Big Data Analytics

B. Distributed Storage / B.3 NoSQL Databases

Lars Schmidt-Thieme

Information Systems and Machine Learning Lab (ISMLL)
Institute for Computer Science
University of Hildesheim, Germany

Syllabus

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			A. Parallel Computing
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Outline

1. Introduction

2. Key-Value Stores

3. Document Databases

4. Document Databases: Partitioning

5. Other NoSQL Databases

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Relational vs Big-Data Technologies

- **Structure:**
  - relational data bases: data is **structured**.
  - big data applications: data often is **raw**.
- **Process:**
  - relational data bases: initially created for **transactional processing**.
  - big data applications: **analytical processing**.
- **Entities:**
  - relational data bases: big if it has **many entities** (rows) of a kind.
  - big data applications: the number of entities is not necessary high, the amount of information that exist for entities may be large.
- **horizontal scaling:**
  - relational data bases: costs for adding new nodes is high.
  - big data applications: scaling should be accomplished inexpensively by **adding new nodes**.

NoSQL Databases

- A NoSQL or Not Only SQL database provides a mechanism for storage and retrieval of data that is modeled in means **other than the tabular relations** used in relational databases.
- Motivations for this approach include
  - **simplicity of design** and
  - **horizontal scaling**.
- The data structure differs from the RDBMS, and therefore
  - some operations are faster in NoSQL, and
  - some operations are faster in RDBMS.
- Most NoSQL stores lack true ACID transactions.
  - ACID: atomicity, consistency, isolation, durability

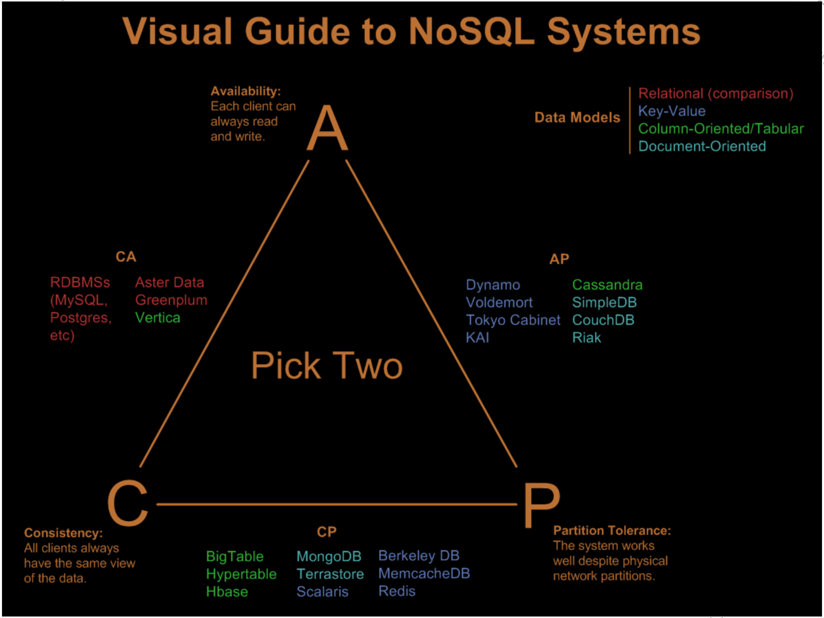
NoSQL Databases / Types and Implementations

- **Key-value:** Redis^{OS}, Amazon DynamoDB, Memcached^{OS}
- **Document:** MongoDB^{OS}, Amazon DynamoDB, Couchbase^{OS}
- **Graph:** Neo4J^{OS}, MS CosmosDB, OrientDB^{OS}
- **Column:** Cassandra^{OS}, HBase^{OS}, MS CosmosDB
- **Object:** Caché, Versant Object Database, ObjectStore, Db4o^{OS}

Note: Popularity ranking of DBMS by type: `https://db-engines.com/en/ranking/`;
^{OS}=open source

BASE vs ACID

- **CAP-theorem**: in the presence of **network partitions**, a DBMBs has to choose between
  - **Consistency**: all reads always return the last write — then clients cannot read/write during a network partition.
  - **Availability**: clients always can read/write — then what they receive might not be consistent at all times
- BASE design:
  - **Basically available**: the system aims for high availability.
  - **Soft state**: the state of the system may change over time, even without input. (due to the eventual consistency model).
  - **Eventual consistency**: the system may not be consistent at all times, but will become consistent over time.



http://blog.scottlogic.con

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Key–Value stores

- Key–Value stores use the **associative array** (dictionary) as their fundamental data model.
  - Data is represented as a collection of key–value pairs.
- One of the simplest non-trivial data models.

Example:

```
{
"Great Expectations": "John",
"Pride and Prejudice": "Alice",
"Wuthering Heights": "Alice"
}
```

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Document Databases

- Data abstraction:
  - relational databases: "relations" (= "tables").
  - document databases: "document".
- Documents are (possibly nested) **dictionaries**.
  - like Python dicts.
  - Documents are not required to have all the same fields (aka sections, slots, parts).
  - Documents are **schemaless**.
- Documents are identified by an ID, e.g.,
  - marked by a special type **ObjectId**,
  - stored by a special key **_id**.
- References are modeled by **foreign keys**.
  - or avoided by using **embedded documents**.

Example 1 / Schema-less

```
{
    _id: ObjectId(7df78ad8902c),
    FirstName: "Bob",
    Age: 35,
    Address: "5 Oak St.",
    Hobby: "sailing"
}
```

```
{
    _id: ObjectId(5df78ad8902c),
    FirstName: "Jonathan",
    Age: 37,
    Address: "15 Wanamassa Point Road",
    Languages: [ 'English', 'German' ]
}
```

Example 2 / Foreign Keys

```
{
    _id: ObjectId(5df78ad8902c),
    FirstName: "Jonathan",
    Age: 37,
    Address: "15 Wanamassa Point Road",
    Children: [ ObjectId(5df78ad89020), ObjectId(5df78ad89021),
                ObjectId(5df78ad89022), ObjectId(5df78ad89023) ]
},{
    _id: ObjectId(5df78ad89020),
    FirstName: "Michael",
    Age: 10,
},{
    _id: ObjectId(5df78ad89021),
    FirstName: " Jennifer ",
    Age: 8,
},{
    _id: ObjectId(5df78ad89022),
    FirstName: "Samantha",
    Age: 5,
},{
    _id: ObjectId(5df78ad89023),
    FirstName: "Elena",
    Age: 2,
}
```

Example 3 / Embedded Documents

```
{
    _id: ObjectId(5df78ad8902c),
    FirstName: "Jonathan",
    Age: 37,
    Address: "15 Wanamassa Point Road",
    Children: {
        { FirstName: "Michael", Age: 10 },
        { FirstName: " Jennifer ", Age: 8 },
        { FirstName: "Samantha", Age: 5 },
        { FirstName: "Elena", Age: 2}
    }
}
```

Organization

- Documents are addressed in the database via a **unique key**.
- Documents can be retrieved by their
  - key
  - content
- Documents are organized through
  - Collections
  - Tags
  - Non-visible Metadata
  - Directory hierarchies
  - Buckets

RDBMS vs. Document Database Terminology

relational database	document database
Database	Database
Table	Collection
Tuple/Row	Document
Column	Field
Primary key	Primary key (e.g., default key _id in mongodb)
Foreign key	Foreign key

Inserting Documents

- **insert** allows to insert a new document.
- **insertMany** allows to insert many documents.

```
db.inventory.insertMany([
   { item: "journal", qty: 25, size: { h: 14, w: 21, uom: "cm" }, status: "A" },
   { item: "notebook", qty: 50, size: { h: 8.5, w: 11, uom: "in" }, status: "A" },
   { item: "paper", qty: 100, size: { h: 8.5, w: 11, uom: "in" }, status: "D" },
   { item: "planner", qty: 75, size: { h: 22.85, w: 30, uom: "cm" }, status: "D" },
   { item: "postcard", qty: 45, size: { h: 10, w: 15.25, uom: "cm" }, status: "A" }
]);
```

Note: Most examples taken from MongoDB [2017].

Query Documents (1/3)

- all documents of a collection:

```
db.inventory.find()
```

```
{ "_id" : ObjectId("59116d5340229e45bb5eea9a"), "item" : "journal", "qty" : 25, "size" : { "h" : 14, "w"
{ "_id" : ObjectId("59116d5340229e45bb5eea9b"), "item" : "notebook", "qty" : 50, "size" : { "h" : 8.5, "
{ "_id" : ObjectId("59116d5340229e45bb5eea9c"), "item" : "paper", "qty" : 100, "size" : { "h" : 8.5, "w"
{ "_id" : ObjectId("59116d5340229e45bb5eea9d"), "item" : "planner", "qty" : 75, "size" : { "h" : 22.85, "
{ "_id" : ObjectId("59116d5340229e45bb5eea9e"), "item" : "postcard", "qty" : 45, "size" : { "h" : 10, "w
```

- all documents with a property:

```
db.inventory.find({ status: "D"})
```

```
{ "_id" : ObjectId("59116d5340229e45bb5eea9c"), "item" : "paper", "qty" : 100, "size" : { "h" : 8.5, "w"
{ "_id" : ObjectId("59116d5340229e45bb5eea9d"), "item" : "planner", "qty" : 75, "size" : { "h" : 22.85, "
```

- all documents with several properties:

```
db.inventory.find({ status: "D", qty: 100})
```

```
{ "_id" : ObjectId("59116d5340229e45bb5eea9c"), "item" : "paper", "qty" : 100, "size" : { "h" : 8.5, "w"
```

Query Documents (2/3)

- instead of querying for exact value matches, one can use query operators:
  - **$lt**, **$gt**, **$lte**, **$gte**: numerical comparison

```
db.inventory.find({ qty: { $gte: 75 } } )
```

```
{ "_id" : ObjectId("59116d5340229e45bb5eea9c"), "item" : "paper", "qty" : 100, "size" : { "h" : 8.5, "w"
{ "_id" : ObjectId("59116d5340229e45bb5eea9d"), "item" : "planner", "qty" : 75, "size" : { "h" : 22.85, '
```

```
db.inventory.find({ qty: { $lte: 75, $gt: 25 } } )
```

```
{ "_id" : ObjectId("59116d5340229e45bb5eea9b"), "item" : "notebook", "qty" : 50, "size" : { "h" : 8.5, "\
{ "_id" : ObjectId("59116d5340229e45bb5eea9d"), "item" : "planner", "qty" : 75, "size" : { "h" : 22.85, '
{ "_id" : ObjectId("59116d5340229e45bb5eea9e"), "item" : "postcard", "qty" : 45, "size" : { "h" : 10, "w
```

  - //: regular expressions.

```
db.inventory.find({ item: /er$/ } )
```

```
{ "_id" : ObjectId("59116d5340229e45bb5eea9c"), "item" : "paper", "qty" : 100, "size" : { "h" : 8.5, "w"
{ "_id" : ObjectId("59116d5340229e45bb5eea9d"), "item" : "planner", "qty" : 75, "size" : { "h" : 22.85, '
```

Query Documents (3/3)

- **$or** or queries:

```
db.inventory.find({ $or: [ { qty: { $lte: 25 } }, { qty: { $gte: 100 } } ] } )
```

```
{ "_id" : ObjectId("59116d5340229e45bb5eea9a"), "item" : "journal", "qty" : 25, "size" : { "h" : 14, "w"
{ "_id" : ObjectId("59116d5340229e45bb5eea9c"), "item" : "paper", "qty" : 100, "size" : { "h" : 8.5, "w"
```

Query Documents (4/4)

- fields of nested documents are queried by dot syntax:

```
db.inventory.find({ "size.h": { $gte: 14 } } )
```

```
{ "_id" : ObjectId("59116d5340229e45bb5eea9a"), "item" : "journal", "qty" : 25, "size" : { "h" : 14, "w"
{ "_id" : ObjectId("59116d5340229e45bb5eea9d"), "item" : "planner", "qty" : 75, "size" : { "h" : 22.85, '
```

Advantages and Disadvantages

- avoiding foreign keys by **embedding documents**:
  - + expensive join operations are not required.
  - – possibly redundant information.
- **schemaless**:
  - + one can add a new field at any time.
  - – one never can be sure a field actually has a value.

Big Data Document Databases

Document databases are useful for big data for two main reasons:

1. Document databases can be **horizontally partitioned** / **sharded**.
    - Documents are distributed over different nodes.
    - Using a **partition/sharding function**
        - e.g., a hash function.
    - works exactly the same way as for RDBMS.

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    - Using a **partition/sharding function**
        - e.g., a hash function.
    - works exactly the same way as for RDBMS.

2. Documents are **sparse representations**,
    - only some fields/keys have values,

    while tuples/rows are **dense**.
    - all columns have values stored explicitely
        - also NULL is explicitely stored.

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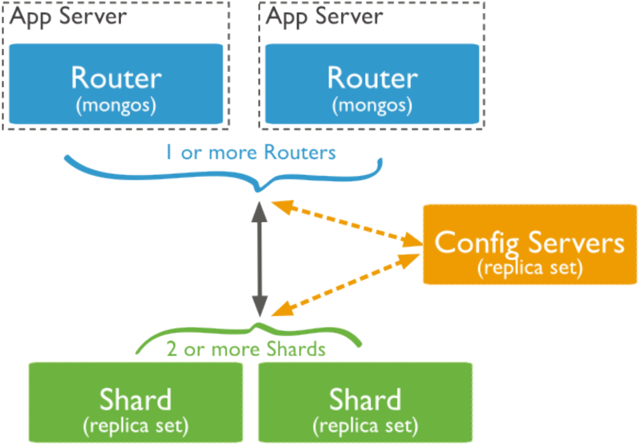
Sharded Document Database / Architecture



[source: https://docs.mongodb.com/manual/core/sharding-introduction/]

Mongo DB (from humongous – slang for enormous)

System Setup / Multiple Hosts

1. install mongodb on all hosts (h0, h1, h2, h3), e.g., for OpenSuSE:

```
zypper in mongodb
```

2. start a **config server** on one host (e.g., h0):

```
mongod --configsvr
```

   - default port is 27019

3. start a **query router** on one host (e.g., h0):

```
mongos --configdb localhost
```

   - default port is 27017

4. start a couple of **shard servers** on other hosts (e.g., h1, h2, h3):

```
mongod --shardsrv
```

   - default port is 27018

5. add shards:

```
mongo --host h0
sh.addShard("h1")
sh.addShard("h2")
```

System Setup / Single Hosts (for Testing)

1. install mongodb, e.g., for OpenSuSE:

```
zypper in mongodb
```

2. start a **config server**:

```
mongod --configsvr --dbpath db-configsrv/
```

   - config information will be stored in directory db-configsrv/.

3. start a **query router**:

```
mongos --configdb localhost:27019
```

   - query routers do not require any data path

4. start a couple of **shard servers**:

```
mongod --port 27021 --dbpath db-shardsrv1/
mongod --port 27022 --dbpath db-shardsrv2/
mongod --port 27023 --dbpath db-shardsrv3/
```

   - use different ports and data paths

5. add shards:

```
mongo
sh.addShard("localhost:27021")
sh.addShard("localhost:27022")
```

Database and Collection Setup

1. enable sharding per database

```
sh.enableSharding("mydb")
```

2. sharding a collection requires the sharding key to be indexed:

```
db.ijcnn1.createIndex( { _id: 1 } )
```

3. shard per collection:

```
sh.shardCollection("mydb.ijcnn1", { _id: 1 })
```

4. import data

```
mongoimport --db mydb --collection ijcnn1 --drop --file ijcnn1.json
```

   - data has to be in json format

- if a database is imported first and then sharded,
  it will be distributed across nodes automatically by the balancer.

Database and Collection Setup

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  - both, data nodes and config nodes

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    - rule of thumb: 1 PB moves through a 1 GB ethernet in ca. 100d.

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  - **not** query it from the central router nodes
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  - **not** query it locally on the shard nodes
    - if data also is replicated, one would need to know which nodes to query
    - the balancer may move data during query time

Database and Collection Setup

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    - if data also is replicated, one would need to know which nodes to query
    - the balancer may move data during query time

- to work on sharded big data, one should
  use technologies provided by the database, e.g.,
  map-reduce.
  - for mongo: mappers and reducers have to be coded in javascript.

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Graph databases

A graph database is a database that uses graph structures with

- nodes,
- edges, and
- node/edge properties

to represent and store data.

Graph databases

- Nodes represent entities such as people, businesses, accounts, or any other item you might want to keep track of.
- Properties are relevant information that relate to nodes.
- Edges are the lines that connect nodes to nodes
- Most of the important information is often stored in the edges.
- Meaningful patterns emerge when one examines the connections and interconnections of nodes, properties, and edges.

Graph databases

- Compared with relational databases, graph databases are often faster for associative data sets
- They map more directly to the structure of object-oriented applications.
- As they depend less on a rigid schema, they are more suitable to manage ad hoc and changing data with evolving schemas.
- Graph databases are a powerful tool for graph-like queries.

Graph queries

- Reachability queries
- shortest path queries
- Pattern queries

Column Databases

- column databases store data column-wise,
  not row-wise
- also many relational data bases allow column-wise physical storage

Object Database

- An object database is a database management system in which information is represented in the form of objects as used in object-oriented programming.
- Most object databases also offer some kind of query language, allowing objects to be found using a declarative programming approach (OQL)
- Access to data can be faster because joins are often not needed.
- Many object databases offer support for versioning.
- They are specially suitable in applications with complex data.

Summary

- **NoSQL databases** denote several types of non-relational databases:
  - **key-value stores**: just store key/value pairs
  - **document databases**: store documents/(nested) dicts
  - **graph databases**: store and query information as a graph
- NoSQL databases are motivated by
  - **simplicity of design** and
  - **horizontal scaling**.
- NoSQL databases usually do not support ACID transactions, but **eventual concistency**
  - **BASE**: basically available, soft state, eventually consistent
  - **CAP theorem:** in presence of Network Partitions, a DBMS needs to choose between Consistency an Availability.

Summary (2/2)

- Document databases are **schemaless**
  - design decision between **foreign keys** and **embedded documents**
- Document databases are queried through **query documents**
  - key-value pairs
  - key-relation-value triples
  - logical aggregations (or)
- Document databases can partition document collections using a **partition/sharding function**.

Further Readings

- cap theorem: Brewer [2012]
- Mongo DB tutorial: MongoDB [2017]

References I

Eric Brewer. CAP Twelve years Later: How the. *Computer*, (2):23–29, 2012.

MongoDB. Mongodb tutorial — query documents, 2017. URL
`https://docs.mongodb.com/manual/tutorial/query-documents/`.