INTRODUCTION TO NOSQL DATABASES

Outline

- Background
- What is NOSQL?
- Who is using it?
- 3 major papers for NOSQL
- CAP theorem
- NOSQL categories
- Conclusion
- References

Background

- Relational databases → mainstay of business
- Web-based applications caused spikes
  - explosion of social media sites (Facebook, Twitter) with large data needs
  - rise of cloud-based solutions such as Amazon S3 (simple storage solution)
- Hooking RDBMS to web-based application becomes trouble

Issues with ***scaling up***

- Best way to provide ACID and rich query model is to have the dataset on a single machine
- Limits to ***scaling up*** (or ***vertical scaling*****:** make a "single" machine more powerful) → dataset is just too big!
- ***Scaling out*** (or ***horizontal scaling*****:** adding more smaller/cheaper servers) is a better choice
- Different approaches for horizontal scaling (multi-node database):
  - Master/Slave
  - Sharding (partitioning)

Scaling out RDBMS: Master/Slave

- Master/Slave
  - All writes are written to the master
  - All reads performed against the replicated slave databases
  - Critical reads may be incorrect as writes may not have been propagated down
  - Large datasets can pose problems as master needs to duplicate data to slaves

Scaling out RDBMS: Sharding

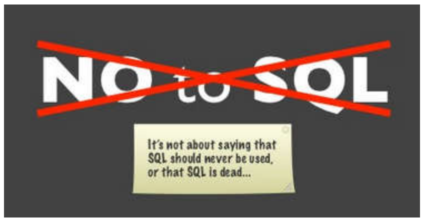
- Sharding (Partitioning)
  - Scales well for both reads and writes
  - Not transparent, application needs to be partition-aware
  - Can no longer have relationships/joins across partitions
  - Loss of referential integrity across shards

Other ways to scale out RDBMS

- Multi-Master replication
- INSERT only, not UPDATES/DELETES
- No JOINs, thereby reducing query time
  - This involves de-normalizing data
- In-memory databases

What is NOSQL?

- The Name:
  - Stands for **N**ot **O**nly **SQL**
  - The term NOSQL was introduced by Carl Strozzi in 1998 to name his file-based database
  - It was again re-introduced by Eric Evans when an event was organized to discuss open source distributed databases
  - Eric states that *"… but the whole point of seeking alternatives is that you need to solve a problem that relational databases are a bad fit for. …"*


~~NO to SQL~~
It's not about saying that SQL should never be used, or that SQL is dead...

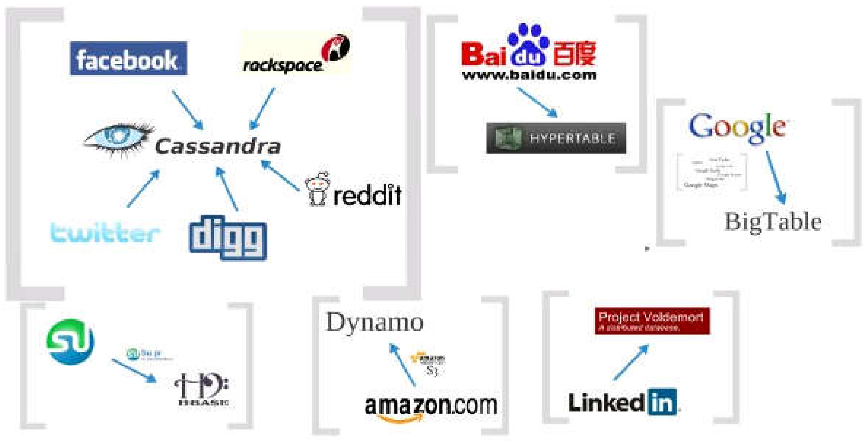
What is NOSQL?

- Key features (advantages):
  - non-relational
  - don't require schema
  - data are replicated to multiple nodes (so, identical & fault-tolerant) and can be partitioned:
    - down nodes easily replaced
    - no single point of failure
  - horizontal scalable
  - cheap, easy to implement (open-source)
  - massive write performance
  - fast key-value access

What is NOSQL?

- Disadvantages:
  - Don't fully support relational features
    - no join, group by, order by operations (except within partitions)
    - no referential integrity constraints across partitions
  - No declarative query language (e.g., SQL) → more programming
  - Relaxed ACID (see CAP theorem) → fewer guarantees
  - No easy integration with other applications that support SQL

Who is using them?



3 major papers for NOSQL

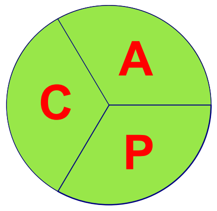
- Three major papers were the “seeds” of the NOSQL movement:
  - BigTable (Google)
  - DynamoDB (Amazon)
    - Ring partition and replication
    - Gossip protocol (discovery and error detection)
    - Distributed key-value data stores
    - Eventual consistency
  - CAP Theorem

The Perfect Storm

- Large datasets, acceptance of alternatives, and dynamically-typed data has come together in a “perfect storm”
- Not a backlash against RDBMS
- SQL is a rich query language that cannot be rivaled by the current list of NOSQL offerings

CAP Theorem

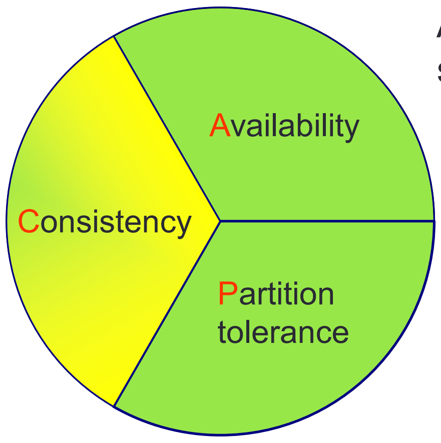
- Suppose three properties of a distributed system (sharing data)
  - **Consistency:**
    - all copies have same value
  - **Availability:**
    - reads and writes always succeed
  - **Partition-tolerance:**
    - system properties (consistency and/or availability) hold even when network failures prevent some machines from communicating with others



CAP Theorem

- **Brewer's CAP Theorem:**
  - *For any system sharing data, it is "impossible" to guarantee simultaneously all of these three properties*
  - You can have at most two of these three properties for any shared-data system
- Very large systems will "partition" at some point:
  - That leaves either **C** or **A** to choose from (traditional DBMS prefers **C** over **A** and **P**)
  - In almost all cases, you would choose **A** over **C** (except in specific applications such as order processing)

CAP Theorem



All client always have the same view of the data

CAP Theorem

- **Consistency**
  - 2 types of consistency:
    1. Strong consistency – ACID (**A**tomicity, **C**onsistency, **I**solation, **D**urability)
    2. Weak consistency – BASE (**B**asically **A**vailable **S**oft-state **E**ventual consistency)

CAP Theorem

- **ACID**
  - A DBMS is expected to support "ACID transactions," processes that are:
  - **Atomicity:** either the whole process is done or none is
  - **Consistency:** only valid data are written
  - **Isolation:** one operation at a time
  - **Durability:** once committed, it stays that way
- **CAP**
  - **Consistency:** all data on cluster has the same copies
  - **Availability:** cluster always accepts reads and writes
  - **Partition tolerance:** guaranteed properties are maintained even when network failures prevent some machines from communicating with others

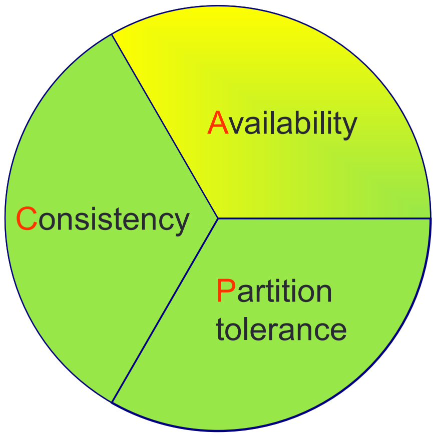
CAP Theorem

- A consistency model determines rules for visibility and apparent order of updates
- Example:
  - Row X is replicated on nodes M and N
  - Client A writes row X to node N
  - Some period of time t elapses
  - Client B reads row X from node M
  - **Does client B see the write from client A?**
  - Consistency is a continuum with tradeoffs
  - **For NOSQL, the answer would be: "maybe"**
  - CAP theorem states: *"strong consistency can't be achieved at the same time as availability and partition-tolerance"*

CAP Theorem

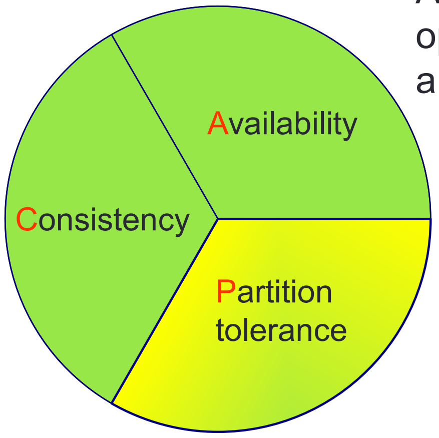
- Eventual consistency
  - When no updates occur for a long period of time, eventually all updates will propagate through the system and all the nodes will be consistent
- Cloud computing
  - ACID is hard to achieve, moreover, it is not always required, e.g. for blogs, status updates, product listings, etc.

CAP Theorem



Each client always can read and write.

CAP Theorem



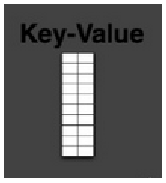
A system can continue to operate in the presence of a network partitions

NOSQL categories

1. Key-value
   - Example: DynamoDB, Voldermort, Scalaris
2. Document-based
   - Example: MongoDB, CouchDB
3. Column-based
   - Example: BigTable, Cassandra, Hbased
4. Graph-based
   - Example: Neo4J, InfoGrid

- "No-schema" is a common characteristics of most NOSQL storage systems
- Provide "flexible" data types

Key-value



- Focus on scaling to huge amounts of data
- Designed to handle massive load
- Based on Amazon's dynamo paper
- Data model: (global) collection of Key-value pairs
- *Dynamo ring partitioning* and *replication*
- Example: (DynamoDB)
  - *items* having one or more attributes (name, value)
  - An *attribute* can be single-valued or multi-valued like set.
  - items are combined into a *table*

Key-value

- Basic API access:
  - get(key): extract the value given a key
  - put(key, value): create or update the value given its key
  - delete(key): remove the key and its associated value
  - execute(key, operation, parameters): invoke an operation to the value (given its key) which is a special data structure (e.g. List, Set, Map .... etc)

Key-value

Pros:

- very fast
- very scalable (horizontally distributed to nodes based on key)
- simple data model
- eventual consistency
- fault-tolerance

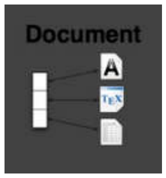
Cons:

- Can't model more complex data structure such as objects

Key-value

Name	Producer	Data model	Querying
SimpleDB	Amazon	set of couples (key, {attribute}), where attribute is a couple (name, value)	restricted SQL; select, delete, GetAttributes, and PutAttributes operations
Redis	Salvatore Sanfilippo	set of couples (key, value), where value is simple typed value, list, ordered (according to ranking) or unordered set, hash value	primitive operations for each value type
Dynamo	Amazon	like SimpleDB	simple get operation and put in a context
Voldemort	LinkeId	like SimpleDB	similar to Dynamo

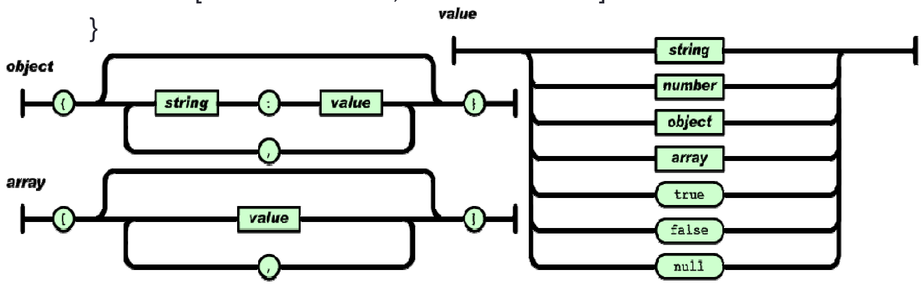
Document-based



- Can model more complex objects
- Inspired by Lotus Notes
- Data model: collection of documents
- Document: JSON (**J**ava**S**cript **O**bject **N**otation is a data model, key-value pairs, which supports objects, records, structs, lists, array, maps, dates, Boolean with **nesting**), XML, other semi-structured formats.

Document-based

- Example: (MongoDB) document
  - {Name:"Jaroslav",
    Address:"Malostranske nám. 25, 118 00 Praha 1",
    Grandchildren: {Claire: "7", Barbara: "6", "Magda: "3", "Kirsten: "1", "Otis: "3", Richard: "1"}
    Phones: ["123-456-7890", "234-567-8963"]
    }

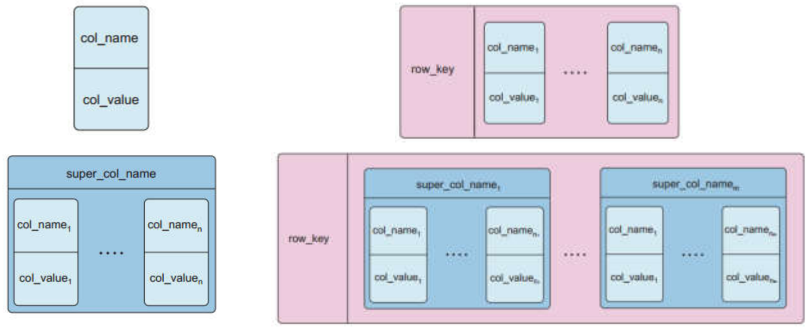


Document-based

Name	Producer	Data model	Querying
MongoDB	10gen	object-structured documents stored in collections; each object has a primary key called ObjectId	manipulations with objects in collections (find object or objects via simple selections and logical expressions, delete, update,)
Couchbase	Couchbase[1]	document as a list of named (structured) items (JSON document)	by key and key range, views via Javascript and MapReduce

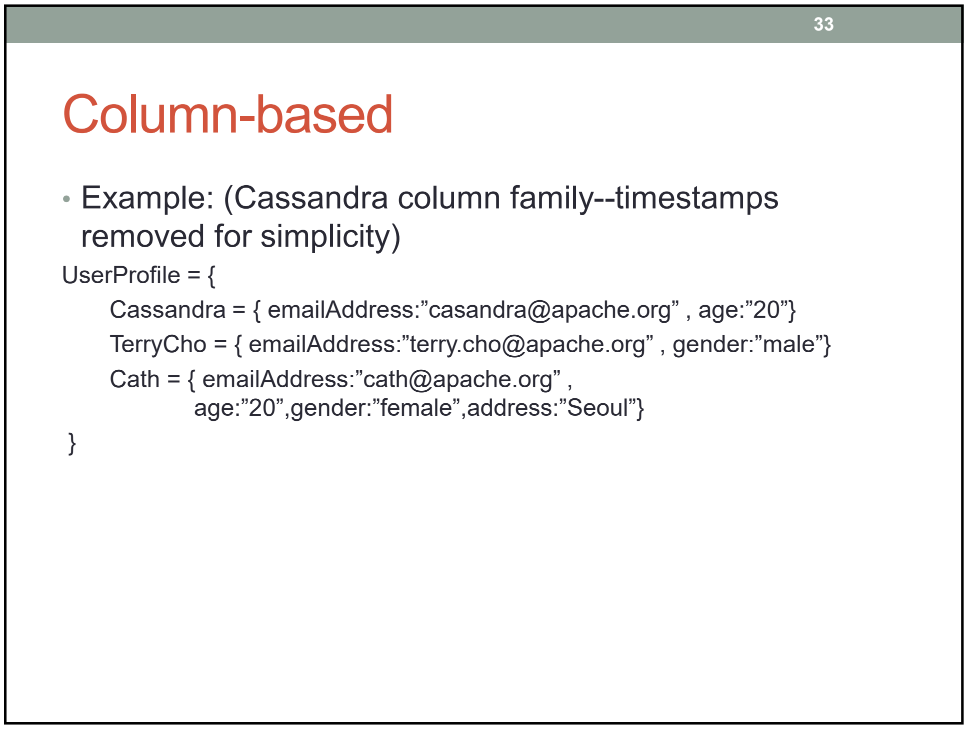
Column-based

- Based on Google's BigTable paper
- Like column oriented relational databases (store data in column order) but with a twist
- Tables similarly to RDBMS, but handle semi-structured
- Data model:
  - Collection of Column Families
  - Column family = (key, value) where value = set of **related** columns (standard, super)
  - indexed by *row key*, *column key* and *timestamp*



Column-based

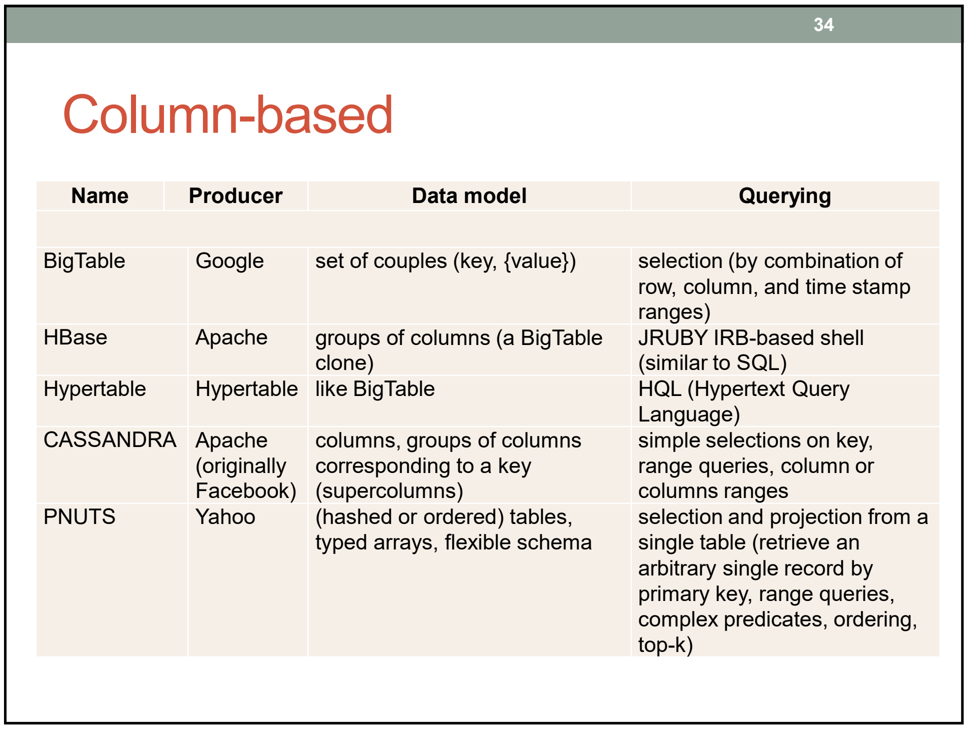
- One column family can have variable numbers of columns
- Cells within a column family are sorted "physically"
- Very sparse, most cells have null values
- **Comparison:** RDBMS vs column-based NOSQL
  - Query on multiple tables
    - **RDBMS:** must fetch data from several places on disk and glue together
    - **Column-based NOSQL:** only fetch column families of those columns that are required by a query (all columns in a column family are stored together on the disk, so multiple rows can be retrieved in one read operation → data locality)



Column-based

- Example: (Cassandra column family--timestamps removed for simplicity)

```
UserProfile = {
      Cassandra = { emailAddress:"casandra@apache.org" , age:"20"}
      TerryCho = { emailAddress:"terry.cho@apache.org" , gender:"male"}
      Cath = { emailAddress:"cath@apache.org" ,
                 age:"20",gender:"female",address:"Seoul"}
}
```

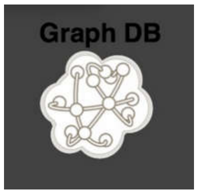


Column-based

Name	Producer	Data model	Querying
BigTable	Google	set of couples (key, {value})	selection (by combination of row, column, and time stamp ranges)
HBase	Apache	groups of columns (a BigTable clone)	JRUBY IRB-based shell (similar to SQL)
Hypertable	Hypertable	like BigTable	HQL (Hypertext Query Language)
CASSANDRA	Apache (originally Facebook)	columns, groups of columns corresponding to a key (supercolumns)	simple selections on key, range queries, column or columns ranges
PNUTS	Yahoo	(hashed or ordered) tables, typed arrays, flexible schema	selection and projection from a single table (retrieve an arbitrary single record by primary key, range queries, complex predicates, ordering, top-k)

Graph-based

- Focus on modeling the structure of data (*interconnectivity*)
- Scales to the complexity of data
- Inspired by mathematical Graph Theory (G=(E,V))
- Data model:
  - (Property Graph) nodes and edges
    - Nodes may have properties (including ID)
    - Edges may have labels or roles
  - Key-value pairs on both
- Interfaces and query languages vary
- *Single-step* vs *path expressions* vs *full recursion*
- Example:
  - Neo4j, FlockDB, Pregel, InfoGrid …



Polyglot Persistence

- Polyglot Persistence is a fancy term to mean that when storing data, it is best to use multiple data storage technologies, chosen based upon the way data is being used by individual applications or components of a single application.

- Different kinds of data are best dealt with different data stores. In short, it means picking the right tool for the right use case.

Conclusion

- NOSQL database cover only a part of data-intensive cloud applications (mainly Web applications)
- Problems with cloud computing:
  - SaaS (**S**oftware **a**s **a** **S**ervice or on-demand software) applications require enterprise-level functionality, including ACID transactions, security, and other features associated with commercial RDBMS technology, i.e. NOSQL should not be the only option in the cloud
  - Hybrid solutions:
    - Voldemort with MySQL as one of storage backend
    - deal with NOSQL data as semi-structured data

      $\rightarrow$ integrating RDBMS and NOSQL via SQL/XML

Conclusion

- Next generation of highly scalable and elastic RDBMS: *NewSQL databases* (from April 2011)
  - they are designed to scale out horizontally on shared nothing machines,
  - still provide ACID guarantees,
  - applications interact with the database primarily using SQL,
  - the system employs a lock-free concurrency control scheme to avoid user shut down,
  - the system provides higher performance than available from the traditional systems.
- Examples: MySQL Cluster (most mature solution), VoltDB, Clustrix, ScalArc, etc.