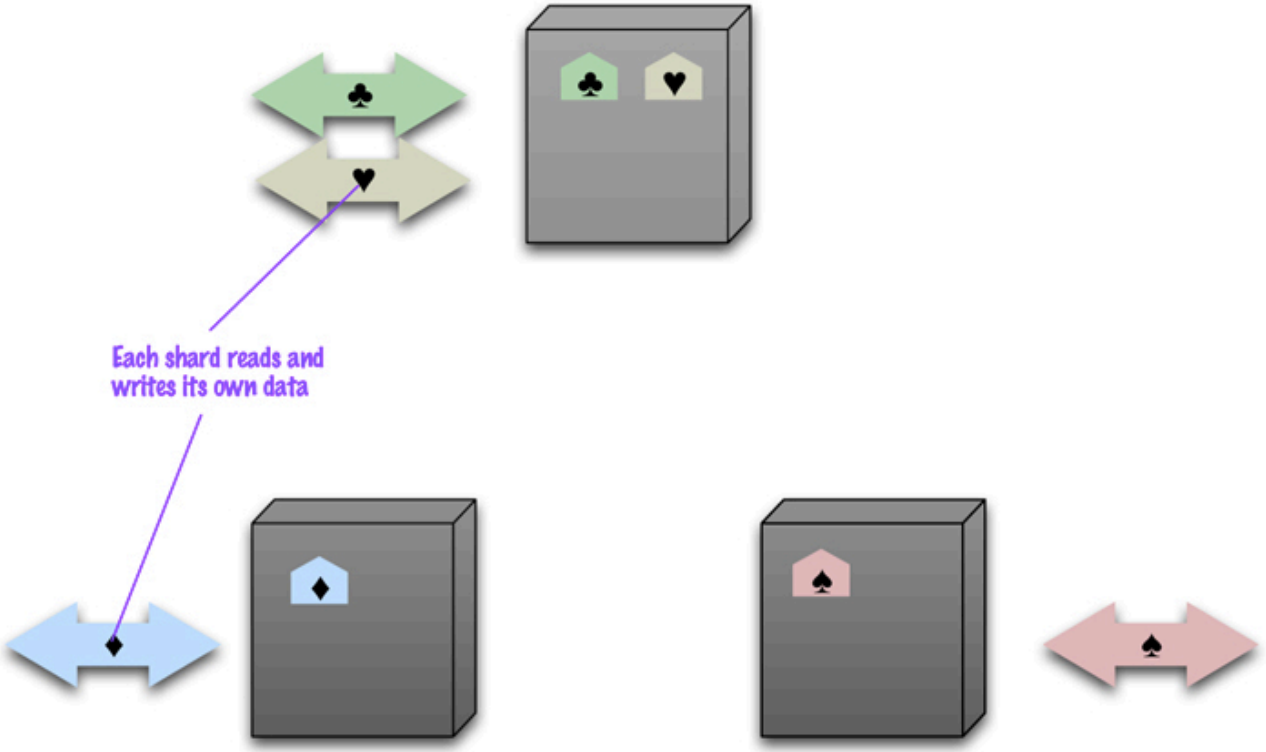
- **Single-leader replication**
  - Clients send all **writes** to a **single node** (the **leader**), which sends a stream of data change events to the other replicas (**followers**).
  - **Reads** can be performed on any replica, but **reads** from followers might be **stale**.
- **Multi-leader replication**
  - Clients send each **write** to one of **several leader nodes**, any of which can accept writes.
  - The leaders send streams of data change events to each other and to any follower nodes.
- **Leaderless replication**
  - Clients send each **write** to **several nodes**, and **read** from **several nodes** in parallel in order to detect and correct nodes with stale data.

Source: Kleppmann (2017), p. 192



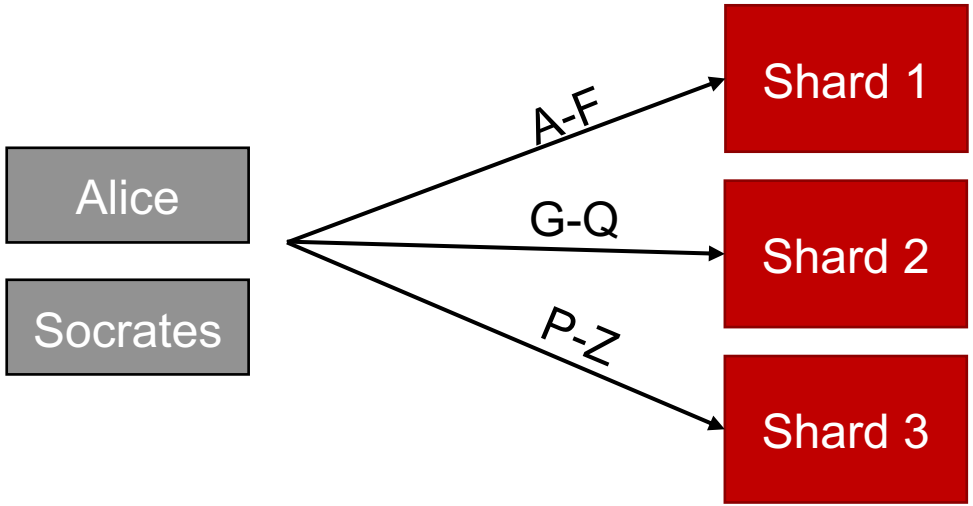
Partitioning

Partitioning (Sharding)



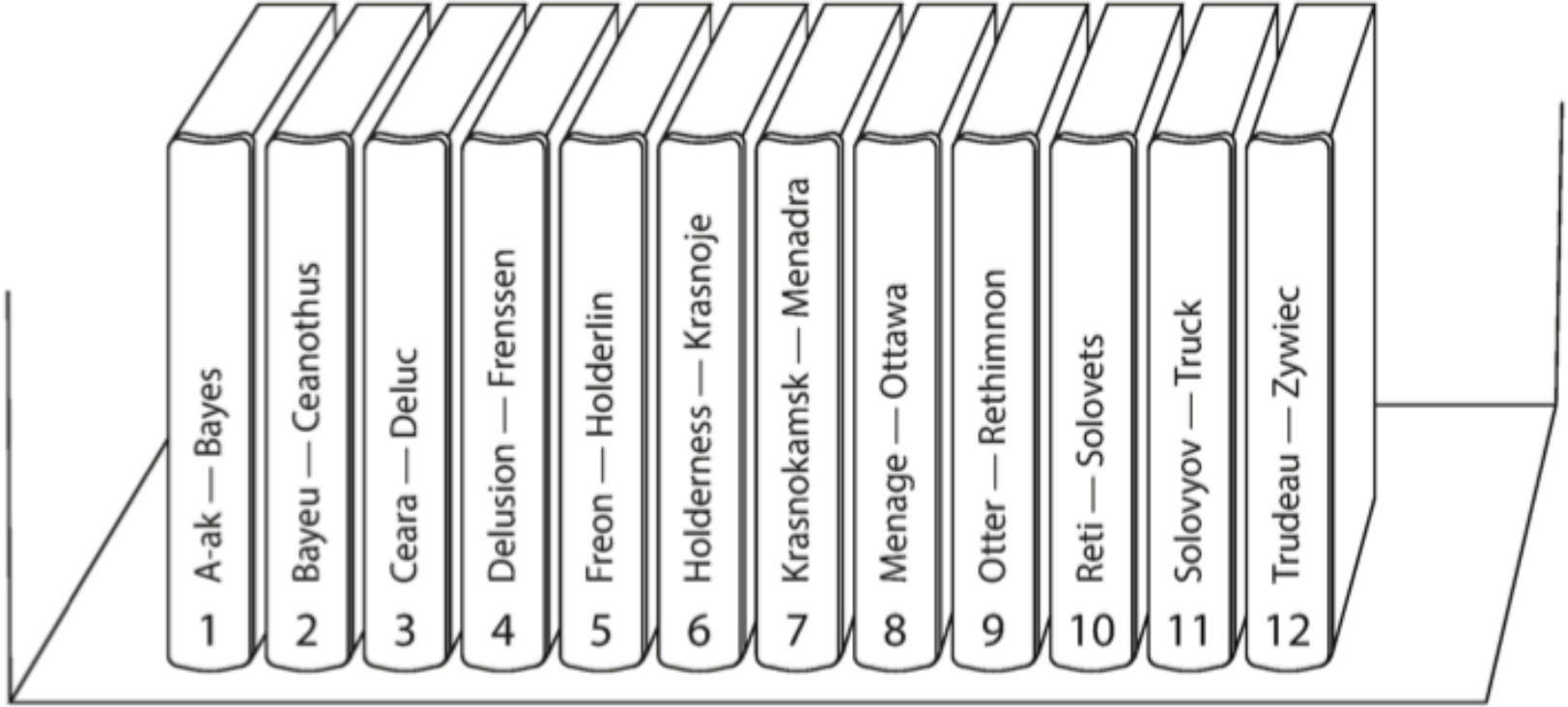
Partitioning (Sharding)

- Horizontal distribution of data over nodes
- Partitioning strategies: Hash-based vs. Range-based
- Difficulty: Multi-Shard-Operations (join, aggregation)



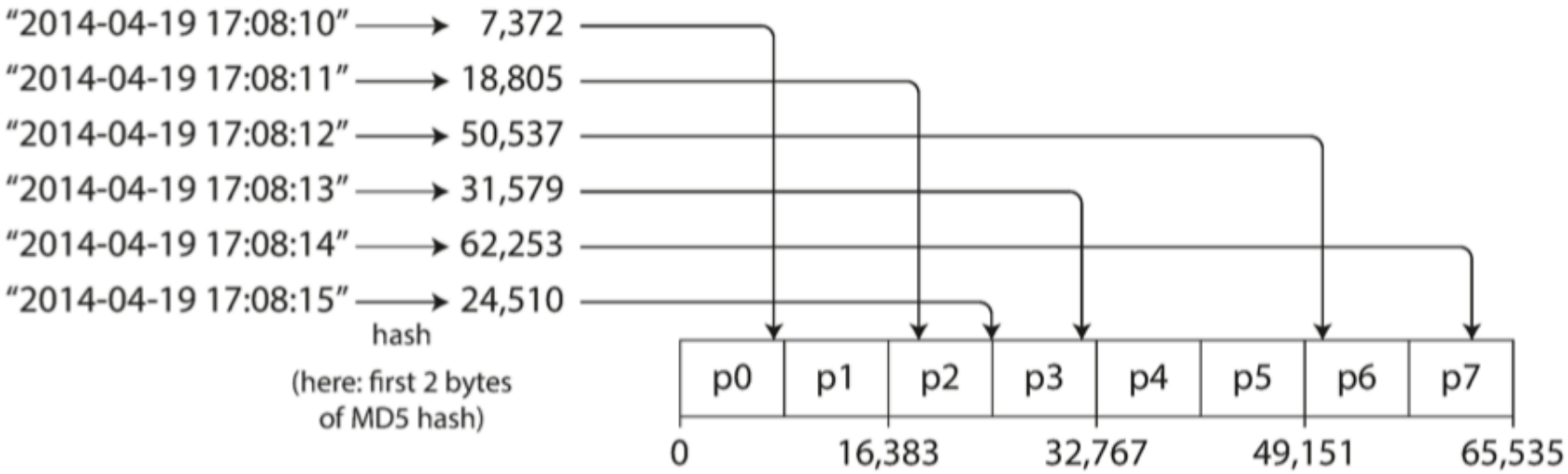
Source: Gessert (2016)

A print encyclopedia is partitioned by key range

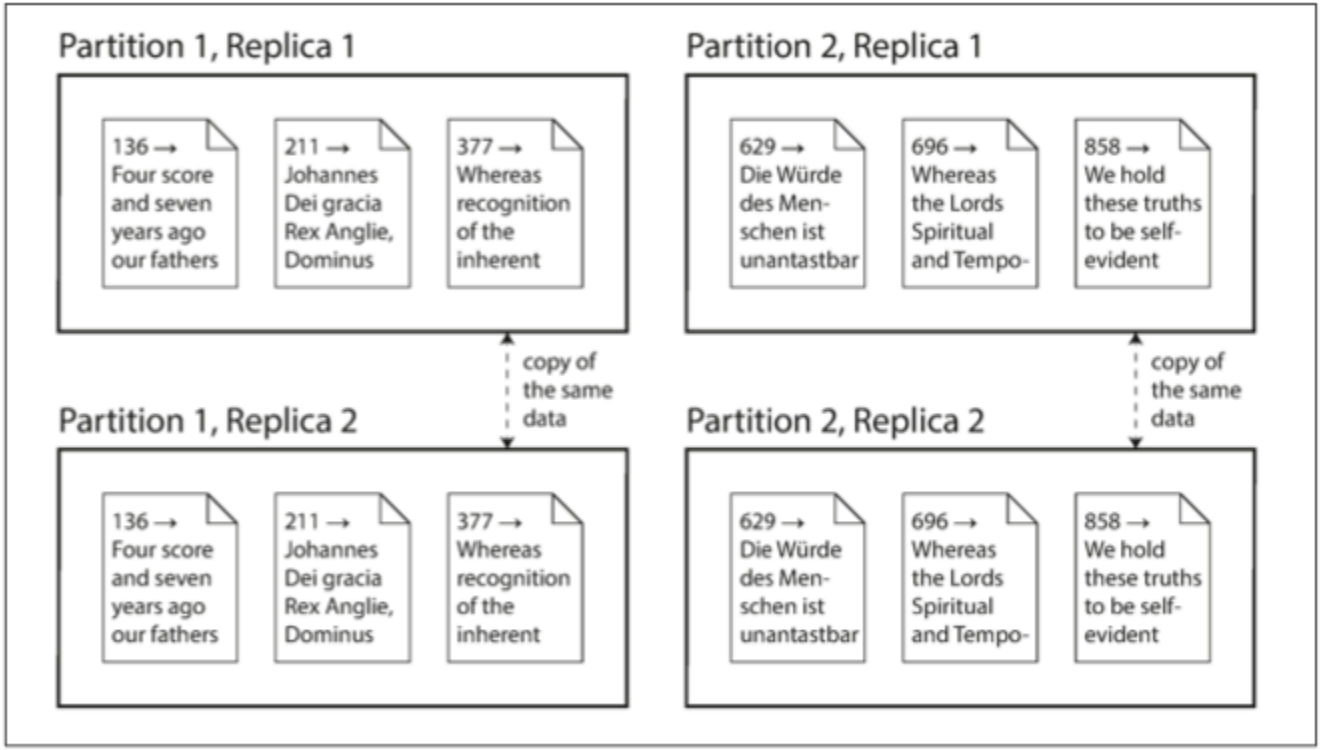


Source: Kleppmann (2017), p. 191

Partitioning by hash of key



Combining Replication and Partitioning



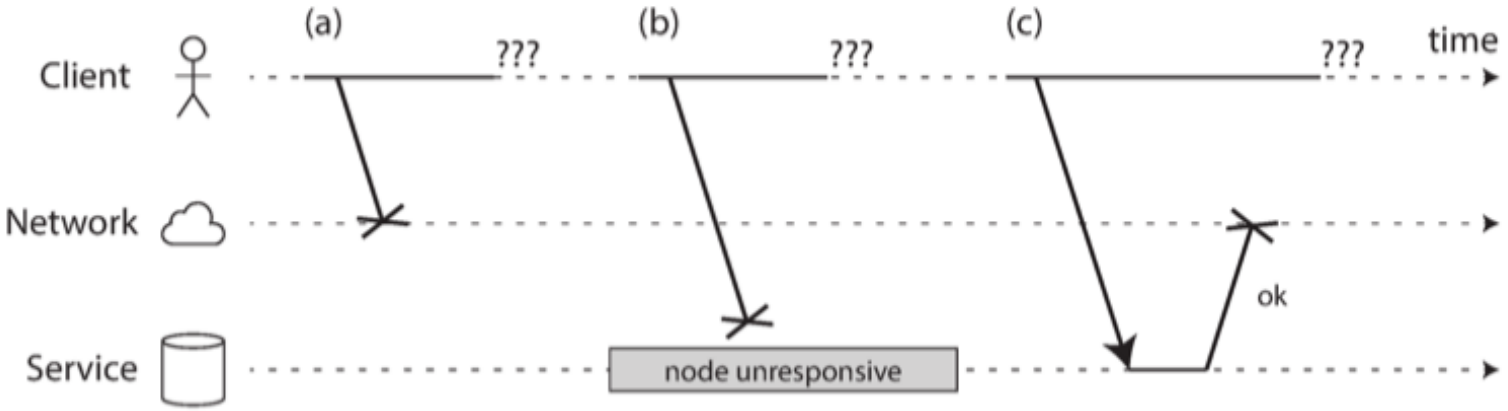
Impact of Replication and Partitioning on

- Reliability
  (Fault tolerance / high availability)
  - Keeping the system running, even when one machine (or several machines, or an entire datacenter) goes down
  - Disconnected operation
  - Allowing an application to continue working when there is a network interruption
- Scalability
  - Being able to handle a higher volume of reads than a single machine could handle, by performing reads on replicas or partitions
  - Storing more data than possible on a single machine by partitioning the data to more nodes
- Latency
  - Placing data geographically close to users, so that users can interact with it faster
- Maintainability
  - Difficult to operate
  - More complicated
  - Sometimes automatic failover possible
  - Problems of Distributed Consistency

Problems of Distributed Systems

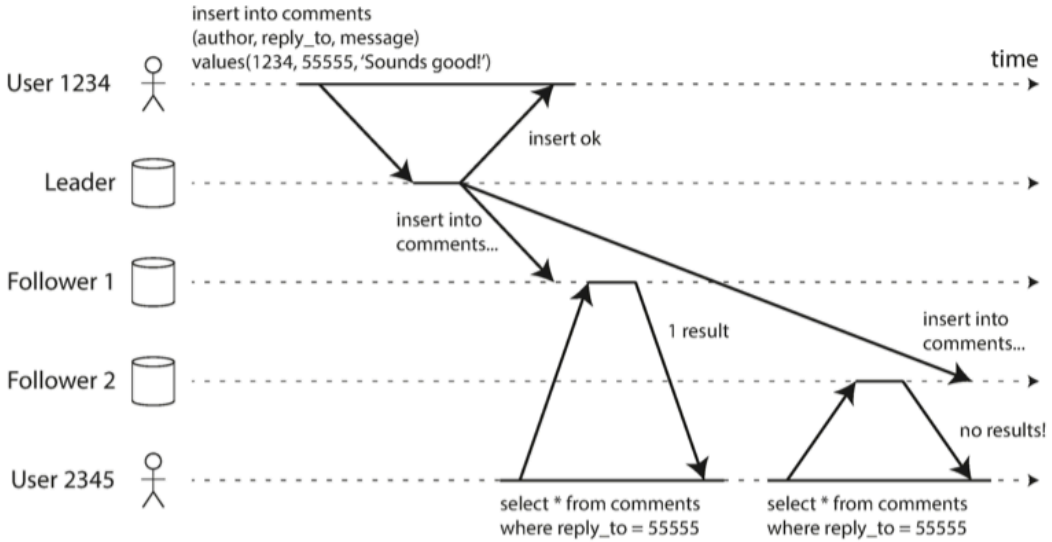
Problems of Distributed Systems

If you send a request and don't get a response, it's not possible to distinguish whether
(a) the request was lost,
(b) the remote node is down, or
(c) the response was lost.



Problems of Distributed Systems

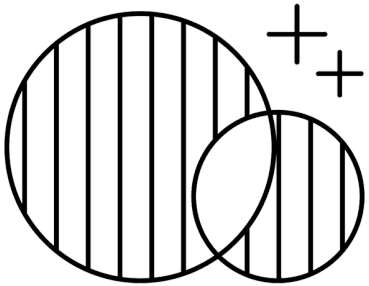
- A user first reads from a fresh replica, then from a stale replica.
- Time appears to go backward.
- To prevent this anomaly, we need monotonic reads.



Distributed Consistency Models

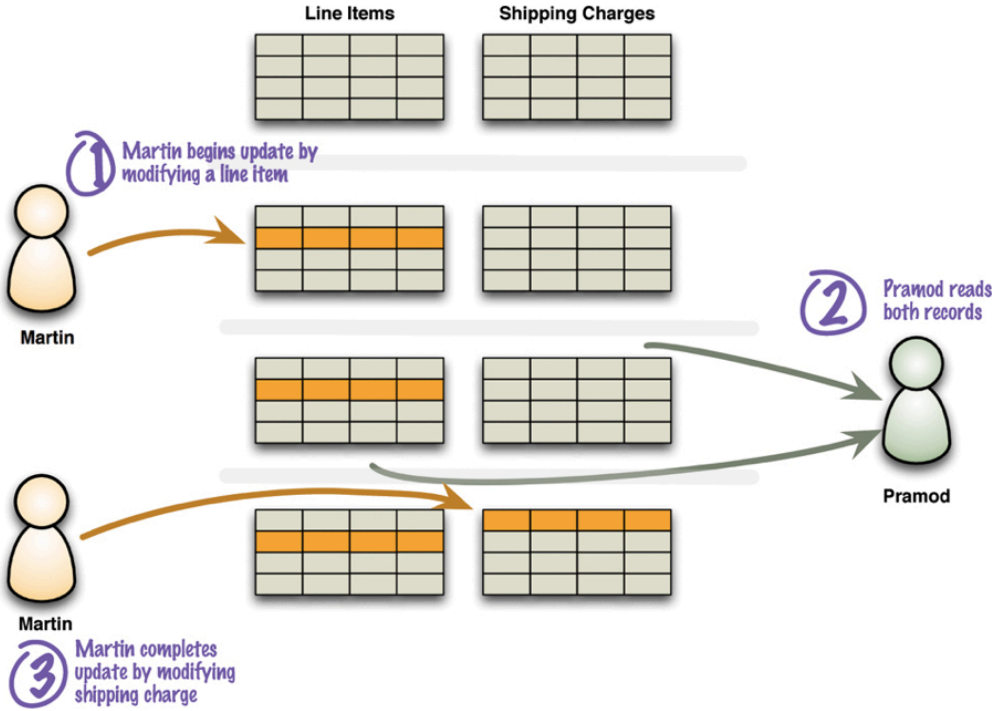
- **Read-after-write consistency**
  - Users should always see data that they submitted themselves.
- **Monotonic reads**
  - After users have seen the data at one point in time, they shouldn't later see the data from some earlier point in time.
- **Consistent prefix reads**
  - Users should see the data in a state that makes causal sense: for example, seeing a question and its reply in the correct order.
- **Linearizability**
  - Every user gets the same (consistent) view on the data independent with which node in a cluster he/she is connected

Source: Kleppmann (2017), p. 165



CAP Theorem

Consistency
(Also known as Linearizability)



Not the same consistency as in ACID!

Source: Fowler (2016)

Different Meaning of Consistency (Linearizability)

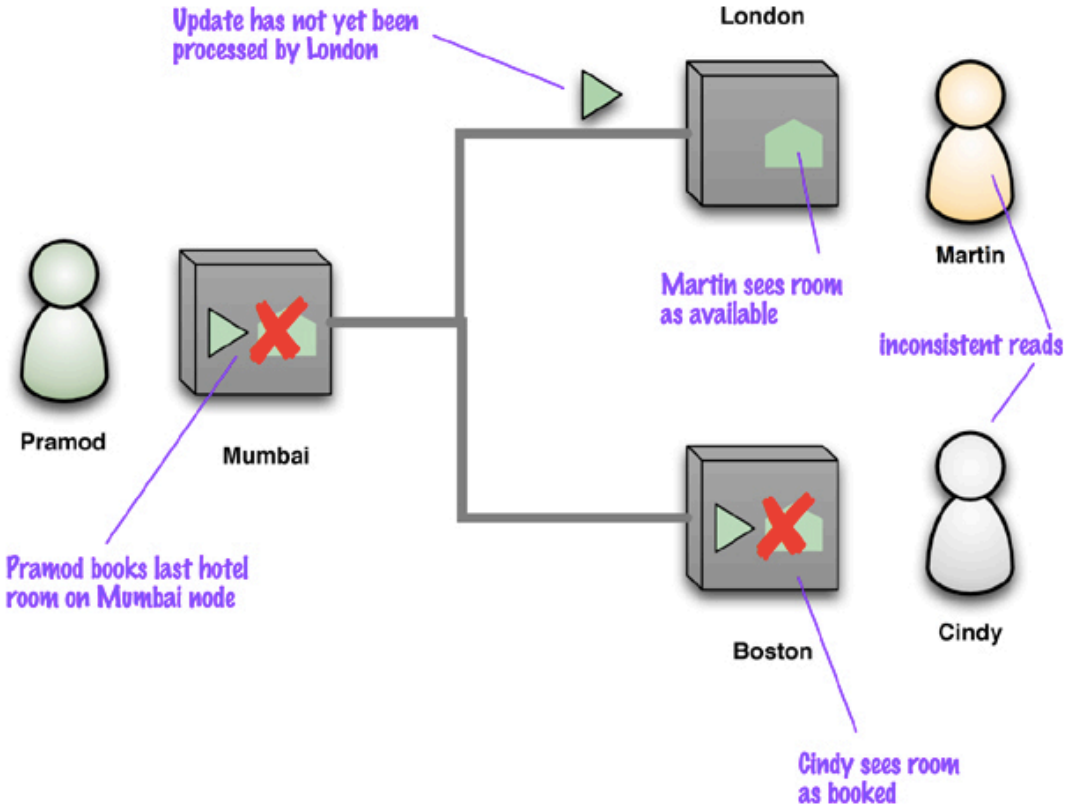
ACID

- Any transaction will bring the database from one valid state to another
- Valid according to all defined rules and constraints

CAP

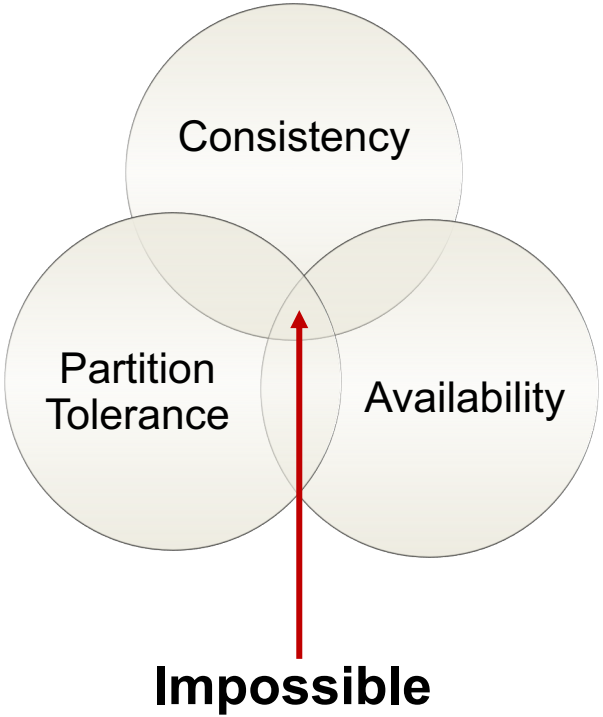
- Every user gets the same (consistent) view on the data independent with which node in a cluster he/she is connected

Inconsistency Problems because of Replication



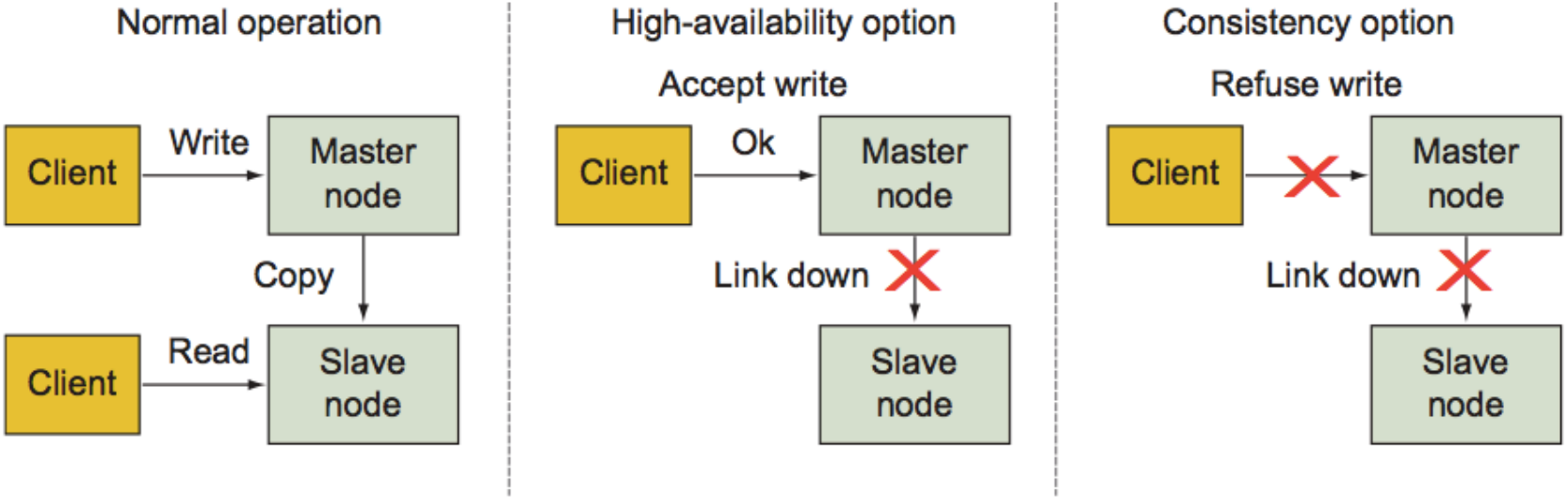
Source: Fowler (2016)

CAP-Theorem



- Only 2 out of 3 properties are achievable at a time:
  - **Consistency:** all clients have the same view on the data
  - **Availability**: every request to a non-failed node most result in correct response
  - **Partition tolerance**: the system has to continue working, even under arbitrary network partitions

CAP-Theorem


Normal operation
Client
Write
Master node
Copy
Client
Read
Slave node
High-availability option
Accept write
Client
Ok
Master node
Link down
Slave node
Consistency option
Refuse write
Client
Master node
Link down
Slave node

CAP-Theorem

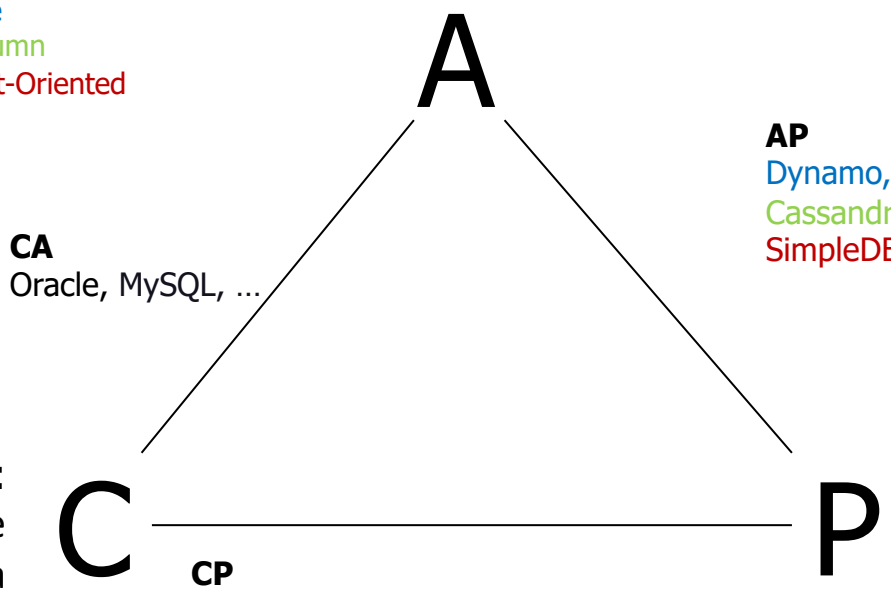
If you have…	then you get…
A single processor or many processors on a working network	Consistency AND availability
Many processors and network failures	Each transaction can select between consistency OR availability depending on the context

Source: McCreary and Kelly (2013)

CAP Triangle

Availability: Every client can always read and write

Data models
- Relational
- Key-Value
- Wide-Column
- Document-Oriented



AP
Dynamo, Redis, Riak, Voldemort
Cassandra
SimpleDB

CA
Oracle, MySQL, …

Consistency:
All clients share the same view on the data

CP
Postgres, MySQL Cluster, Oracle RAC
BigTable, HBase, Accumulo, Azure Tables
MongoDB, RethinkDB, DocumentsDB

Partition tolerance:
All nodes continue working under network partitions

Source: Gessert (2017)

Problematic and Unrealistic Definition of CAP Theorem

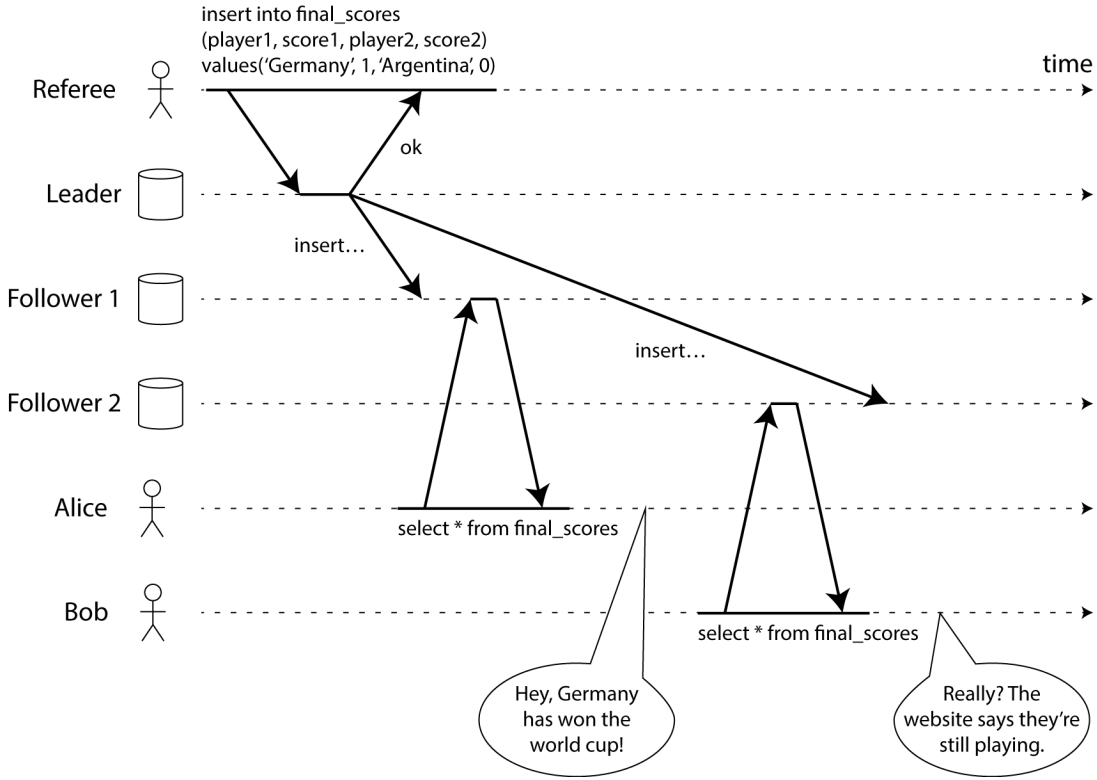
- Availability
  - Instance available. No chance of of waiting for self-repair or delay
- Network Partition
  - Could be arbitrary long!
- Consistency
  - Very strong type of consistency ➔ Linearizability

- What about Node failure?
- What about Latency?

Consistency (Linearizability)

- „If operation B started after operation A successfully completed,
- then operation B must see the system in the same state as it was on completion of operation A, or a newer state.”

Consistency (Linearizability)



PACELC – Alternative for CAP

Partition: Availability vs. Consistency, Else: Latency vs. Consistency

if there is a partition (P)

- how does the system trade off availability and consistency (A and C)

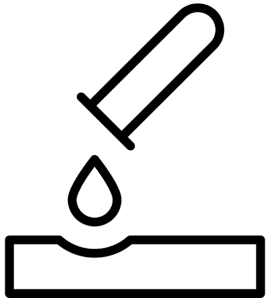
else (E)

- when the system is running normally in the absence of partitions, how does the system trade off latency (L) and consistency (C)

Classification of distributed storage systems:

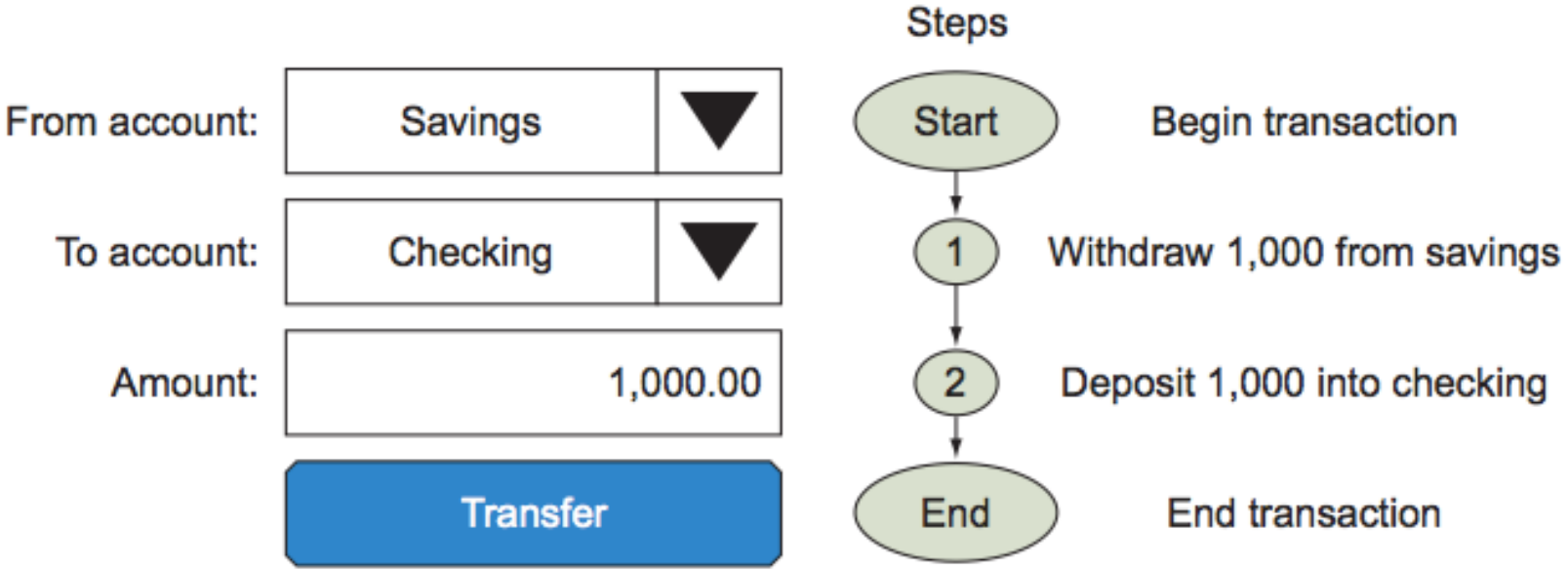
- PA/EL: Dynamo, Cassandra, Riak
- PC/EC: ACID Databases (like PostgreSQL), Big Table, Hbase
- PA/EC: MongoDB
- PC/EL: PNUTS

Source: Abadi (2012)



ACID vs. BASE

Transaction



ACID Properties of a Transaction

- Atomicity
  - each transaction is "all or nothing": if one part of the transaction fails, the entire transaction fails, and the database state is left unchanged.
- Consistency
  - any transaction will bring the database from one valid state to another
  - valid according to all defined rules and constraints
- Isolation
  - concurrent execution of transactions results in a system state that would be obtained if transactions were executed serially, i.e., one after the other
- Durability
  - once a transaction has been committed, it will remain so, even in the event of power loss, crashes, or errors

Source: Wikipedia https://en.wikipedia.org/wiki/ACID

BASE

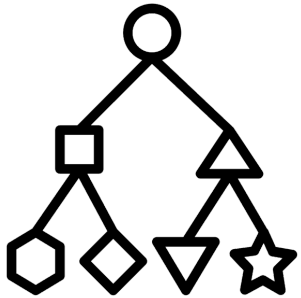
- Basic Availability
- Soft-state
- Eventual consistency

ACID vs. BASE

Vs.

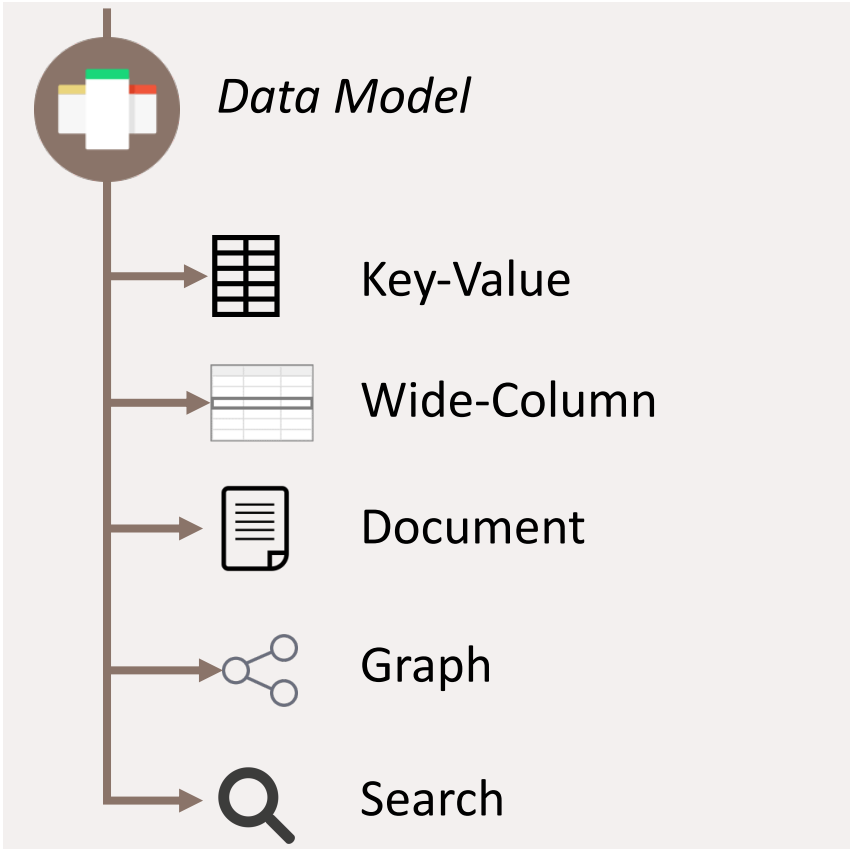
Acid	Base
• Get transaction details right • Block any reports while you are working • Be pessimistic: anything might go wrong! • Detailed testing and failure mode analysis • Lots of locks and unlocks	• Never block a write • Focus on throughput, not consistency • Be optimistic: if one service fails it will eventually get caught up • Some reports may be inconsistent for a while, but don't worry • Keep things simple and avoid locks

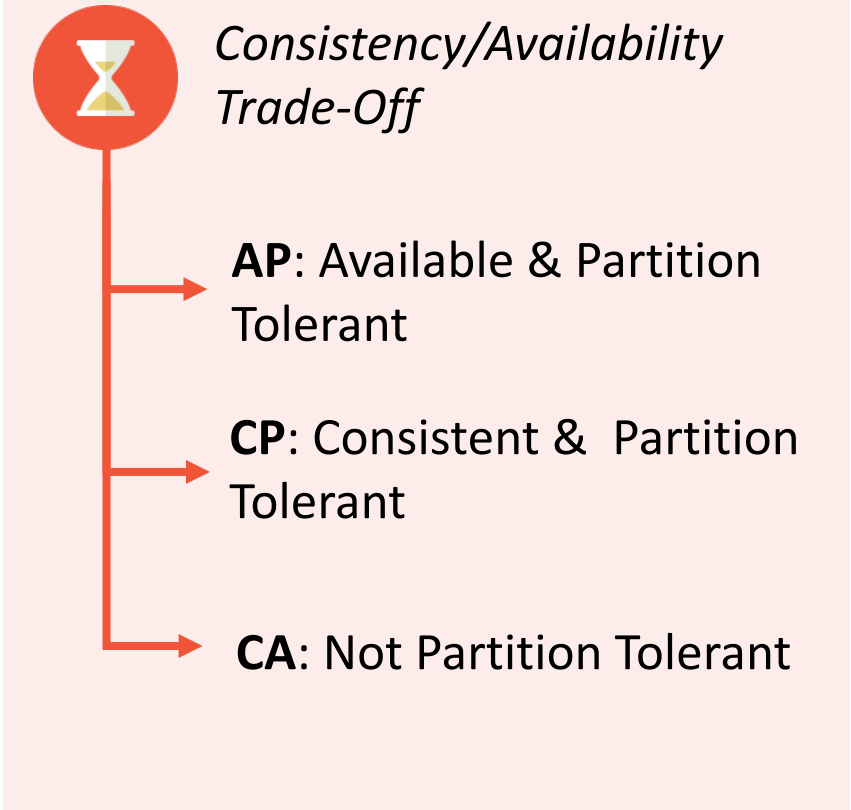
Source: McCreary and Kelly (2013)



NoSQL Classification

NoSQL System Classification

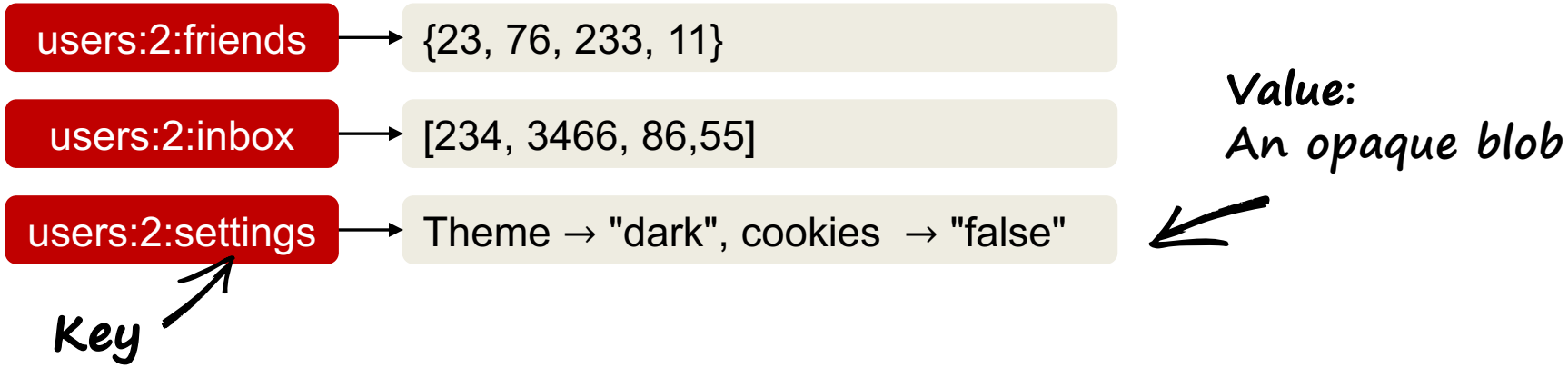




Source: Gessert (2017)

Key-Value Stores

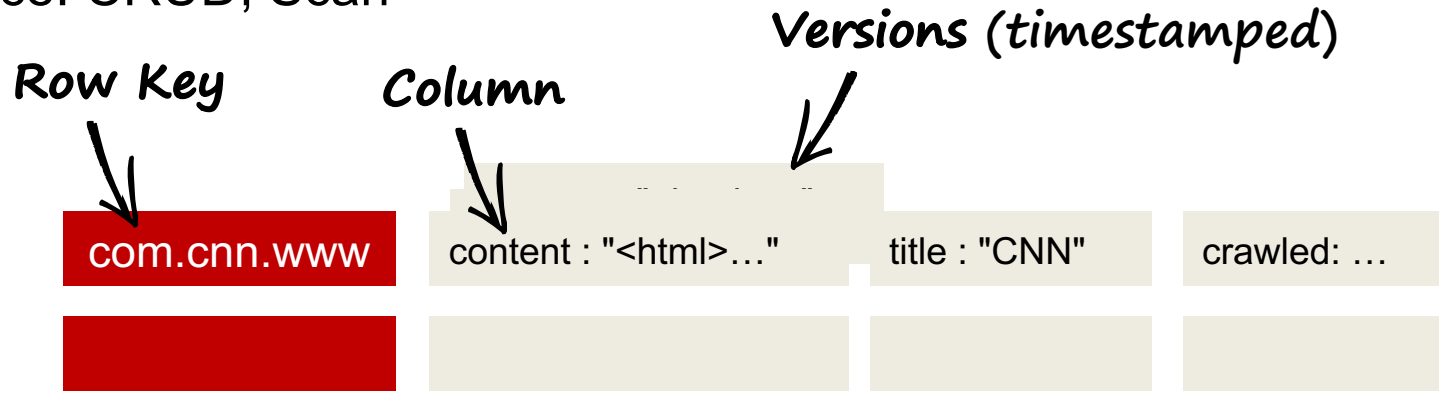
- Data model: (key) -> value
- Interface: CRUD (Create, Read, Update, Delete)



- Examples: Redis (CP), Amazon Dynamo (AP), Riak (AP)

Wide-Column Stores

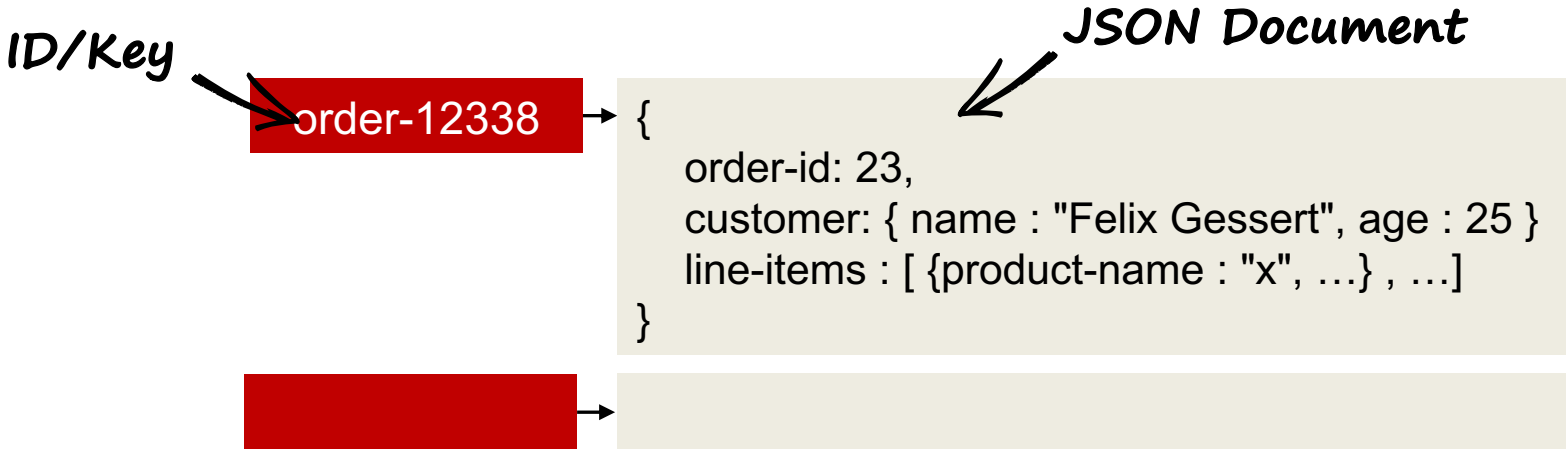
- Data model: (rowkey, column, timestamp) -> value
- Interface: CRUD, Scan



- Examples: Cassandra (AP), Google BigTable (CP), HBase (CP)
- Two-dimensional key-value store
- NOT equal to column-oriented storage like in SAP HANA!

Document Stores

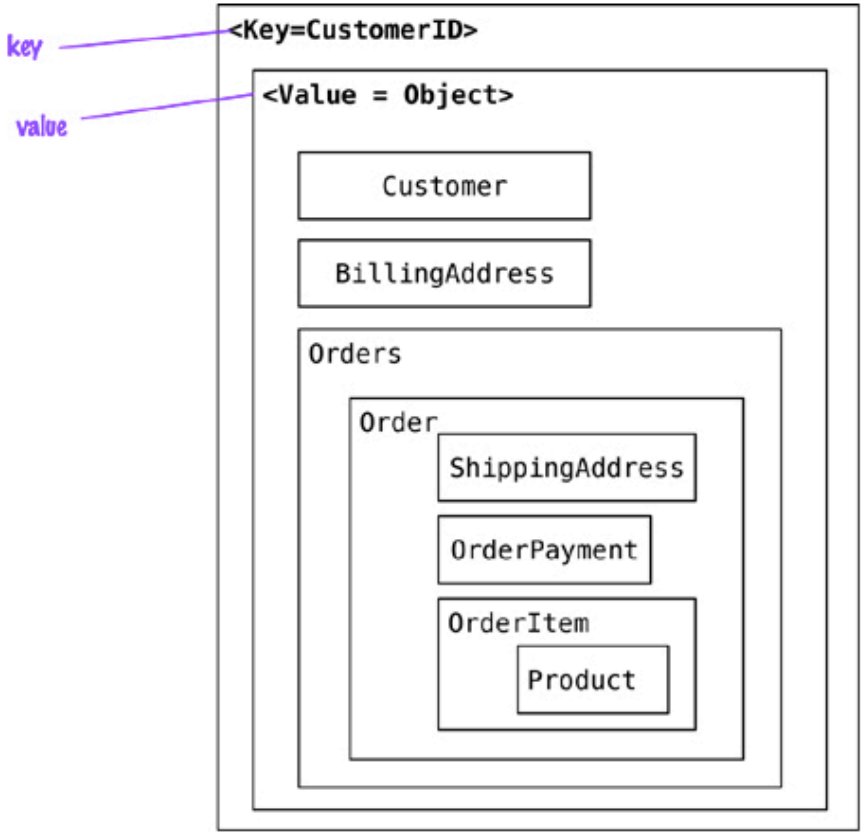
- Data model: (collection, key) -> document
- Interface: CRUD, Querys, Map-Reduce



- Examples: MongoDB (CP), CouchDB (AP), RethinkDB (CP)

Source: Gessert (2017)

Document Stores



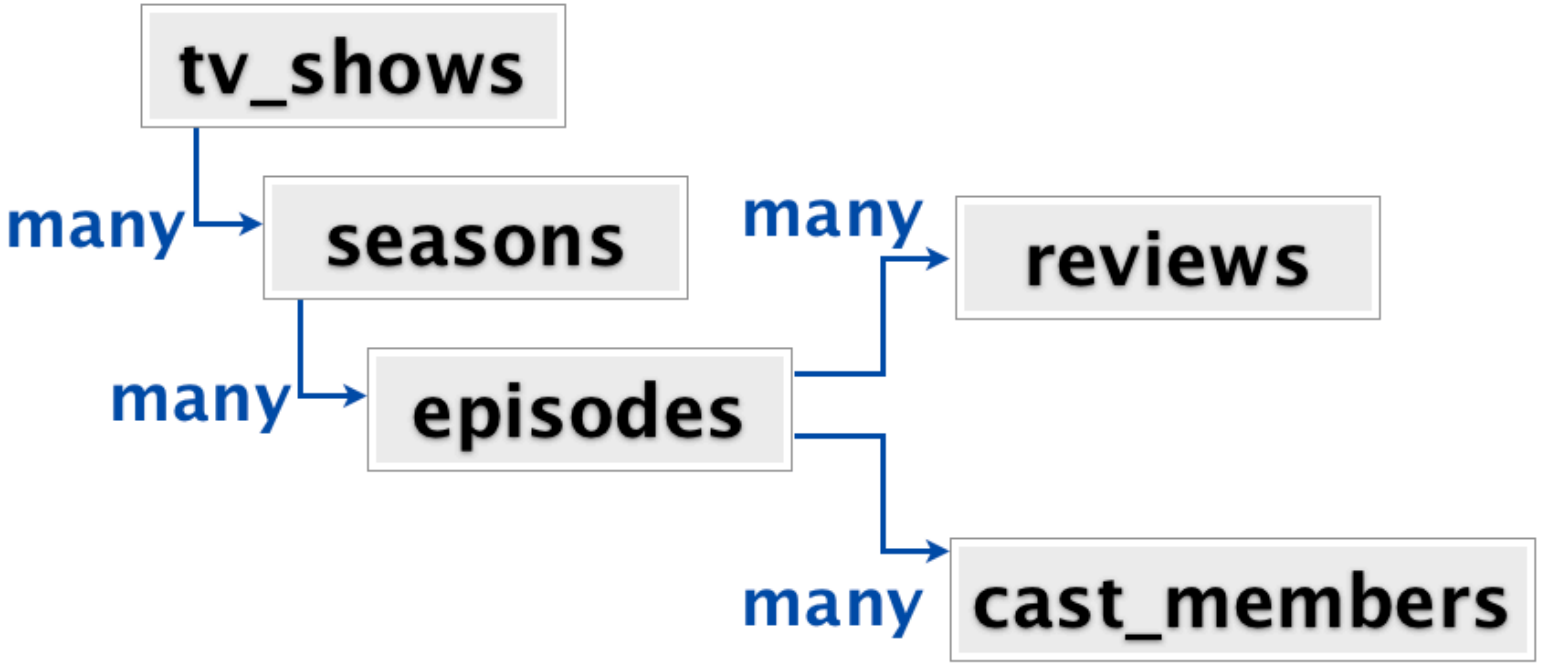
JSON

```
# Customer object
{
"customerId": 1,
"customer": {
  "name": "Martin",
  "billingAddress": [{"city": "Chicago"}],
  "payment": [{"type": "debit","ccinfo": "1000-1000-1000-1000"}],
  "orders":[{"orderId":99}]
 }
}

# Order object
{
"customerId": 1,
"orderId": 99,
"order":{
  "orderDate":"Nov-20-2011",
  "orderItems":[{"productId":27, "price": 32.45}],
   "orderPayment":[{"ccinfo":"1000-1000-1000-1000",
           "txnId":"abelif879rft"}],
   "shippingAddress":{"city":"Chicago"}
   }
}
```

Source: Fowler (2016)

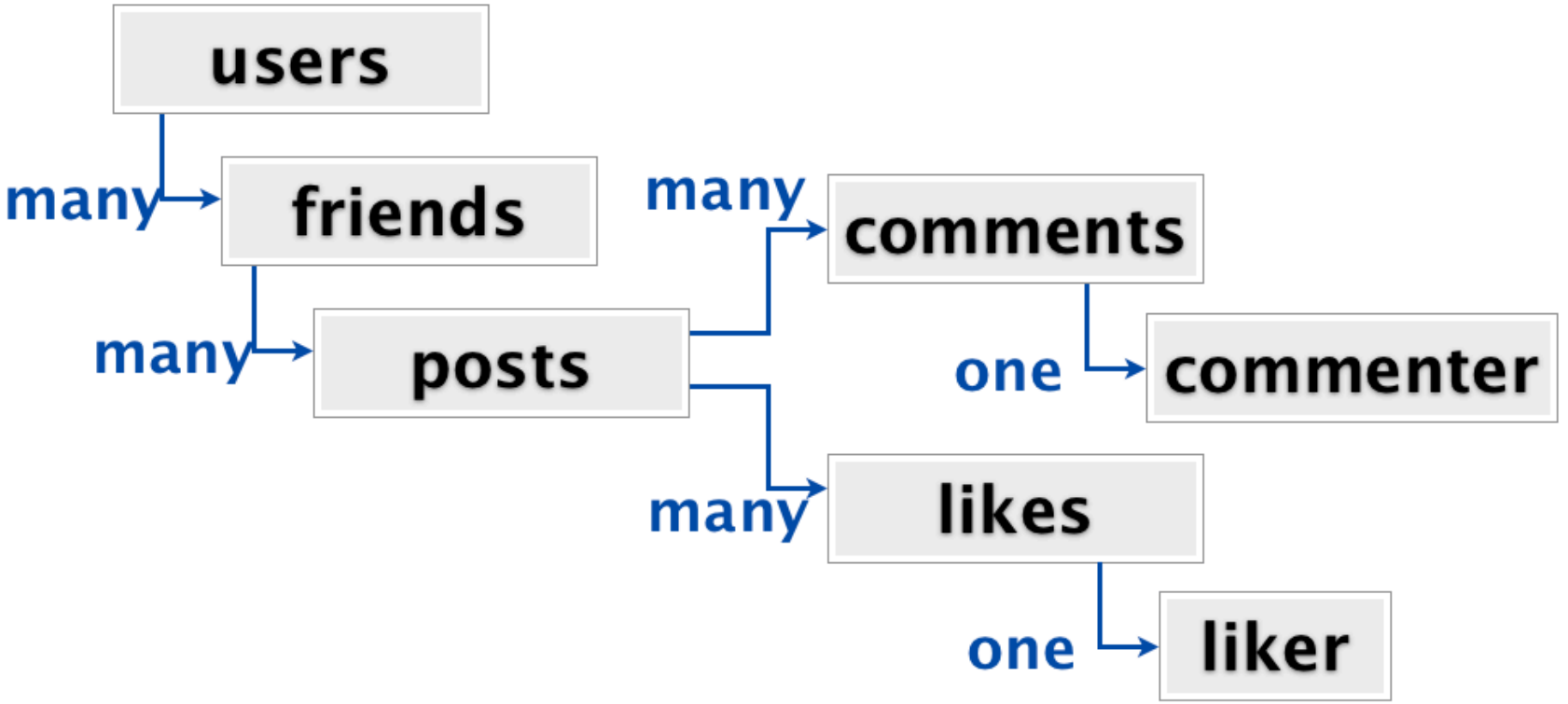
Not all Tree Structures should be saved in Document Databases



Not all Tree Structures should be saved in Document Databases

```
{title: 'Babylon 5',
 seasons: [
  {season_number: '1',
    episodes: [
     {ordinal_within_season: '1',
      title: 'Midnight on the Firing Line'
      reviews: [{...}],
      cast_members: [{...}]
     }
    ]
  }
 ]
}
```

Not all Tree Structures should be saved in Document Databases



MongoDB (CP)

- From humongous ≅ gigantic
- Schema-free document database with tunable consistency
- Allows complex queries and indexing
- Sharding (either range- or hash-based)
- Replication (either synchronous or asynchronous)
- Storage Management:
  - Write-ahead logging for redos (journaling)
  - Storage Engines: memory-mapped files, in-memory, Log-structured merge trees (WiredTiger), …

Basics of MongoDB

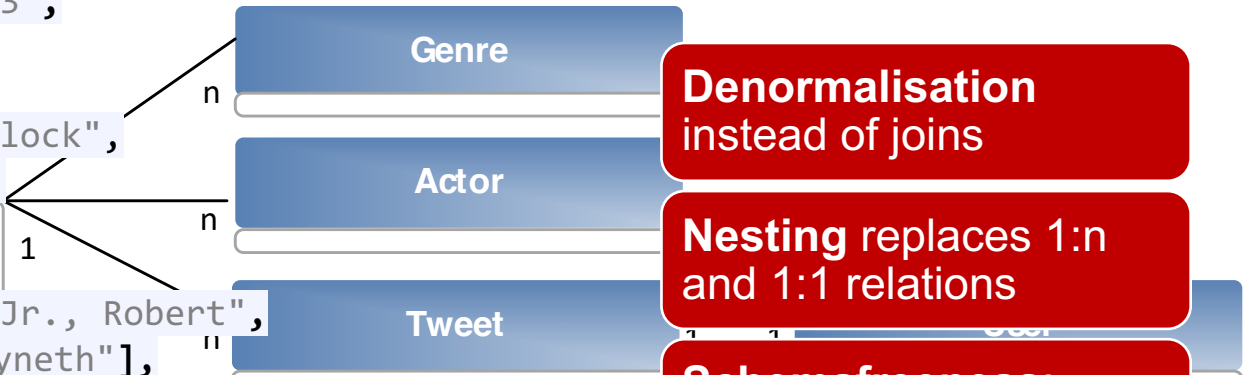
```
> mongod &
> mongo imdb
MongoDB shell version: 2.4.3
connecting to: imdb
> show collections
movies
tweets
> db.movies.findOne({title : "Iron Man 3"})
{
    title : "Iron Man 3",
    year : 2013 ,
    genre : [
         "Action",
         "Adventure",
         "Sci -Fi"],
    actors : [
         "Downey Jr., Robert",
         "Paltrow , Gwyneth",]
}
```

Properties

Arrays, Nesting allowed

Data Modelling of MongoDB

```
{
    "_id" : ObjectId("51a5d316d70beffe74ecc940")
    title : "Iron Man 3",
    year : 2013,
    rating : 7.6,
    director: "Shane Block",
    genre : ["Action",
         "Adventure",
         "Sci -Fi"],
    actors : ["Downey Jr., Robert",
         "Paltrow , Gwyneth"],
    tweets : [ {
            "user" : "Franz Kafka",
            "text" : "#nowwatching Iron Man 3",
            "retweet" : false,
            "date" : ISODate("2013-05-29T13:15:51Z")
    }]
}
```



Denormalisation instead of joins

Nesting replaces 1:n and 1:1 relations

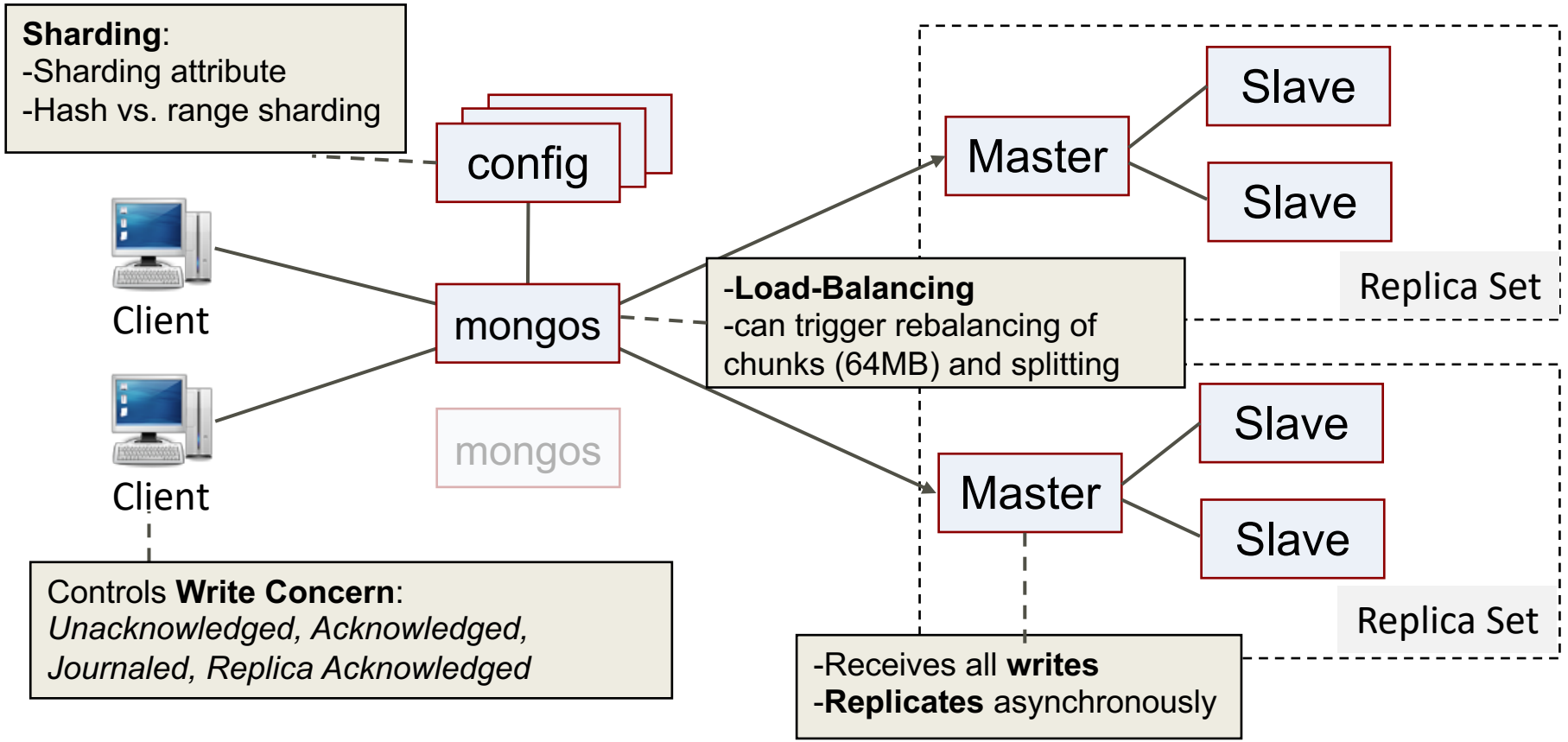
Schemafreeness: Attributes per document

Unit of atomicity: document

Movie
Document

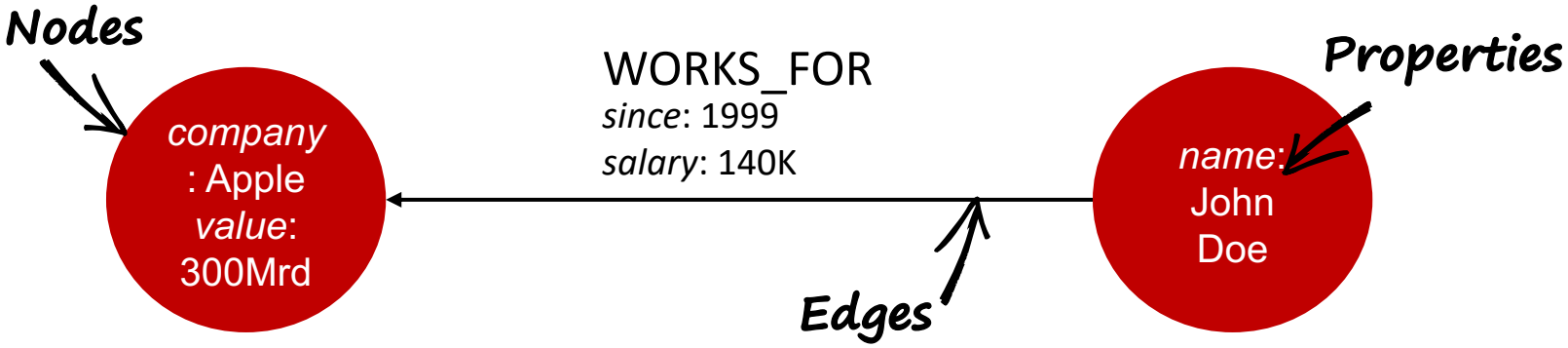
Principles

Sharding and Replication of MongoDB



Graph Databases

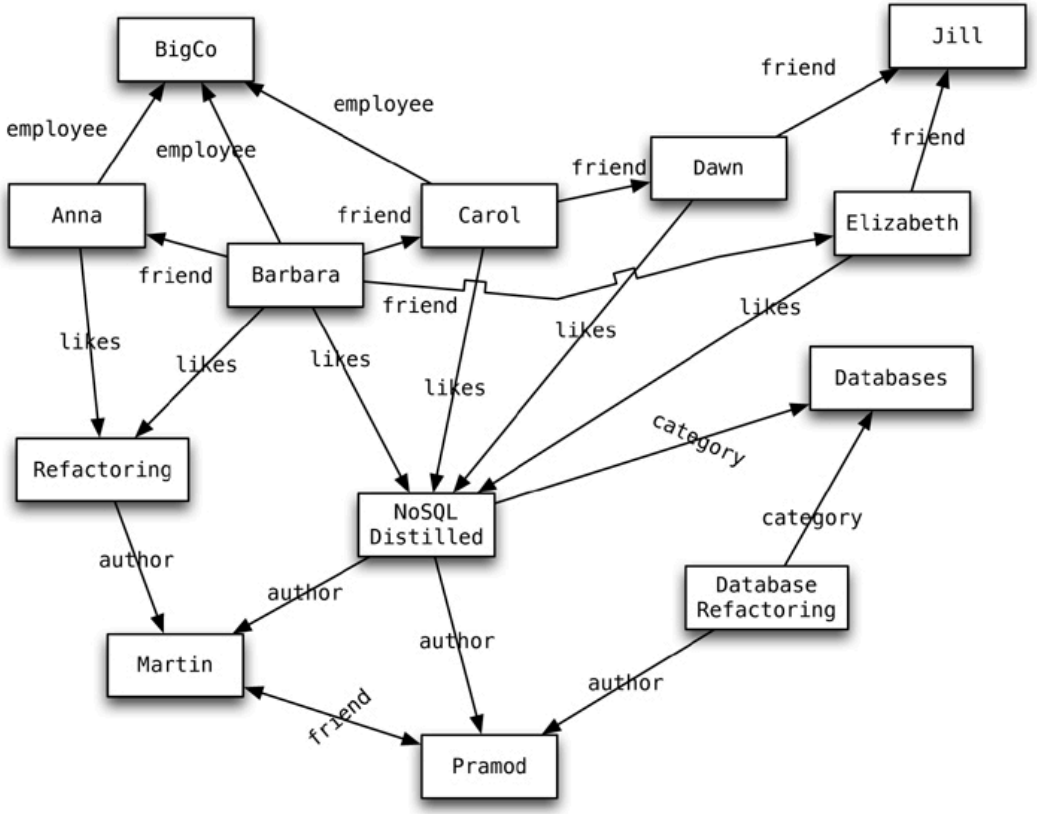
- Data model: G = (V, E): Graph-Property Modell
- Interface: Traversal algorithms, querys, transactions



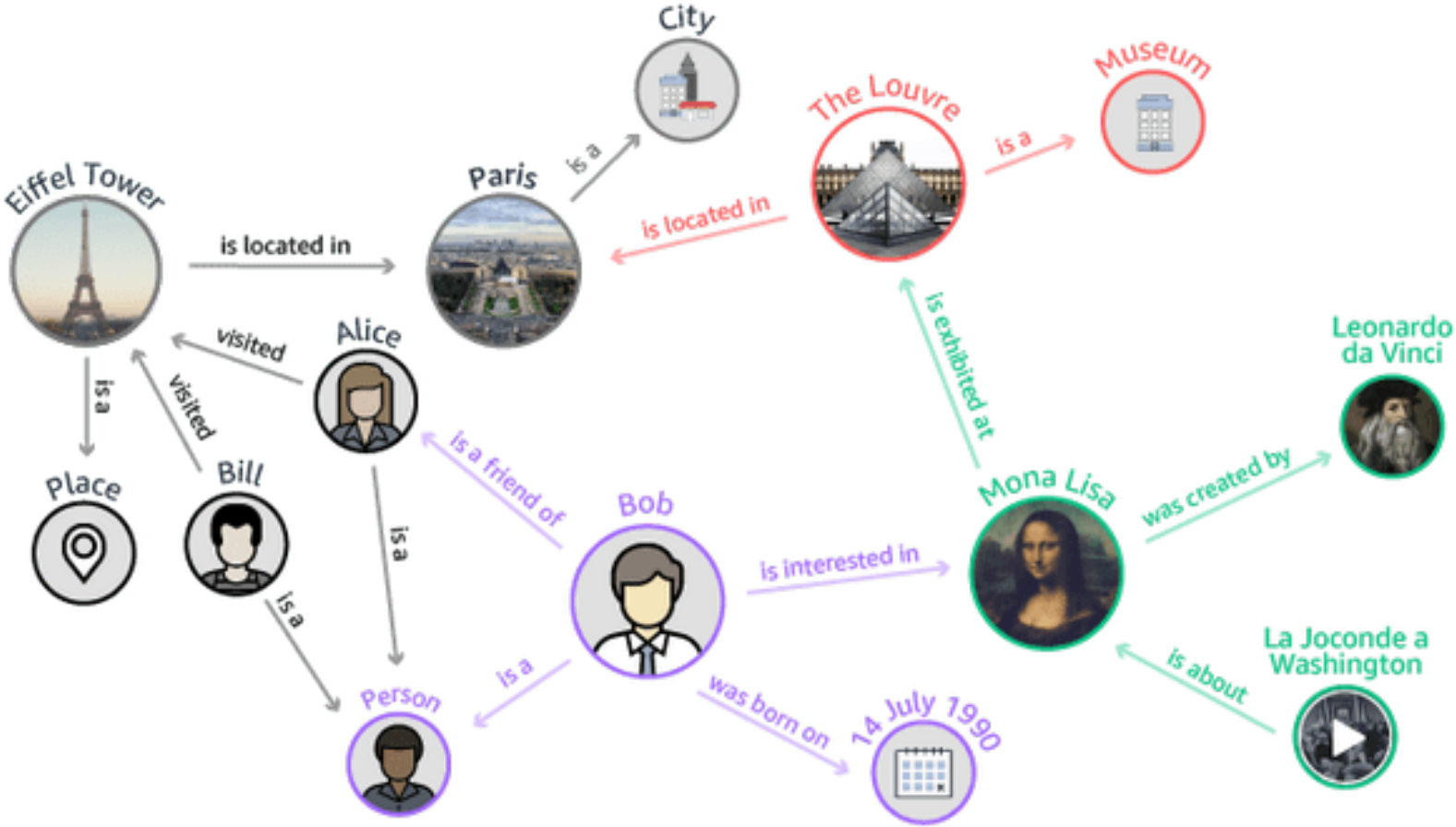
- Examples: Neo4j (CA), InfiniteGraph (CA), OrientDB (CA)

Source: Gessert (2017)

Graph Structures

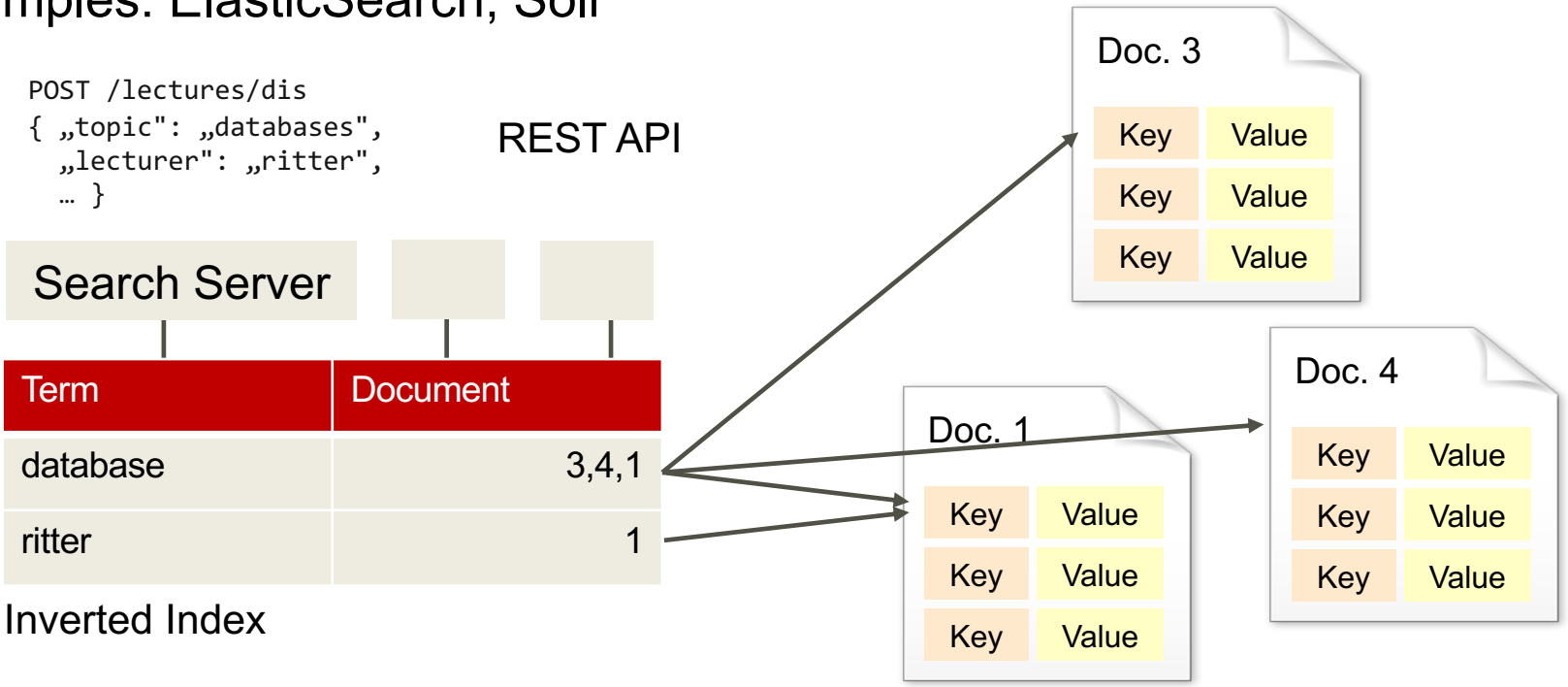


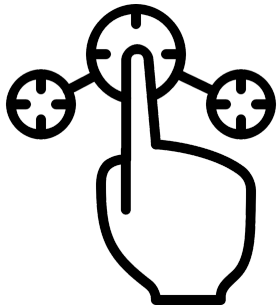
Knowledge Graph



Search Platforms

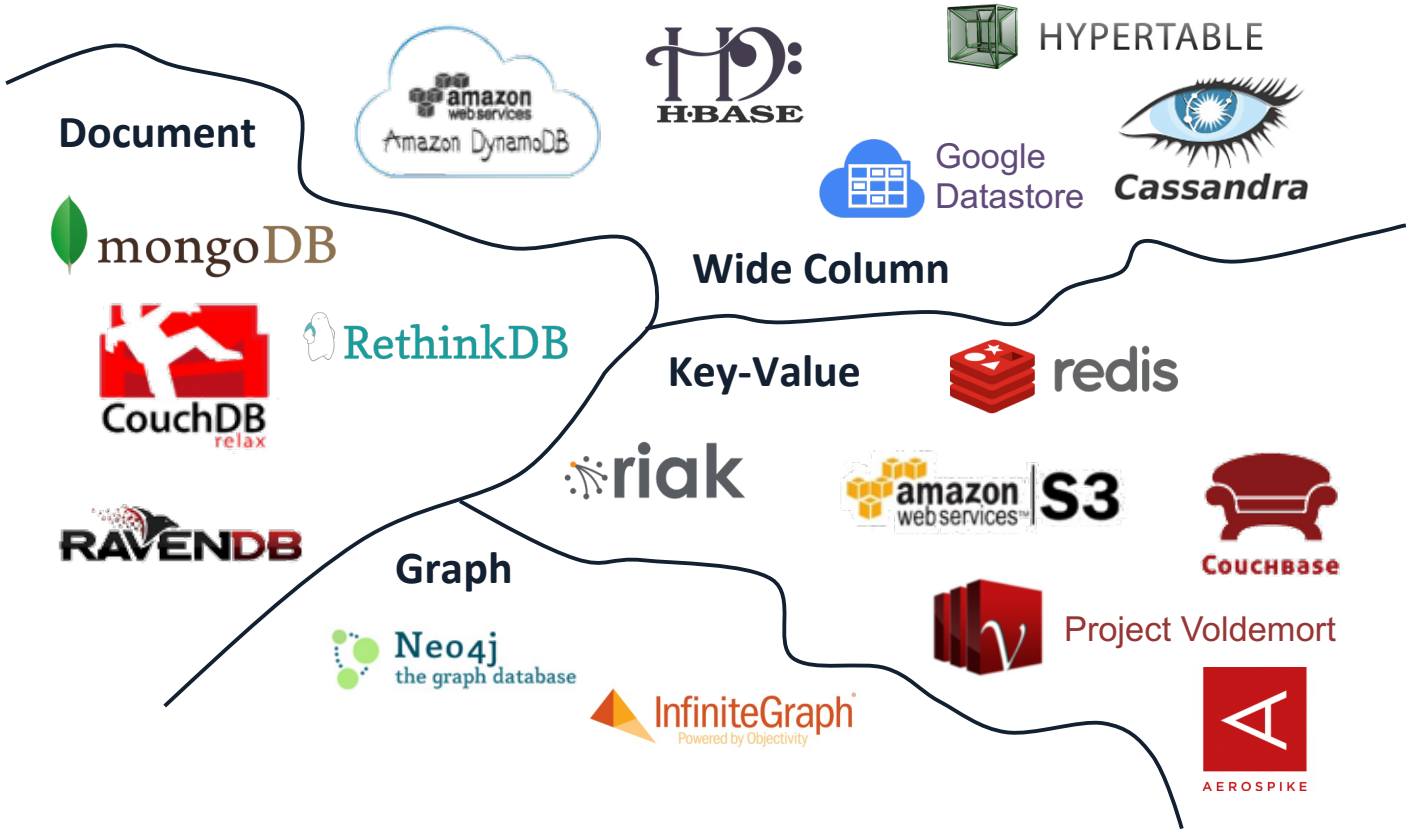
- Data model: vectorspace model, docs + metadata
- Examples: ElasticSearch, Solr





NoSQL Selection

NoSQL Landscape



Database Popularity May 2020

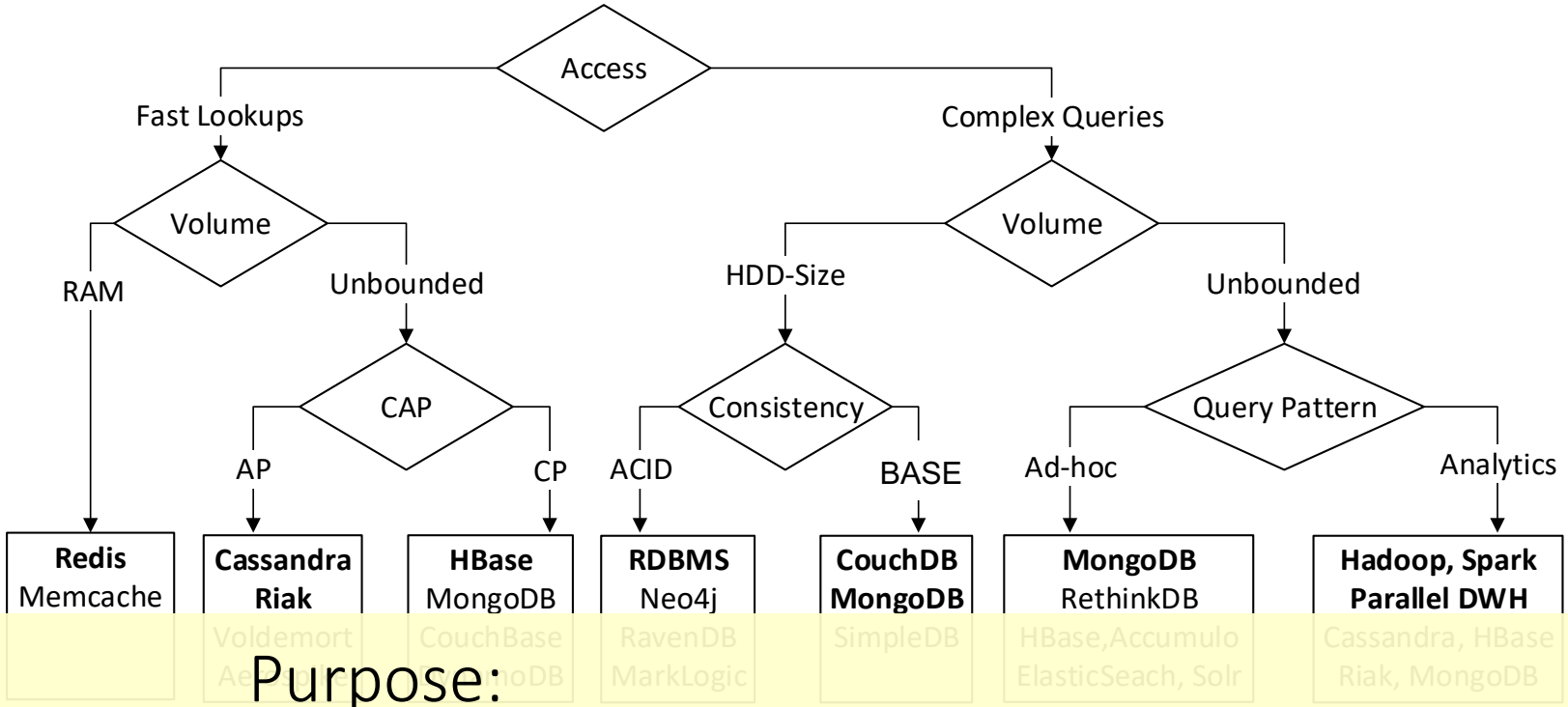
#	System	Model	Score
1.	Oracle	Relational DBMS	1345
2.	MySQL	Relational DBMS	1282
3.	MS SQL Server	Relational DBMS	1078
4.	PostgreSQL	Relational DBMS	514
5.	**MongoDB**	**Document store**	439
6.	DB2	Relational DBMS	162
7.	**Elasticsearch**	**Search engine**	149
8.	**Redis**	**Key-value store**	143
9.	SQLite	Relational DBMS	123
10.	MS Access	Relational DBMS	120
11.	**Cassandra**	**Wide column store**	119
12.	MariaDB	Relational DBMS	90
13.	**Splunk**	**Search engine**	88
14.	Hive	Relational DBMS	82
15.	Terradata	Relational DBMS	74
16.	**Amazon DynamoDB**	**Multi-modal store**	65
17.	SAP Adaptive Server	Relational DBMS	54
18.	**Solr**	**Search engine**	53
19.	FileMaker	Relational DBMS	51
20.	SAP HANA	Relational DBMS	51
21.	**Neo4j**	**Graph DBMS**	50
22.	**HBase**	**Wide column store**	50
23.	Azure SQL Database	Relational DBMS	43
24.	**Azure Cosmos DB**	**Multi-modal store**	31
25.	**Couchbase**	**Document store**	29

Scoring: Google/Bing results, Google Trends, Stackoverflow, job offers, LinkedIn

Source: https://db-engines.com/en/ranking

Know your Tools

“Having a big toolbox is impressive. But knowing **when to use what tool** and why separates the true expert from the show-off.” *Gregor Hohpe*



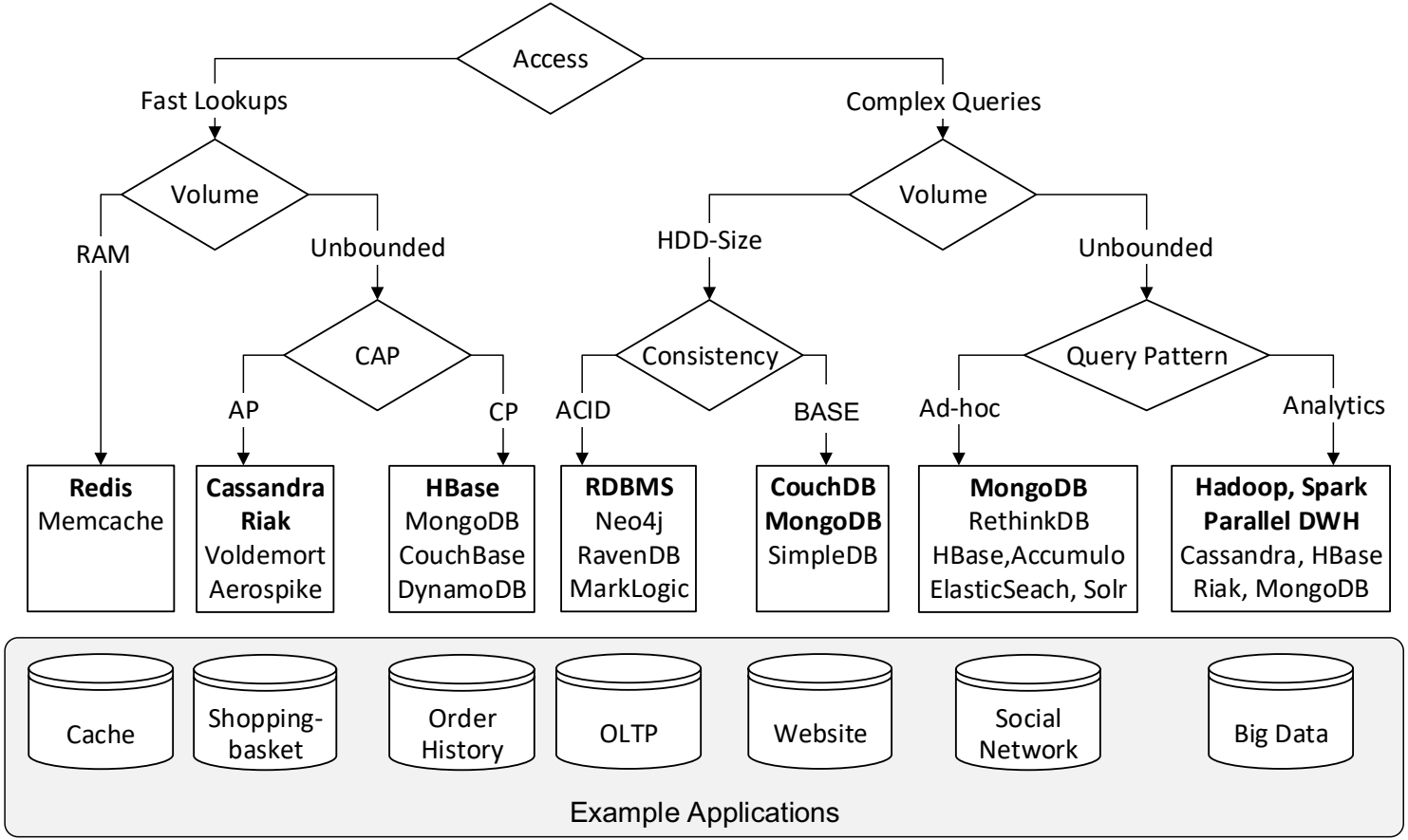
Purpose:

Application Architects: narrowing down the potential system candidates based on requirements

Database Vendors/Researchers: clear communication and design of system trade-offs

Source: Gessert (2017)

NoSQL Decision Tree

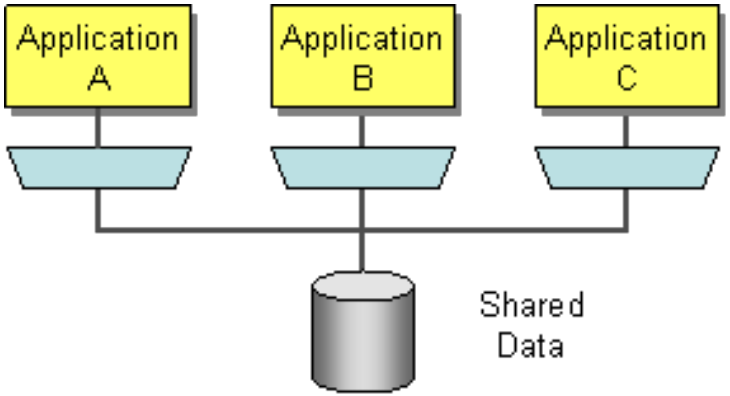


Source: Gessert (2017)

Polyglot Persistence

Integration through a shared database

- **Problem**: How can I integrate multiple distributed applications or services so that they work together and can exchange information?



- **Solution**: Integrate applications by having them store their data in a single **Shared Database**.

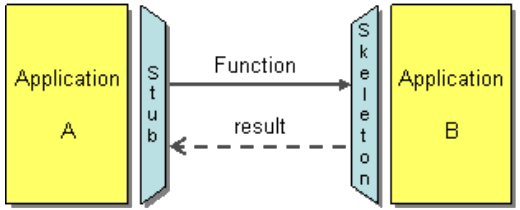
Polyglot Persistence

Source: Fowler (2016)

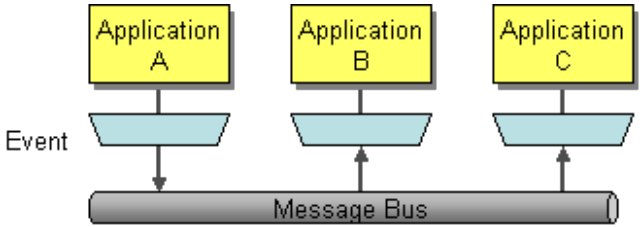
Integration without a shared Database

Service Integration Patterns

Web API



Message Queue



File Transfer Integration