Big Data
Lecture 2 – From SQL to NoSQL: Spark SQL and NoSQL databases

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Towards NoSQL

What we've seen so far

- Hadoop and Spark as **distributed data processing** frameworks.
- Data from **text files** stored in a **distributed file system** (HDFS).

What we're going to see

- Data can be stored and managed by **database systems**.
- As opposed to a **file system**, a **database** provides:
  - Data model and query language.
  - Indexing and integrity constraints.
  - Fine-grained security mechanisms.
  - Concurrency control.
  - Backup and recovery.
- The most popular database systems are based on the **relational data model** (▸ Source).

The relational data model

☞ In the **relational model**, a database is a collection of **tables**, or **relations**.

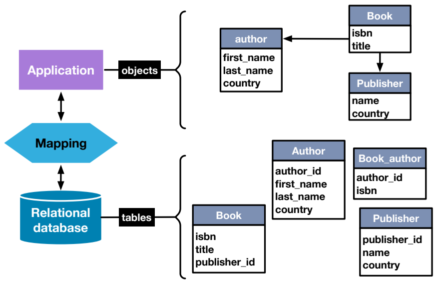
- A **row** in a table (or, a **tuple** in a **relation**) describes an **entity**.
- A **column** in a table (or, an **element** in a **tuple**) represents an **attribute** of an entity.
- A **relationship** between two entities is expressed as common values in one or more columns of their respective tables.
- The relational model provides an *open-ended* collection of **scalar types** (e.g., *boolean*, *integer* . . .).
  - Open-ended: users are allowed to define custom types.

☞ The values in a given column must have the **same type**.

Relational data model limitations: impedance mismatch

Definition (Impedance mismatch)

Impedance mismatch refers to the challenges encountered when one needs to map objects used in an application to tables stored in a relational database.



Impedance mismatch: solutions

Object-oriented databases

- Data is stored as **objects**.
- Object-oriented applications save their objects as they are.
- **Examples.** ConceptBase, Db4o, Objectivity/DB.

Disadvantage

- Not as popular as relational database systems.
- Requires familiarity with object-oriented concepts.
- No standard query language.

Impedance mismatch: solutions

Object relational mappers (ORM)

- Use of libraries that map objects to relational tables.
- The application manipulates objects.
- The ORM library translates object operations into SQL queries.
- **Examples.** SQLAlchemy, Hibernate, Sequelize.

Disadvantage

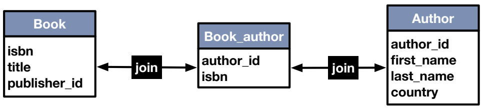
- **Abstraction.** Weak control on how queries are translated.
- **Portability**. Each ORM has a different set of APIs.

Limitations of the relational model: graph data

Normalization

- In a relational databases, tables are **normalized**.
- Data on **different entities** are kept in **different tables**.
- This reduces **redundancy** and guarantees **integrity**.

- In a **normalized** relational database, links between entities are expressed with **foreign key constraints**.
- Need to join different tables (**expensive** operation).



Limitations of the relational model: data distribution

Objective of a relational database system

- Privilege data **integrity** and **consistency**.
- Different mechanisms to ensure integrity and consistency.
  - Primary and foreign key constraints.
  - Transactions.

- Mechanisms to enforce data integrity and consistency have a **cost**.
  - Manage transactions.
  - Check that new data complies with the given integrity constraints.
- Things get worse in **distributed databases**.
  - Data is distributed across several machines.
  - Join operations become very expensive.
  - Integrity mechanisms become very expensive.

Distributed database

Definition (Distributed database)

A **distributed database** is one where data is stored across several **machines**, a.k.a, **nodes**.

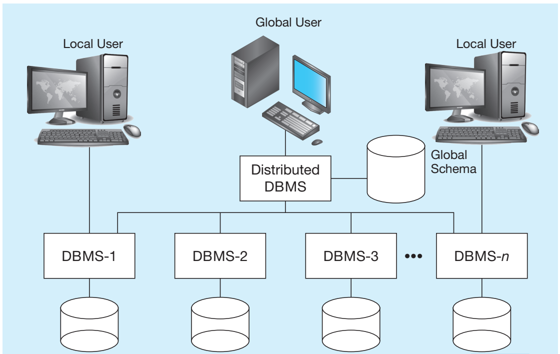
Shared-nothing architecture

- Each node has its own CPU, memory and storage.
- Nodes only share the network connection.

Pros/cons of a distributed database

- Allows storage and management of large volumes of data. ☺
- Far more complex than a single-server database. ☹

Distributed database



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Distributing data: when?

Small-scale data

- Data distribution is not a good option when the **data scale is small**.
- With **small-scale data**, the performances of a distributed database are **worse** than a single-server database.
  - **Overhead.** We lose more time distributing and managing data than retrieving it.

Large-scale data

- If the data does not fit in a single machine, data distribution is the only option left.
- Distributed databases allow **more concurrent database requests** than single-server databases.

Distributing data: how?

Data distribution options

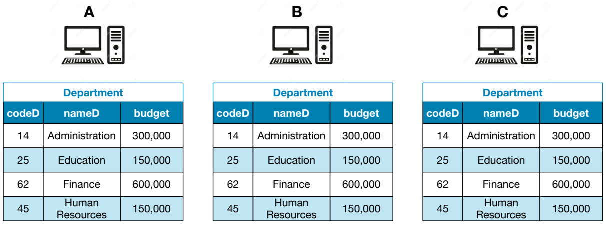
- **Replication.** Multiple copies of the same data stored on different nodes.
- **Sharding.** Data partitions stored on different nodes.
- **Hybrid.** Replication + Sharding.

Properties

- **Location transparency**: applications do not have to be aware of the location of the data.
- **Replication transparency**: applications do not need to be aware that the data is replicated.

Replication

- The same piece of data is replicated across different nodes.
    - Each copy is called a **replica**.
- **Replication factor.** The number of nodes on which the data is replicated.



Department		
codeD	nameD	budget
14	Administration	300,000
25	Education	150,000
62	Finance	600,000
45	Human Resources	150,000

Department		
codeD	nameD	budget
14	Administration	300,000
25	Education	150,000
62	Finance	600,000
45	Human Resources	150,000

Department		
codeD	nameD	budget
14	Administration	300,000
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Replication

Advantages

- **Scalability.** Multiple nodes can serve queries on the same data.
- **Latency.** Queries can be served by geographically proximate nodes.
- **Fault tolerance.** The database keeps serving queries even if some nodes fail.

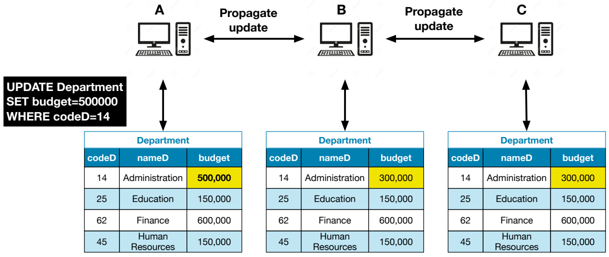
Disadvantages

- **Storage cost.** Storage is used to keep multiple copies of the same data.
- **Consistency.** All replicas must be kept in sync.

Replication

Replica consistency

When a replica is updated, the other replicas must be updated as well.



```
UPDATE Department
SET budget=500000
WHERE codeD=14
```

Department		
codeD	nameD	budget
14	Administration	500,000
25	Education	150,000
62	Finance	600,000
45	Human Resources	150,000

Department		
codeD	nameD	budget
14	Administration	300,000
25	Education	150,000
62	Finance	600,000
45	Human Resources	150,000

Department		
codeD	nameD	budget
14	Administration	300,000
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Replication

Synchronous updates

- Updates are propagated immediately to the other replicas.
- **Small inconsistency window.** The replicas will be inconsistent for a short interval of time. ☺
- If updates are frequent, the database might be too busy propagating updates than serving queries. ☹

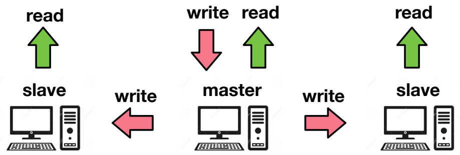
Asynchronous updates

- Updates are propagated at regular intervals.
- More efficient when updates are frequent. ☺
- Long inconsistency window. ☹

Replication

Master-slave replication

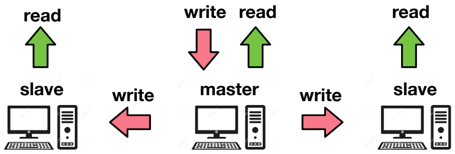
- **Write** operations are only possible on the **master node**.
- The **master node** propagates the updates to the **slave nodes**.
- **Read** operations are served by both the master and the slave nodes.



Replication

Master-slave replication

- Prevents **write conflicts**. ☺
    - Only one replica is written at any given time.
- Single **point of failure**. ☹
    - If the master fails, write operations are unavailable.
    - Algorithms exist to **elect** a new master.
- **Read conflicts** are possible. ☹

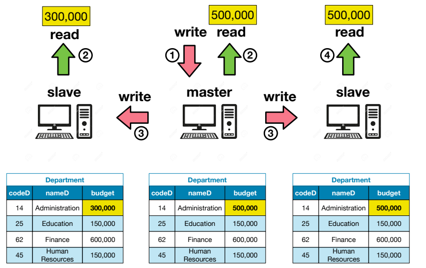


Replication

Master-slave replication read conflict

Two **read** operations on the **same data** might return **different values**.

Write: update (Department, budget=500,000) **Read**: select (Department, budget)



Department		
codeD	nameD	budget
14	Administration	300,000
25	Education	150,000
62	Finance	600,000
45	Human Resources	150,000

Department		
codeD	nameD	budget
14	Administration	500,000
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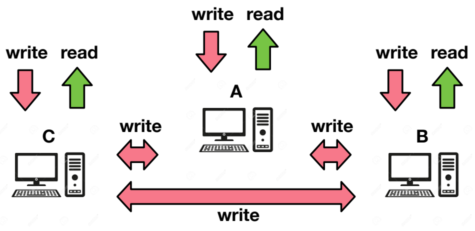
62	Finance	600,000
45	Human Resources	150,000

Department		
codeD	nameD	budget
14	Administration	500,000
25	Education	150,000
62	Finance	600,000
45	Human Resources	150,000

Replication

Peer-to-peer replication

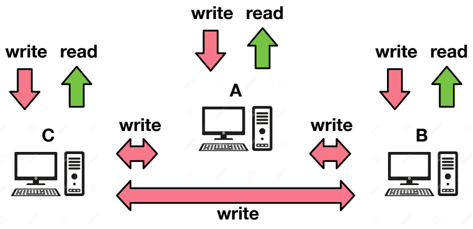
- **Read** and **write** operations are possible on **any node**.



Replication

Peer-to-peer replication

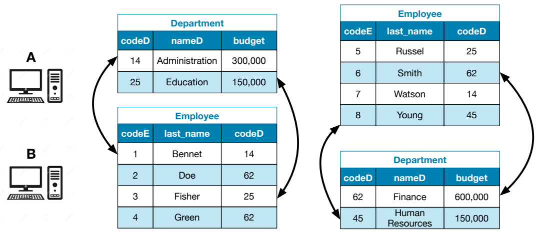
- No single point of failure. ☺
- Write and read conflicts are possible. ☹



Sharding

Sharding

- Data is partitioned into balanced, non-overlapping **shards**.
- Shards are distributed across the nodes.



Department		
codeD	nameD	budget
14	Administration	300,000
25	Education	150,000

Employee		
codeE	last_name	codeD
1	Bennet	14
2	Doe	62
3	Fisher	25
4	Green	62

Employee		
codeE	last_name	codeD
5	Russel	25
6	Smith	62
7	Watson	14
8	Young	45

Department		
codeD	nameD	budget
62	Finance	600,000
45	Human Resources	150,000

Sharding

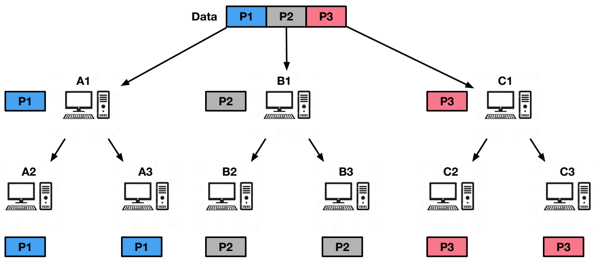
Advantages

- **Load balance.** Data can be uniformly distributed across nodes.
- **Inconsistencies** cannot arise (non-overlapping shards).

Disadvantages

- When a node fails, all its partitions are lost.
- Join operations might need to be performed across nodes.
- When data is added, shards might need to be rebalanced.

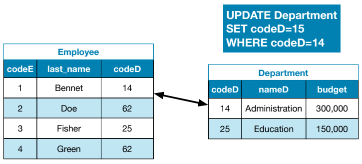
Combining replication and sharding



Consistency: first definition

Definition (Consistency)

A database is **consistent** if the data respect all the **integrity constraints** imposed by the database administrator.



UPDATE Department
SET codeD=15
WHERE codeD=14

Employee

codeE	last_name	codeD
1	Bennet	14
2	Doe	62
3	Fisher	25
4	Green	62

Department

codeD	nameD	budget
14	Administration	300,000
25	Education	150,000

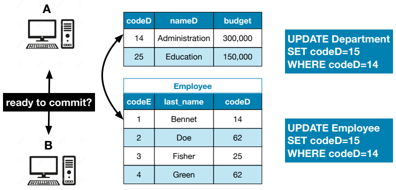
- **Transactions** are used to keep a database consistent.

ACID

Atomicity, **C**onsistency, **I**solation, **D**urability.

Consistency in distributed databases

- **Distributed transactions** are used to keep a distributed database consistent.
- **Transaction managers** in all the nodes involved in the transaction need to communicate before committing.
- This communication is expensive.



codeD	nameD	budget
14	Administration	300,000
25	Education	150,000

Employee

codeE	last_name	codeD
1	Bennet	14
2	Doe	62
3	Fisher	25
4	Green	62

UPDATE Department
SET codeD=15
WHERE codeD=14

UPDATE Employee
SET codeD=15
WHERE codeD=14

Consistency vs Availability

- Data being manipulated by a transaction is **locked**.
  - Locked data is **unavailable** for both read and write operations.
- Locking guarantees the **consistency** of the database.
- Locking reduces the **availability** of the database.

Relational vs NoSQL databases

- Relational databases favor **consistency** over **availability**.
  - **ACID**-compliant databases.
- NoSQL databases favor **availability** over **consistency**.
  - **BASE**: **B**asic **A**vailability, **S**oft state, **E**ventually consistent.

Consistency: second definition

Definition (Consistency)

A (distributed) database is **consistent** if reads and updates behave as if there were a single copy of the data. (Source).

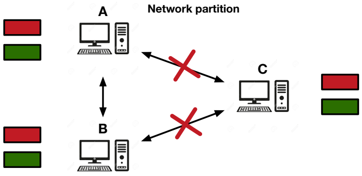
- This second definition of consistency refers to **replication consistency**.
- Enforcing (strong) consistency creates problems with availability.
- What to do when the nodes of a cluster cannot communicate (network issues)?

The **CAP theorem** describes the relation between **consistency**, **availability** and **partition tolerance**.

The CAP theorem

Consistency (C), Availability (A), Partition tolerance (P)

- **Consistency.** As intended by the **second definition**.
- **Availability.** A database can still execute read/write operations when some nodes fail.
- **Partition tolerance.** The database can still operate when a **network partition** occurs.



The CAP theorem

Theorem (CAP, Brewer 1999)

Given the three properties of **consistency**, **availability** *and* **partition tolerance**, *a networked shared-data system can have at most two of these properties.*

Proof

Suppose that the system is **partition tolerant (P)**. When a network partition occurs, we have two options.

1. **Allow write operations**. This makes the database **available (A)**, but **not consistent (C)**.
   - Some of the replicas might not be synced due to the network partition.
2. **Disable write operations**. This makes the database **consistent (C)** but **not available (A).**

The CAP theorem

Theorem (CAP, Brewer 1999)

Given the three properties of **consistency**, **availability** *and* **partition tolerance**, *a networked shared-data system can have at most two of these properties.*

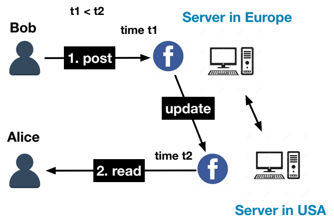
Proof

- The only way that we can have a **consistent (C)** and **available (A)** database is when network partitions do not occur.
- But if we assume that network partitions never occur, the system is **not partition tolerant (P)**.

☞ When there isn't any network partition, the CAP theorem **does not** impose constraints on availability or consistency.

The CAP theorem

Why choosing availability over consistency?



Alice does not see Bob's post between $t1$ and $t2$.
Is it really an issue?

CAP theorem and NoSQL databases

CP Databases

- MongoDB.
- CouchDB.
- Redis.
- HBese.

AP databases

- Cassandra.
- DynamoDB.

NoSQL databases

NoSQL: interpretations of the acronym

- *Non SQL*: strong opposition to SQL.
- *Not only SQL*: NoSQL and SQL coexistence.

Goals

- Address the **object-relational impedance mismatch**.
- Provide better scalability for **distributed databases**.
- Provide a better modeling of **semi-structured data**.

NoSQL databases

Families

- **Key-value** databases.
- **Document-oriented** databases.
- **Column-oriented** databases.
- **Graph** databases.

- The first three families use the notion of **aggregate** to model the data.
  - They differ in how the aggregates are organized.
- Graph databases are somewhat **outliers**.
  - They were not conceived for data distribution in mind.
  - They were born ACID-compliant.

☞ There is not a single NoSQL database and there is not a "NoSQL" query language.

Aggregate

- An **aggregate** is a data structure used to store the data of a specific entity.
  - In that, it is similar to a row in a relational table.
- We can **nest** an aggregate into another aggregate.
  - This is a huge difference from a row in a relational table.
- An aggregate is a **unit of data** for **replication** and **sharding**.
  - All data in an aggregate will never be split across two shards.
  - All data in an aggregate will always be available on one node.
  - Unlike a relational database, we can control how data is distributed.

Aggregate vs relational row

Denormalized table

- In a relational database, the following table would not be in **first normal form**.
- The column *categories* contains a list of values.
    - Searching for all products in category *kitchen* would be hard with SQL.

article_id	name	producer	categories
234543	Bamboo utensil spoon	KitchenMaster	home, kitchen, spatulas

☞ In a relational database, we can address this problem by **normalizing** the table.

Aggregate vs relational row

First normal form

- The following table is in **first normal form**.
- But we introduced **redundancy**.
    - What if we update the producer name of the article 234543?
    - In a distributed database, the rows corresponding to this article might be on **different nodes**.

article_id	name	producer	categories
234543	Bamboo utensil spoon	KitchenMaster	home
234543	Bamboo utensil spoon	KitchenMaster	kitchen
234543	Bamboo utensil spoon	KitchenMaster	spatulas

☞ We can **further normalize** the table to avoid redundancy.

Aggregate vs relational row

Second normal form

- To avoid redundancy, we split the table into three tables in **second normal form**.
- In a distributed database, the rows in these tables might be on different nodes.
    - We might need **cross-node join** operations, which are very expensive.

article

article_id	name	producer
234543	Bamboo utensil spoon	KitchenMaster

article_category

article_id	category_id
234543	1
234543	2
234543	3

category

category_id	name
1	kitchen
2	home
3	spatulas

Aggregate vs relational row

Aggregate

- In an **aggregate**, list of values are **allowed**.
- Searching for all products in category *kitchen* is supported.

```
{
  "article_id": 234543,
  "name": "Bamboo utensil spoon",
  "producer": "KitchenMaster",
  categories: ["home", "kitchen", "spatulas"]
}
```

☞ All data in an aggregate is never split across different nodes.

▲

- **Denormalization** is allowed in the aggregate.
- Data that are queried together are stored in the same node.

```
{
  "code_employee": 12353,
  "first_name": "John",
  "last_name": "Smith",
  "salary": 50000,
  "position": "Assistant director",
  department: {
      "dept_code": 12,
      "dept_name": "Accounting",
      budget: 120000
    }
}
```

▲

- Aggregates are **schemaless**.
- Aggregates might not have the same attributes.

```
{
  "code_employee": 12353,
  "first_name": "John",
  "last_name": "Smith",
  "salary": 50000,
  "position": "Assistant director",
  department: {
      "dept_code": 12,
      "dept_name": "Accounting",
      budget: 120000
    }
}
```

```
{
  "code": 345321,
  "first_name": "Jennifer",
  "last_name": "Green",
}
```

☞ We don't need to fix a rigid the schema. NULL values are avoided.

```
{
  "code_employee": 12353,
  "first_name": "John",
  "last_name": "Smith",
  "salary": 50000,
  "position": "Assistant director",
  departments: [
    {
      "dept_code": 12,
      "dept_name": "Accounting",
      budget: 120000
    },
    {
      "dept_code": 145,
      "dept_name": "HR",
      budget: 250000
    }
  ]
}
```

```
{
  "code_employee": 12353,
  "first_name": "John",
  "last_name": "Smith",
  "salary": 50000,
  "position": "Assistant director",
  departments: [
    {
      "dept_code": 12,
      "dept_name": "Accounting",
      budget: 120000
    },
    {
      "dept_code": 145,
      "dept_name": "HR",
      budget: 250000
    }
  ]
}
```

☞ We can update **atomically** the salary of an employee. How would we represent the same in a relational database?

▲

- We use a **denormalized table** (same as aggregate).
- **However**, we have no guarantees that the rows relative to the employee John Smith will be stored in the same node.

code_emp	first_name	last_name	salary	position	dept_code	dept_name	budget
234543	John	Smith	50000	Assistant director	12	Accounting	120000
234543	John	Smith	50000	Assistant director	145	HR	250000

☞ The update of the salary of a single employee might be a **cross-node operation**.

```
{
  "code_employee": 12353,
  "first_name": "John",
  "last_name": "Smith",
  "salary": 50000,
  "position": "Assistant director",
  departments: [
    {
      "dept_code": 12,
      "dept_name": "Accounting",
      budget: 120000
    },
    {
      "dept_code": 145,
      "dept_name": "HR",
      budget: 250000
    }
  ]
}
```

☞ Updating the information on a department is a **non-atomic operation**

Aggregate-based NoSQL databases

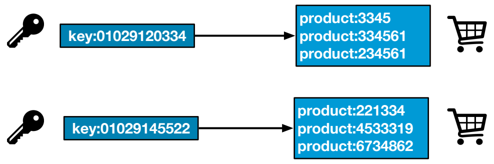
- Aggregates are **schemaless**.
  - No need to adhere to a rigid schema.
  - Flexible evolution of the database.
- Normalization is not required.
  - We accept some **redundancies** in exchange of faster queries.
  - Remember: storage hardware is **cheap** today.
- All data in an aggregate is stored in a **single node**.
  - With aggregates, we are in control of how the data is distributed.
- In general, updates on an aggregate are **atomic operations**.
  - If an update entails many write operations, either all are executed or none.
- Cross-aggregate updates are **not guaranteed** to be atomic.
  - Multi-aggregate transactions might be supported and used if necessary.

Key-value databases

Idea

Data are modeled as **key-value pairs**.

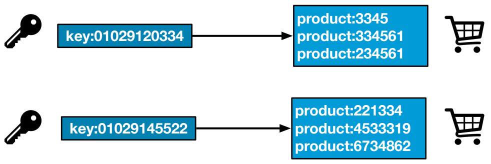
- **Key**: alphanumeric string, usually auto-generated by the database.
- **Value**: an aggregate.
- **Query**: get an aggregate given its key.



Key-value databases

Idea

- Data is partitioned based on the key.
- Partitions are distributed across different nodes.
- Little to no checks on integrity constraints.
- **Goal.** High scalability and fast read/write queries.



key:01029120334
product:3345
product:334561
product:234561

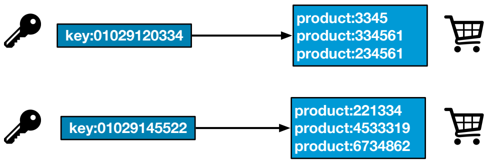
key:01029145522
product:221334
product:4533319
product:6734862

Key-value databases

Application scenarios

Scenario 1. Session store.

- A Web application starts a session when a user logs in.
- The application stores **session data** in the database.
  - User profile information, messages, personalized themes...
- Each session is assigned a **unique identifier** (the key).
- Session data is only queried by the identifier.



key:01029120334
product:3345
product:334561
product:234561

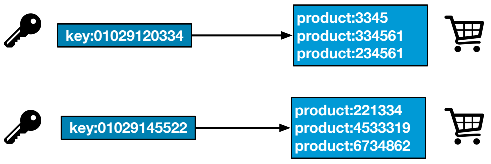
key:01029145522
product:221334
product:4533319
product:6734862

Key-value databases

Application scenarios

Scenario 2. Shopping cart.

- An e-commerce website may receive billions of orders in seconds.
- Each shopping cart has a **unique identifier** (the key).
- Shopping cart data is only queried by the identifier.
- Shopping cart data can be easily replicated to handle node failures.



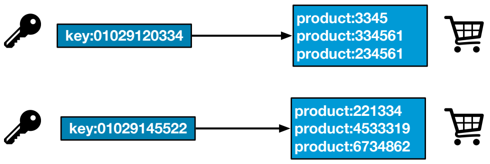
key:01029120334
product:3345
product:334561
product:234561

key:01029145522
product:221334
product:4533319
product:6734862

Key-value databases

Existing key-value databases

- **Amazon DynamoDB**. One of the first NoSQL databases.
- **Riak**.
- **Redis**. Possibility of tuning data persistence.
- **Voldemort**.



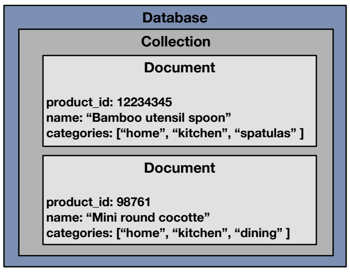
key:01029120334
product:3345
product:334561
product:234561

key:01029145522
product:221334
product:4533319
product:6734862

Document-oriented databases

Idea

- Data is modeled as **key-value pairs**, and searching aggregates based on their **attribute values** is supported.



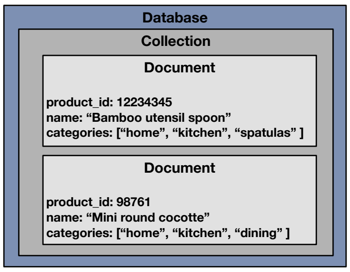
Database
Collection
Document
product_id: 12234345
name: “Bamboo utensil spoon”
categories: [“home”, “kitchen”, “spatulas”]
Document
product_id: 98761
name: “Mini round cocotte”
categories: [“home”, “kitchen”, “dining”]

It is possible to search for all products in category *kitchen*.

Document-oriented databases

Existing document-oriented databases

- **MongoDB**, **CouchDB**, **OrientDB**.



Database
Collection
Document
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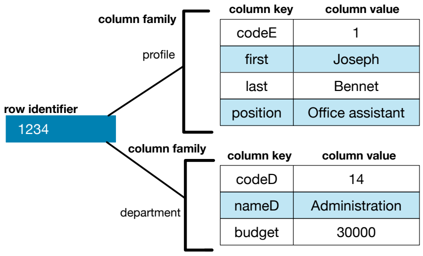
name: “Bamboo utensil spoon”
categories: [“home”, “kitchen”, “spatulas”]
Document
product_id: 98761
name: “Mini round cocotte”
categories: [“home”, “kitchen”, “dining”]

Column-oriented databases

Idea

- Similar to document-oriented database but. an aggregate can be broken into smaller data units called **columns**.



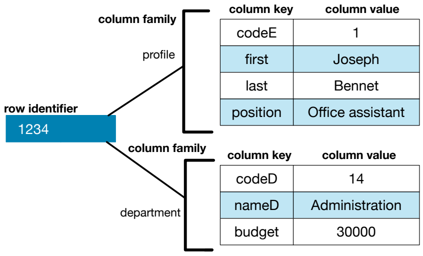
column key	column value
codeE	1
first	Joseph
last	Bennet
position	Office assistant

column key	column value
codeD	14
nameD	Administration
budget	30000

Column-oriented databases

Idea

- Columns can be organized into **column families**.
- Columns in the same family are stored on the same node.



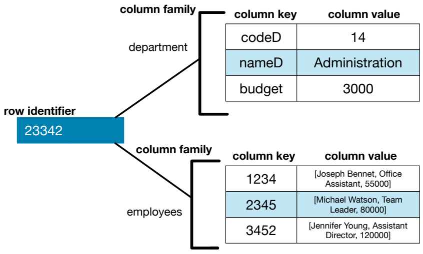
column key	column value
codeE	1
first	Joseph
last	Bennet
position	Office assistant

column key	column value
codeD	14
nameD	Administration
budget	30000

Column-oriented databases

Idea

- The value of a column can be an aggregate (**wide column**).



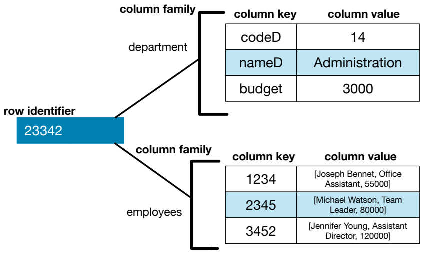
column key	column value
codeD	14
nameD	Administration
budget	3000

column key	column value
1234	[Joseph Bennet, Office Assistant, 55000]
2345	[Michael Watson, Team Leader, 80000]
3452	[Jennifer Young, Assistant Director, 120000]

Column-oriented databases

Existing column-oriented databases

- **Cassandra**, **HBase**, **BigTable** (Google).



column key	column value
codeD	14
nameD	Administration
budget	3000

column key	column value
1234	[Joseph Bennet, Office Assistant, 55000]
2345	[Michael Watson, Team Leader, 80000]
3452	[Jennifer Young, Assistant Director, 120000]

Graph databases

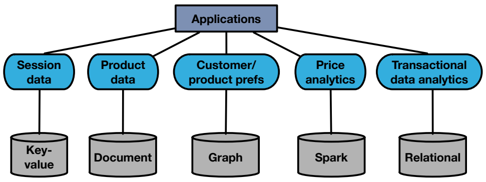
Idea

- Their data model is optimized for storing and retrieving **graph data**.
- Relationships are **first-class citizens**.
    - In relational databases they are implicit in **foreign key constraints**.
    - In aggregate-based NoSQL stores, they are represented with nested aggregates or references.
- Existing graph databases: **Neo4j**, **InfiniteGraph**, **AllegroGraph**.

NoSQL databases: conclusions

Polyglot persistence

- NoSQL databases are **not** going to replace relational databases.
- Use of different data storage technologies based on the data type.
- This is called **polyglot persistence**.



MongoDB general concepts

MongoDB

- General-purpose database system based on the **document data model**.
- **MongoDB Community**: open-source and free edition of MongoDB.
- **MongoDB Enterprise**: needs a subscription.

- A record in MongoDB is stored in a **document**.
  - A document is an **aggregate**.
- Documents are stored in **collections**.
  - A collection is similar to a relational table.
- A MongoDB **database** is a set of collections.

MongoDB characteristics

- **Impedance mismatch** reduction.
  - Documents are **JSON objects**.
  - One-to-one mapping to objects in programming languages.
- **Flexible schema**.
  - Documents in the same collections do not have to have the same fields.
- **Rich query language**.
  - Data aggregation.
  - Text and geospatial queries.
- **High availability**.
  - Data redundancy with **replication**.
  - Automatic failover.
- **Horizontal scalability**.
  - **Sharding** distributes data across several machines.
  - Support for the creation of **zones** of data.

Data modeling

- Data modeling in relational databases is guided by **normalization**.
- In MongoDB, data modeling can but does not have to follow normalization rules.

Data modeling criteria

- Consider the application usage of data (queries, updates).
- Consider the inherent structure of the data.

Flexible schema

Consider a **collection** of documents:

- Documents do not have to have the same fields.
- The data type for a field can differ across documents.

It is possible to specify **schema validation criteria** to make sure documents have a similar structure.

Data modeling

Denormalized data

- It is possible to **embed documents** in a MongoDB document.
- Denormalized data allow applications to retrieve and manipulate related data in a **single database operation**.

```
{
    "_id":"movie:1",
    "title":"Vertigo",
    "country":"DE",
    "director":{
      "_id":"artist:3",
      first_name: "Alfred",
      "last_name":"Hitchcock"
    }
}
```

Data modeling

```
{
    "_id":"movie:1",
    "title":"Vertigo",
    "country":"DE",
    "actors": [
      {
        "_id": "artist:15",
        "first_name": "James",
        "last_name": "Stewart",
        "role": "John Ferguson"
      },
      {
        _id: "artist:16",
        first_name: "Kim",
        last_name: "Novak"
      }
    ]
}
```

Data modeling

Normalized data

- Documents can store **references** to other documents.
- References are used instead of embedded documents.
- Used to **reduce data redundancy**.

Collection `movie`

```
{
  "_id":"movie:1",
  "title":"Vertigo",
  "country":"DE",
  "director": "artist:3"
}
```

Collection `artist`

```
{
  "_id":"artist:3",
  first_name: "Alfred",
  "last_name":"Hitchcock"
}
```

Data modeling

Denormalized data

- Ability to **retrieve related data** in a **single database operation**. ☺
- **Update** related data in a **single atomic write operation**.☺
- Data redundancy. ☹

Normalized data

- Useful when embedding would result in data redundancy with no or little improvement for read operations. ☺
- Useful to represent complex **many-to-many relationships**.☺
- Splits data across different documents (need for **join operations**). ☹

Data modeling

One-to-one relationship

- **Example.** One department has only one manager (and that person can only manage one department).
- Use an **embedded document**.

```
{
  "_id": "dept:1",
  "name": "Acconting",
  budget: 50000,
  manager: {
    "_id": "emp:1",
    "first_name": "John",
    "last_name": "Smith",
    "salary": 80000
  }
}
```

Data modeling

One-to-few relationship

- **Example.** The addresses of a person.
- Use an **embedded document**.

```
{
  "_id": "pers:1",
  "first_name": "John",
  "last_name": "Smith",
  addresses: [
    {street: "123 Sesame St", "city": "New York City", "country": USA},
    {street: "3 House Avenue", "city": "New York City", "country": USA}
  ]
}
```

☞ Difficult to find all people from New York City!

Data modeling

One-to-many relationship

- **Example.** A product is composed of several hundred replacement parts.
- Use **normalized documents**.

Collection Product

```
{
  "_id":"product:1",
  "name":"Smoke detector",
  "manufacturer": "SmokeSafety Inc.",
  "parts": ["part:345", "part:213"]
}
```

Collection Part

```
{
  "_id":"part:345",
  "partno": "123-aff-456",
  "cost": 0.94
}
```

☞ The same model can represent a **many-to-many relationship**.

Data modeling

One-to-squillions relationship

- **Example.** Log messages associated to a host.
- Each host might be associated to millions of log messages.
- Use **normalized documents**.

Collection Host

```
{
  "_id":"host:1",
  "name":"host.example.com",
  "ipaddr": "192.168.3.2"
}
```

Collection LogMessage

```
{
  "_id":"msg:1",
  "message": "CPU failure"
  "host": "host:1"
}
```

☞ Storing the messages in the host document might overflow the document size limit of 16MB.

Data modeling

Two-way referencing

- **Example.** We need to track **tasks** assigned to **people**.
- The application needs to retrieve the tasks assigned to a person.
- The application needs to get the person responsible for specific tasks.
- References are stored in both documents.

Collection Person

```
{
  "_id":"person:1",
  "name":"John Smith",
  "tasks": ["task:1", "task:5",
           "task:7"]
}
```

Collection Task

```
{
  "_id":"task:1",
  "description": "Budget finalization"
  "due_date":ISODate("2021-04-01"),
  "responsible": "person:1"
}
```

☞ Reassigning a task to another person entails two updates.

Data modeling

Half-way denormalization

- **Example.** Employees and the departments where they work.
- **Fully denormalized schema**: all properties of a department are embedded in an employee document.
- **Problem.** Updating the department budget can be **expensive**.

```
{
  "_id":"emp:1",
  "name":"John Smith",
  "salary": 50000,
  "position": "secretary",
  "department": {
    "_id": "dept:1",
    "name": "Accounting",
    "budget": 12000
  }
}
```

```
{
  "_id":"emp:1",
  "name":"Jennifer Young",
  "salary": 70000,
  "position": "director",
  "department": {
    "_id": "dept:1",
    "name": "Accounting",
    "budget": 12000
  }
}
```

Data modeling

Half-way denormalization

- **Solution**. Only denormalize the fields that are queried often together with the parent document.

Collection `Employee`

```
{
  "_id":"emp:1",
  "name":"John Smith",
  "salary": 50000,
  "position": "secretary",
  "department": {
    "_id": "dept:1",
    "name": "Accounting"
  }
}
```

Collection `Department`

```
{
  "_id":"dept:1",
  " budget": 12000
}
```

Data modeling – Exercise

We want to create a database in MongoDB for managing information about students in a school and the courses they take. For each student, we want to store his/her name, first name and number; for each course, we want to store its title, the number of credits and the name of the lecturers.

- Propose a **normalized solution**. How many read operations would you need to get the title of all the courses followed by a student?
- Discuss a possible **denormalized solution**. How many read operations would you need to get the title of all the courses followed by a student?

References

- Jules Damji et al. *Learning Spark: Lightning-Fast Data Analytics.* "O'Reilly Media, Inc.", 2020. ▸ Click here

- Hoffer, Jeffrey A. *Modern Database Management.* 10/e. Pearson Education India, 2011. ▸ Click here =