NoSQL Storage Systems

A Data Modeling Techniques Perspective

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R-DBMS Limitations

Contents

The R-DBMS World in Brief

Relational Model from the 70's

- tables, rows, fixed columns
- attributes are pre-defined in a schema
- CREATE TABLE-like statements (DDL part of SQL)
- User-centered query language (SQL) as an abstraction layer

DB Design

Normalization normalization normalization!

- prevent from redundancy and anomalies

The R-DBMS World in Brief (cont'd)

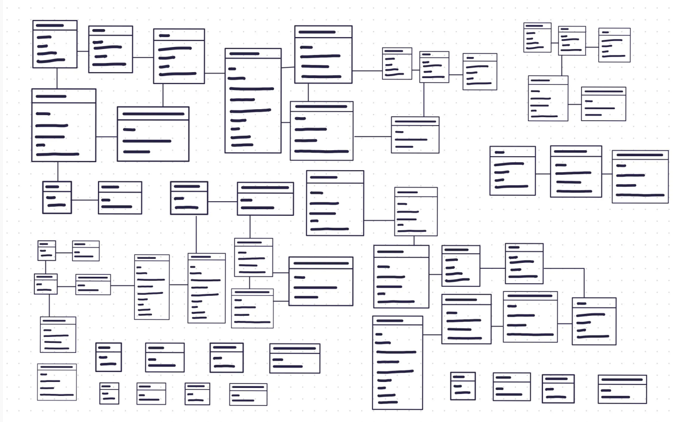
ACID Transactions

Atomicity - Consistency - Isolation - Durability

Consistency and integrity enforcement

- Schema-data consistency
- Domain constraints (value range, regexp)
- References (FK and inclusion dependencies)
- Uniqueness (PK)
- Tuple-based constraints (e.g., $R.A > R.B/2$)

Relational Model: a—Sort of—Real-Life Example



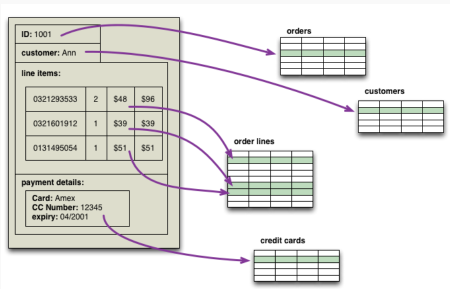
Source: Data Model, Directus docs.

Relational Database Limitations

Impedance mismatch

How to fit complex objects from PL to flat tables ?!

- decomposition into many vertical fragments: ORM to the rescue



Source: Aggregate Oriented Database, M. Fowler, 19 Jan. 2012.

Database Tuning

Overcome the performance bottleneck

- Hardware/system/software architecture (e.g. caching)
- Query workload and application-driven model
  - Indexes, views, hints, SQL S-F-W rewriting
  - Denormalization : introduce redundancy
  - Clustering relations : speed up join queries
  - Partitioning

The ultimate DB system

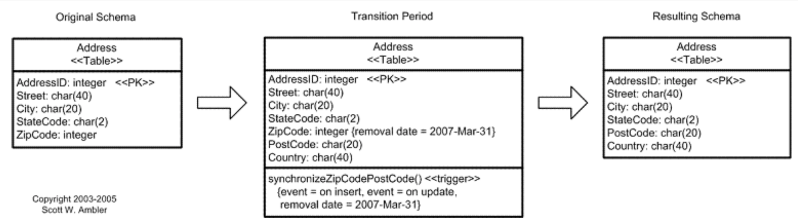
Pre-compute query answers and cache them locally!

Relational Database Limitations (bis)

Evolving/unknown structural requirements

Database refactoring

- alter schema + migrate data is expensive
- don't forget to sync apps



Scaling

Vertical scaling

- Upgrade hardware resources: CPU/RAM/Disk
- Expensive and limited to the most recent technologies

Parallel processing and data distribution

Not that easy

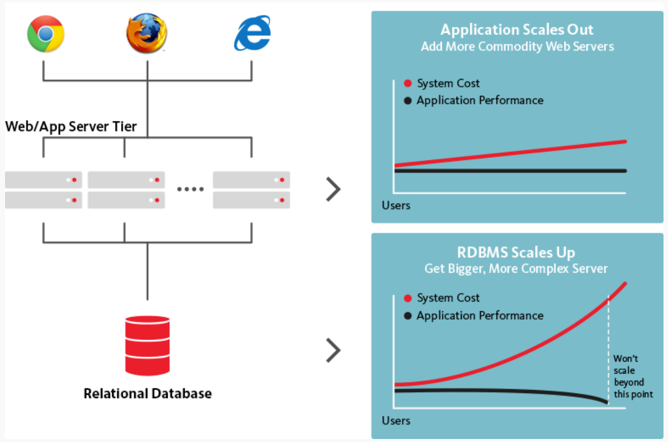
- Drawback n°1: global locking/logging for ACID Tx
- Drawback n°2: joins on multiple nodes

Relational Database limitations (ter)

Overhead cost at run time

- the price to pay for the **friendly declarative layer** :
  - parsing, optimization, sub-optimal execution, buffer management
- the price to pay for the **normalization** :
  - recomposition of entities with deadly joins
- the price to pay for the **consistency of ACID Tx** :
  - latches, locks and logs management

Scale Up vs. Scale Out



Source: Database Scaling Made Simple, DZone (src. Paris Technology), 24 May 2017.

NoSQL

No(t only)SQL

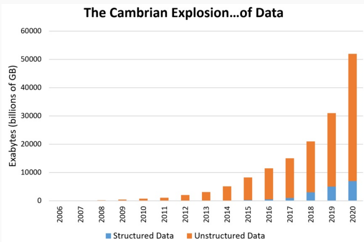
No standard definition

New apps for new requirements

- "*Cloud OLTP*" vs. traditional [TPC-C]-like serving workload
- "*big OLAP*" addresses Volume-Velocity-Variety-Veracity

New (big) data

90% of the World's data was created in the last 2 years

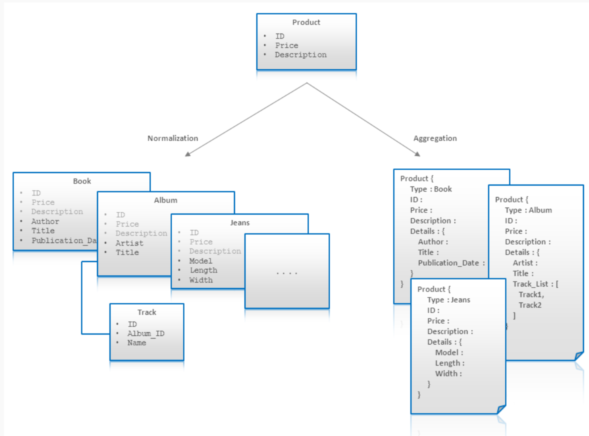


Source: When Is Big Data Big?, Cprime.

Key Concepts

- **Aggregate** data model
  - group logical pieces of data units and distribute by key (DHT)
  - duplicate pieces among aggregates if necessary
  - must conform to data access patterns
- "Free structure"
  - **schema-less** design
- Data **distribution** over many servers
  - Horizontal partitioning (aka. *sharding*) w.r.t. query scope: increase data volume
  - Replication: increase fault tolerance (availability)
- **Weak consistency** (vs. ACID Tx)
- **Low-level call interface** (vs. SQL)

The Aggregation Principle



Source: NoSQL Data Modeling Techniques, Highly Scalable Blog, 01 March 2012.

Distribution: main techniques, main ideas

1. Distributed Hash Tables (DHT)
    - Rendezvous Hashing, Consistent Hashing
2. Consistency: 2PC and Paxos (strong), Vector Clocks (eventual)
3. The CAP Theorem

Warning

- Much more to do with distributed systems rather than a databases course
- But super relevant to NoSQL

Distributed Hash Table

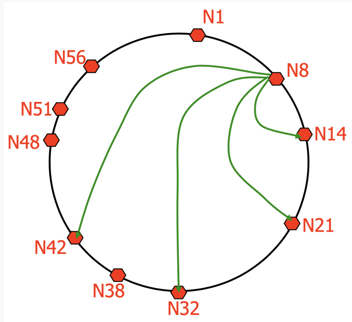
Implements a distributed storage over N servers

- Each key-value pair (k, v) is stored at some server $h(k)$
- API : `write(`k`,`v`)` ; `read(`k`)`

Use standard hash function : service key k by server h(k)

- Problem n°1 : a client knows only one random server, doesn't know how to access $h(k)$
- Problem n°2 : if new server joins, then $N \to N+1$, and the entire hash table needs to be reorganized
- Problem n°3 : we want replication, i.e. store the object at more than one server

Ring DHT



Finger Table at Node N_8

idx	hashcode	root
0	$8 + 2^0 = 9$	~~N_{14}~~
1	$8 + 2^1 = 10$	~~N_{14}~~
2	$8 + 2^2 = 12$	N_{14}
3	$8 + 2^3 = 16$	N_{21}
4	$8 + 2^4 = 24$	N_{32}
5	$8 + 2^5 = 40$	N_{42}

find root of K54 from N_8 : to N_{42}, then N_{51}, and finally reach next node (N_{56})

CAP Theorem : Pick 2 out of 3!

Conjecture from E. Brewer (PODC 2000) Proof from S. Gilbert and N. Lynch (SIGACT News 2002)

Consistency

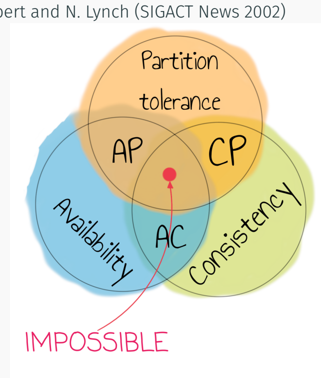
All nodes see the same data at the same time

Availability

Every request receives a response about whether it succeeded or failed

Partition tolerance

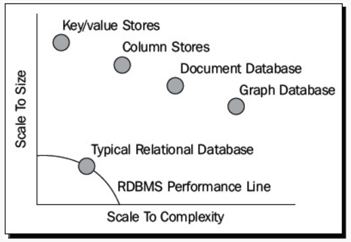
The system continues to operate despite arbitrary partitioning due to network failures



Source: Big Data World, Part 5: CAP Theorem, P. Finkelshteyn, JetBrains Blog, 3 June 2021.

The NoSQL Data Models

Warning: Typical Ad for NoSQL but fake news inside...



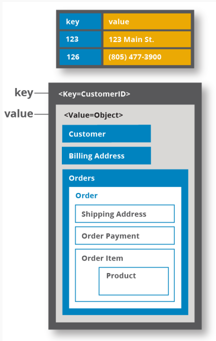
- There exist tons of data stores : see N★SQL
- **XML Stores** are Doc. Stores and **RDF Stores** are Graph Stores
- **Column Stores** are actually stores of **Extensible Records**, a.k.a. Columnar/Column-Family/Wide Column Stores

Key-Value Store

Think *File system* or *LDAP repos.* more than database

Products

Riak, Redis, Voldemort, Memcached, LevelDB

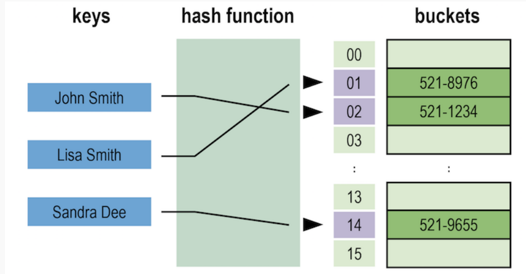


Key		Value
AB5D	⟶	01000110110111010101110100
AC4F	⟶	01101110100011111001000010
2A45	⟶	11011100111110101000010111
...	⟶	...

K-V Store (cont'd)

Data structure of an associative array, map or dictionary

- Hash partitioning with **consistent hashing**
- Distributed Hash Tables (**DHT**)



SVG source file "Hash table 4 1 1 0 0 1 0 LL" by J. Stolfi - Own work

K-V Store (cont'd)

- Only primary index : lookup value v by key k
- Simple operations :
  - `get(k)`
  - `put(k,v)`
  - `delete(k)`
- Value is **obfuscated**

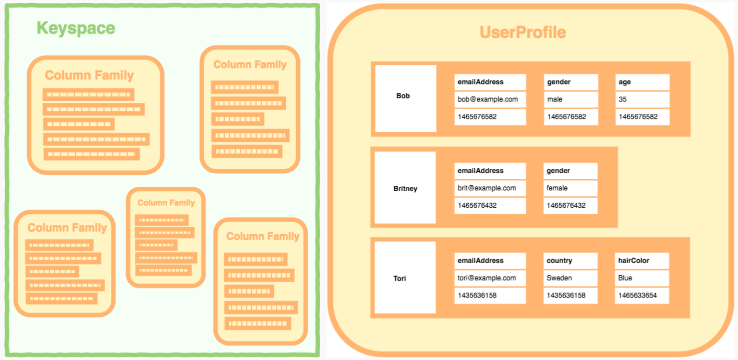
Ordered K-V Store

- Sorted keys b.t.w. of range partitioning
- short-scan range queries $[\![k, k+n]\!]$

Column-Family Store

Products

Cassandra, HBase, Hypertable



Source: What is a Column Store Database?, Ian, Database Guide, 23 June 2016.

Column-Family Store (cont'd)

- Column Family is close to relational table
- 1 CF = 1 file: expose the physical model to the user
- Group columns by query scope/logical units :
  - {name, adress}, financial info, login info
- Random sharding by hash code from keys onto DHT

Popularized by **Google BigTable**

Column-Family Store (cont'd)

CF Store encodes a 4-level hash map

`[Keyspace][ColumnFamily][Key][Column]`

Example

```
"ApplicationData": {
    "UserInfo": {
        "Alice": {
            "age":   25,
            "email": "alice@mit.org",
            "state": "MA" } } }
```

- Keys are shared among CF's
- Columns are sorted (not row keys)
- May have one more level of nesting (*Super Columns*)

Document Store

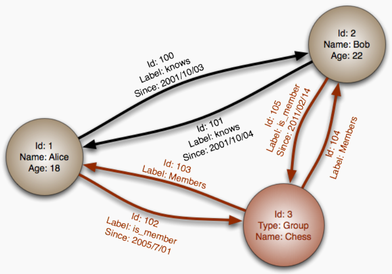
Document Store (con't)

A document is a **pointerless object**

- e.g. JSON
- nested values + extensible records (schema-less)

In addition to K-V store : may have **secondary indexes**

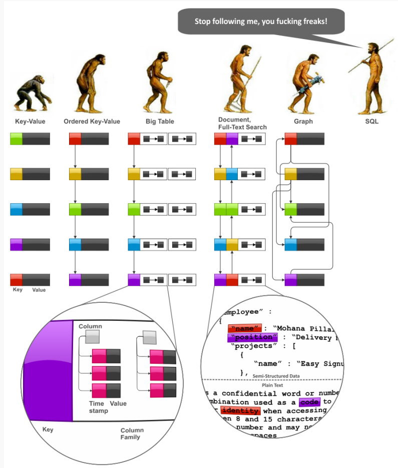
Graph Store



Originally uploaded by Ahzf (Transferred by Obersachse)

- Partitioning is not that easy ! It is not a "truly NoSQL" data model

SQL Freaks



Polyglot Persistence

How to Choose the Right Database System ?

The sixty-four-thousand-dollar question !

150+ options on the N★SQL repos ...

- First attempt : Pros & Cons
- Second attempt : compare
- Too many offers, too many criteria !

What about your own requirements ?

Data

Examine and segment the data

- Event
- Domain
- Critical
- Business
- Temporal
- Geo
- Meta
- Session
- Log
- Message
- ...

Data Model

- Complexity
  - determine the degree of structure : from FS to Graph
  - denormalize : no need to recompose entities in queries
    - embed one-to-many relationships
    - anyway, joins in apps for
      (a) many-to-many relationships
      (b) frequent updates (e.g., msgs of a user)
- Volume
- Schema flexibility
- Integrity constraints
- Data access patterns

Queries

Typical Queries look like ? SQL needed? LINQ needed ? BI/Analytic-Tools needed? MapReduce needed ? Ad-Hoc Queries needed? Background Data Analytics ? Secondary Indices? Range queries ? Complex Aggregations ? ColumnDB needed for Analytics ? Views needed ? ...

Queries (cont'd)

Carefully profile the workload

Example - Altoros Tech. Report, 2013 Source : Yahoo Cloud Serving Benchmark (YCSB) [Cooper et al., SoCC 2010]

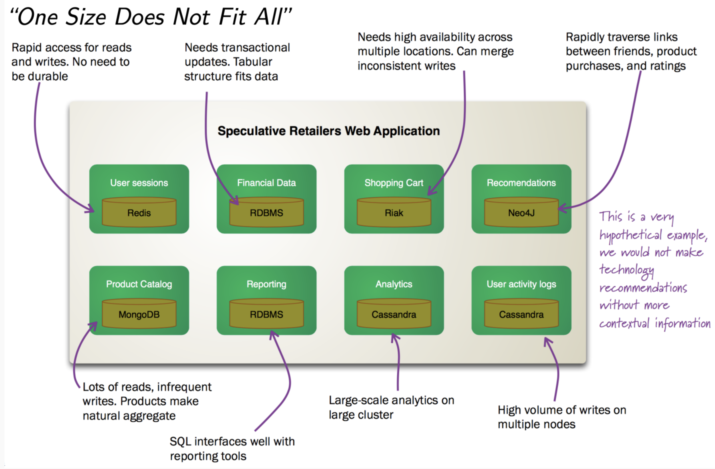
- update-heavily : e-commerce
- read-mostly : content tagging
- read-only : user profile cache
- 95/5 read/insert ratio : user status updates or inbox messages
- scan-short-ranges : threaded conversations
- 50/50 read-modify-write/read ratio : access to a user database
- 10/90 read/insert ratio : data migration

Similar approaches in CouchBase and Datastax (Cassandra) Whitepaper

The Many Other Requirements

- Persistence design
  - on-disk, on-memory, SSTable, append-only, ...
- Consistency model
  - strong, weak, eventual, read-your-writes, ...
- Performance
  - latency, throughput, degree of concurrency
- Architecture
  - distributed, grid, cloud, mobile, p2p, replication, auto-scaling, load balancing, partitioning, ...
- Any non-functional requirement!
  - refactoring frequency, 24/7 system, dev. qualification, simplicity, security, licence model, community support, documentation, ...

Polyglot Persistence



NewSQL

Back to the Future

The Six SQL Urban Myths by M. Stonebraker

- Myth n°1 : SQL is too slow, so use a lower level interface
- Myth n°2 : I like a K-V interface, so SQL is a non-starter
- Myth n°3 : SQL systems don't scale
- Myth n°4 : There are no open source, scalable SQL engines
- Myth n°5 : ACID is too slow, so avoid using it
- Myth n°6 : In CAP, choose AP over CA

Auxiliary activities of an R-DBMS

TPC-C on the Shore prototype

[S. Harizopoulos et al. SIGMOD 2008]

- logging 17% : everything written twice, log must be forced
- latching 19% : dbms is multithreaded (latch for the lock table)
- locking 17% : required for ACID semantics
- B-tree and buffer management operations 35%
- Useful work is 12% only!

Recipe to Scalable R-DBMS = NewSQL

Give up with the 4 time-consuming activities yet keeping SQL and ACID Tx whenever it is necessary

App #1

Web application that needs to display lots of customer information; the user's data is rarely updated, and when it is, you know when it changes because updates go through the same interface.

Store this information persistently using a **K/V store**

App #2

Department of Motor Vehicle (DMV) : lookup objects by multiple fields (driver's name, license number, birth date, etc) ; "eventual consistency" is ok, since updates are usually performed at a single location.

Document store

App #3

eBay style application. Cluster customers by country ; separate the rarely changed 'core' customer information (address, email) from frequently-updated info (current bids).

Column-Family store

App #4

Everything else (e.g. a serious DMV application)

Scalable R-DBMS

Database Landscape