

TDDD43 Advanced Data Models and Databases

Topic: NoSQL

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“NoSQL”

- Some interpretations (without precise definition):
 - “no to SQL”
 - “not only SQL”
 - “not relational”
- 1998: first used for an RDBMS* that omitted usage of SQL
- 2009: picked up again to name a conference on “open-source, distributed, non-relational databases”
- Since then, “NoSQL database” loosely specifies a class of non-relational DBMSs
 - Relax some requirements of RDBMSs to gain efficiency and scalability for use cases in which RDBMSs are a bad fit

*RDBMS = relational database management system

Goal of the lecture

What are key characteristics of such systems?

What do databases supported by these systems look like?

What can you do with these databases?
(in comparison to the databases supported by RDBMSs)

Relational Database Management Systems

- Well-defined formal foundations (*relational data model*)

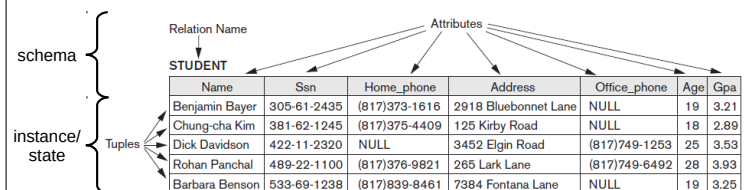


Figure from “Fundamentals of Database Systems” by Elmasri and Navathe, Addison Wesley.

Relational Database Management Systems

- Well-defined formal foundations (*relational data model*)
- SQL – powerful declarative language
 - querying
 - data manipulation
 - database definition
- Support of transactions with ACID properties (**A**tomicity, **C**onsistency preservation, **I**solation, **D**urability)
- Established technology (developed since the 1970s)
 - many vendors
 - highly mature systems
 - experienced users and administrators

Business world has evolved

- Organizations and companies (whole industries) shift to the digital economy powered by the Internet
- Central aspect: new IT applications that allow companies to *run their business* and to *interact with costumers*
 - Web applications
 - Mobile applications
 - Connected devices (“Internet of Things”)



Image source: <https://pixabay.com/en/technology-information-digital-2082642/>

New Challenges for Database Systems

- Increasing numbers of concurrent users/clients
 - tens of thousands, perhaps millions
 - globally distributed
 - expectations: consistently high performance and 24/7 availability (no downtime)
- Different types of data
 - huge amounts (generated by users and devices)
 - data from different sources together
 - frequent schema changes or no schema at all
 - semi-structured and unstructured data
- Usage may change rapidly and unpredictably



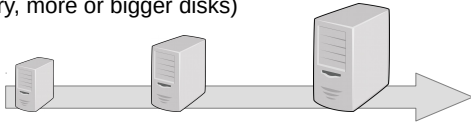
Image source: <https://www.flickr.com/photos/groucho/522369279/>

Scalability

- Data scalability: system can handle *growing amounts of data* without losing performance
- Read scalability: system can handle *increasing numbers of read operations* without losing performance
- Write scalability: system can handle *increasing numbers of write operations* without losing performance

Vertical Scalability vs. Horizontal Scalability

- Vertical scalability (“scale up”)
 - Add resources to a server (e.g., more CPUs, more memory, more or bigger disks)



- Horizontal scalability (“scale out”)
 - Add nodes (more computers) to a distributed system



Image source: <https://pixabay.com/en/server-web-network-computer-567943/>

Typical* Characteristics of NoSQL Systems

- Ability to scale horizontally over many commodity servers with high performance, availability, and fault tolerance
 - achieved by giving up ACID guarantees
 - and by partitioning and replication of data
- Non-relational data model, no requirements for schemas

*Attention, there is a *broad variety* of such systems and not all of them have these characteristics to the same degree

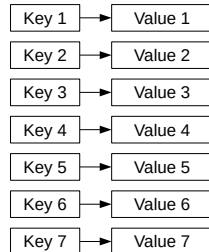
NoSQL Data Models

Data Models

- Key-value model
- Document model
- Wide-column models
- Graph database models

Key-Value Stores: Data Model

- Database is simply a set of key-value pairs
 - keys are unique
 - values of arbitrary data types
- Values are opaque to the system



Example

- Assume a relational database consisting of a single table:

User	login	name	website	twitter
	alice12	Alice	http://alice.name/	NULL
	bob_in_se	Bob	NULL	@TheBob
	charlie	Charlie	NULL	NULL

- How can we capture this data in the key-value model?

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- Let's add another table:

Fav	user	favorite
	alice12	bob_in_se
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Key-Value Stores: Querying

- Only CRUD operations in terms of keys
 - CRUD: create, read, update, delete
 - put(key, value); get(key); delete(key)
- No support for value-related queries
 - Recall that values are opaque to the system (i.e., no secondary index over values)
- Accessing multiple items requires *separate requests*
 - Beware: often no transactional capabilities



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- Accessing multiple items requires *separate requests*
 - Beware: often no transactional capabilities
- Advantage of these limitations: partition the data based on keys ("*horizontal partitioning*", also called "*sharding*") and distributed processing can be very efficient

Example (cont'd)

- Assume we try to find all users for whom Bob is a favorite
- It is possible (how?), but very inefficient
- What can we do to make it more efficient?



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 - Add redundancy (downsides: more space needed, updating becomes less trivial and less efficient)



Examples of Key-Value Stores

- In-memory key-value stores
 - Memcached
 - Redis
- Persistent key-value stores
 - Berkeley DB
 - Voldemort
 - RiakDB



Data Models

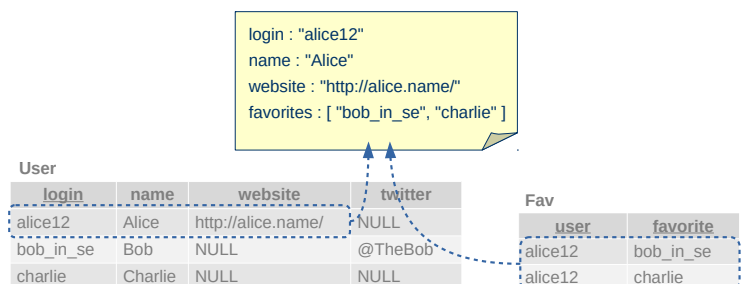
- Key-value model
- Document model ←
- Wide-column models
- Graph database models



Image source: <https://pxhere.com/en/photo/1188160>

Document Stores: Data Model

- Document: a set of fields consisting of a name and a value
 - field names are unique within the document
 - values are scalars (text, numeric, boolean) or lists



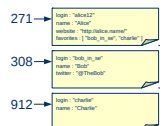
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 - in some systems, values may also be other documents

```
login : "alice12"
name : "Alice"
website : "http://alice.name/"
favorites : [ "bob_in_se", "charlie" ]
address : {
  street : "Main St"
  city : "Springfield"
}
```

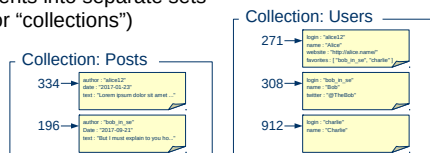
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 - each document additionally associated with a unique identifier (typically system-generated)
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 - each document additionally associated with a unique identifier (typically system-generated)
 - schema free*: different documents may have different fields
 - grouping of documents into separate sets (called "domains" or "collections")
- Partitioning based on collections and/or on document IDs
- Secondary indexes over fields in the documents possible
 - different indexes per domain/collection of documents

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```
db.Users.find( {name: "Alice"} )
```
 - Find all docs in collection *Users* whose *age* is greater than 23


```
db.Users.find( {age: { $gt: 23 } } )
```
 - Find all docs about *Users* who favorite Bob


```
db.Users.find( { favorites: { $in: [ "bob_in_se" ] } } )
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 - Find all docs about *Users* who favorite Bob


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db.Users.find( {favorites: { $in: ["bob_in_se"]}} )
```
- However, no cross-document queries (like joins)
 - have to be implemented in the application logic

Examples of Document Stores

- Amazon's SimpleDB



- CouchDB



- Couchbase



- MongoDB



Data Models

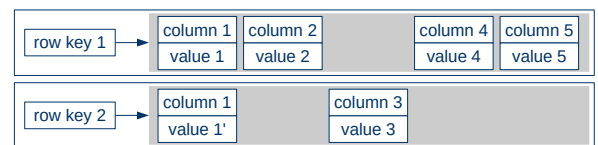
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also called
column-family models
or
extensible-record models

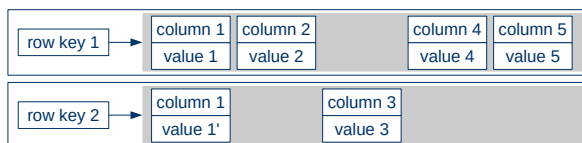
Wide-Column Stores: Data Model (Basic)

- Database is a set of "rows" each of which ...
 - ... has a unique key, and
 - ... a set of key-value pairs (called "columns")
- Schema free: different rows may contain different columns



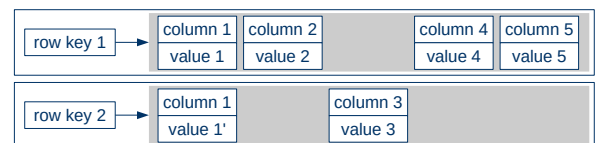
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 - a) extensible, b) schema-free, and c) potentially sparse



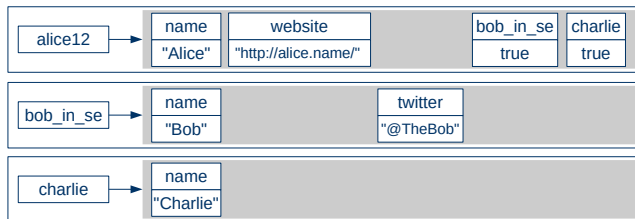
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- Like the document model without nesting



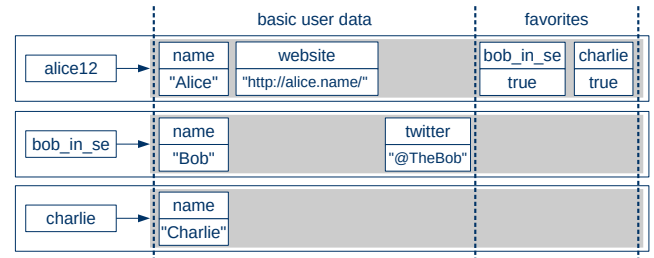
Example (cont'd)

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- Data may be partitioned ...
 - ... based on row keys (*horizontal partitioning*),
 - ... but also based on column families (*vertical partitioning*),
 - ... or even on both

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- Data may be partitioned ...
 - ... based on row keys (*horizontal partitioning*),
 - ... but also based on column families (*vertical partitioning*),
 - ... or even on both
- Secondary indexes can be created over arbitrary columns

Wide-Column Stores: Querying

- Querying in terms of keys or conditions on column values
- Queries expressed in a system-specific query language or in terms of program code using an API
 - Conceptually similar to queries in document stores
- No joins
 - Again, must be implemented in the application logic

Examples of Wide-Column Stores

- Basic form (no column families):

- Amazon SimpleDB
- Amazon DynamoDB



- With column families:

- Google's BigTable
- Hadoop HBase
- Apache Cassandra



Data Models

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- Graph database models

See next lecture

Data Models

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- Document model
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There are also *multi-model NoSQL stores*

Examples:

- OrientDB (key-value, documents, graph)
- ArangoDB (key-value, documents, graph)
- Cosmos DB (key-value, documents, wide-column, graph)



Typical* Characteristics of NoSQL Systems

- Ability to scale horizontally over many commodity servers with high performance, availability, and fault tolerance
 - achieved by giving up ACID guarantees
 - and by partitioning and replication of data
- Non-relational data model, no requirements for schemas
 - data model limitations make partitioning effective

*Attention, there is a *broad variety* of such systems and not all of them have these characteristics to the same degree

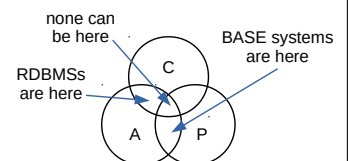
BASE rather than ACID

What is BASE?

- Idea: by giving up ACID guarantees, one can achieve much higher performance and scalability
- **Basically Available**
 - system available whenever accessed, even if parts of it unavailable
- **Soft state**
 - the distributed data does not need to be in a consistent state at all times
- **Eventually consistent**
 - state will become consistent after a certain period of time
- BASE properties suitable for applications for which some inconsistency may be acceptable

CAP Theorem

- Only 2 of 3 properties can be guaranteed at the same time in a distributed system with data replication



- **Consistency**: the same copy of a replicated data item is visible from all nodes that have this item
 - Note that this is something else than consistency in ACID
- **Availability**: all requests for a data item will be answered
 - Answer may be that operation cannot be completed
- **Partition Tolerance**: system continues to operate even if it gets partitioned into isolated sets of nodes

Consistency Models

- **Strong consistency:** after an update completes, every subsequent access will return the updated value
 - may be achieved without consistency in the CAP theorem
- **Weak consistency:** no guarantee that all subsequent accesses will return the updated value
 - **eventual consistency:** if no new updates are made, eventually all accesses will return the last updated value
 - **inconsistency window:** the period until all replicas have been updated in a lazy manner

Consistency Models (cont'd)

- Let:
 - N be the number of nodes that store replicas
 - R be the number of nodes required for a successful read
 - W be the number of nodes required for a successful write
- Then:
 - Consistency as per CAP requires $W = N$
 - Strong consistency requires $R + W > N$
 - Eventual consistency if $R + W \leq N$
 - High read performance means a great N and $R = 1$
 - Fault tolerance/availability (and relaxed consistency) $W = 1$

Summary

- NoSQL systems support non-relational data models (key-value, document, wide-column, graph)
 - schema free
 - support for semi-structured and unstructured data
 - limited query capabilities (no joins!)
- NoSQL systems provide high (horizontal) scalability with high performance, availability, and fault tolerance
 - achieved by:
 - data partitioning (effective due to data model limitations)
 - data replication
 - giving up consistency requirements

Reading Material

- **NoSQL Databases: a Survey and Decision Guidance.** F. Gessert. *Blog post*, August 2016.
- **Data Management in Cloud Environments: NoSQL and NewSQL Data Stores.** K. Grolinger et al. *Journal of Cloud Computing* 2:22, 2013
 - Considers not only NoSQL but also NewSQL systems
 - Includes comprehensive comparison of various systems over a large number of dimension
- **Scalable SQL and NoSQL Data Stores.** R. Cattell. *ACM SIGMOD Record* 39(4), 2011
 - More detailed overview of several example systems
- **NoSQL Databases.** C. Strauch. *Lecture Notes*, 2012
 - Comprehensive discussion of several example systems

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